

Delaware Erosion & Sediment Control Handbook

JULY 2023



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Illinois Urban Manual
Maryland Standards and Specifications for Soil Erosion and Sediment Control
Virginia Erosion and Sediment Control Handbook

This Handbook has been revised with the intention that it will become a “living document”. That is, it has been structured in such a way that keeping the Handbook current and up-to-date will be much easier. As such, the Delaware Sediment & Stormwater Program will issue additions, deletions, updates, etc. as necessary. Any changes will be adopted following public notice requirements in accordance with 7 Del. C. §6004 and will be filed in the Register of Regulations pursuant to 29 Del. C. §10113.

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Contents

ACKNOWLEDGEMENTS	i
1.0 Introduction	
1.1 Background	1-1
1.2 Regulatory Authority (<i>Reserved</i>)	1-9
1.3 Delaware State Program Structure (<i>Reserved</i>)	1-11
2.0 Principles of Erosion & Sediment Control (ESC)	
2.1 Source Control Measures (<i>Reserved</i>)	2-1
2.2 Site Planning for Erosion & Sediment Control (ESC) (<i>Reserved</i>)	2-4
3.0 Standards & Specifications for Erosion and Sediment Control (ESC) Practices	
3-A Symbols	3-A1
3.1 Sediment Trapping Practices	
3.1.1 Straw bale barrier	3.1.1-1
3.1.2 Silt fence	3.1.2-1
3.1.2.1 Standard	
3.1.2.2 Reinforced	
3.1.2.3 Super	
3.1.3 Sediment trap	3.1.3-1
3.1.3.1 Pipe outlet	3.1.3-3
3.1.3.2 Stone outlet	3.1.3-5
3.1.3.3 Riprap outlet	3.1.3-7
3.1.3.4 Compost log	3.1.3-11
3.1.4 Temporary sediment basin	3.1.4-1
3.1.5 Storm drain inlet protection	3.1.5-1
3.1.5.1 Type 1	
3.1.5.2 Type 2	
3.1.5.3 Type 3	
3.1.6 Culvert inlet protection	3.1.6-1
3.1.7 Compost filter log	3.1.7-1
3.1.8 Flocculation	3.1.8-1
3.2 Dewatering Practices	
3.2.1 Portable dewatering practices	3.2.1-1
3.2.1.1 Portable sediment tank	
3.2.1.2 Geotextile dewatering bag	
3.2.2 Pumping pit	3.2.2-1
3.2.2.1 Type 1	
3.2.2.2 Type 2	
3.2.3 Dewatering device	3.2.3-1
3.2.3.1 Skimmer dewatering device	

3.2.4	Dewatering basins	3.2.4-1
3.2.4.1	Type1	
3.2.4.2	Type2	
3.3	Water Control Practices	
3.3.1	Temporary swale	3.3.1-1
3.3.2	Temporary earth berm	3.3.2-1
3.3.3	Vegetated channel	3.3.3-1
3.3.3.1	Parabolic	
3.3.3.2	Triangular/Trapezoidal	
3.3.3.3	Channel pipe drain	
3.3.3.4	Channel stone drain	
3.3.4	Lined channel	3.3.4-1
3.3.4.1	Parabolic	
3.3.4.2	Triangular/Trapezoidal	
3.3.5	Diversion	3.3.5-1
3.3.6	Check dam	3.3.6-1
3.3.7	Subsurface drain	3.3.7-1
3.3.8	Pipe slope drain	3.3.8-1
3.3.9	Chute	3.3.9-1
3.3.9.1	Riprap	
3.3.9.2	Gabion mattress	
3.3.10	Riprap outlet protection	3.3.10-1
3.3.10.1	Riprap outlet protection - 1	
3.3.10.2	Riprap outlet protection - 2	
3.3.11	Riprap stilling basin	3.3.11-1
3.4	Soil Stabilization Practices	
3.4.1	Topsoiling	3.4.1-1
3.4.2	Slope treatment	3.4.2-1
3.4.2.1	Benching	
3.4.2.2	Grooving	
3.4.2.3	Serrating	
3.4.2.4	Erosion control log	
3.4.3	Vegetative stabilization	3.4.3-1
3.4.3.1	Soil Testing	3.4.3-3
3.4.3.2	Temporary stabilization	3.4.3-5
3.4.3.3	Permanent stabilization	3.4.3-7
3.4.3.4	Sodding	3.4.3-15
3.4.4	Streambank & shoreline stabilization	3.4.4-1
3.4.5	Mulching	3.4.5-1
3.4.6	Stabilization matting	3.4.6-1
3.4.6.1	Slope	
3.4.6.2	Channel	
3.4.7	Stabilized construction entrance	3.4.7-1
3.4.8	Dust control	3.4.8-1

3.5	Waterway Construction Practices	
3.5.1	Temporary waterway crossings	3.5.1-1
3.5.1.1	Temporary culvert	3.5.1-5
3.5.1.2	Temporary timber mat	3.5.1-7
3.5.1.3	Temporary bridge	3.5.1-9
3.5.1.4	Temporary ford	3.5.1-11
3.5.2	Stream diversion	3.5.2-1
3.5.2.1	Utility crossing diversion pipe	
3.5.2.2	Coffer dam	
3.5.2.3	Diversion channel	
3.5.3	Turbidity curtain	3.5.3-1
3.6	Pollution Prevention Practices	
3.6.1	Construction site pollution prevention	3.6.1-1
3.6.2	Concrete washout	3.6.2-1
3.6.3	Concrete mixing operation.....	3.6.3-1
3.6.4	Fueling & spill control.....	3.6.4-1
3.7	Misc. Practices	
3.7.1	ESC for minor land development	3.7.1-1
3.7.2	Sensitive area protection	3.7.2-1
3.7.3	Soil stockpile	3.7.3-1

APPENDICES

A-1	Update notices
A-2	Glossary
A-3	Geotextile application guide
A-4	Stabilization matting application guide
A-5	Riprap and stone properties tables
A-6	Compost material properties

DESIGN GUIDES

DG-1	FHWA HEC-15, Design of Flexible Channel Linings
DG-2	FHWA HEC-14 Chapter XI, Riprap Basin
DG-3	NRCSEFM Chapter 16, Streambank & Shoreline Stabilization

SUPPLEMENTS

S-1	Standards & Specifications for Highway Construction BMP's (Available from DeIDOT)
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1.0 INTRODUCTION

1.1 BACKGROUND

1.1.1 THE EROSION PROCESS

Soil erosion is the process by which the land's surface is worn away by the action of wind, water, ice and gravity. Natural, or geologic erosion has been occurring at a relatively slow rate since the earth was formed, and is a tremendous factor in creating the earth as we know it today. The rolling hills of the Piedmont and the broad expanse of the Coastal Plain are both a result of the geologic erosion and sedimentation process in Delaware. Except for some cases of shoreline and stream channel erosion, natural erosion occurs at a very slow and uniform rate and remains a vital factor in maintaining environmental balance.

Water-generated erosion is unquestionably the most severe type of erosion, particularly in developing areas; it is, therefore, the problem to which this handbook is primarily addressed. It is helpful to think of the erosive action of water as the effects of the energy developed by rain as it falls, or as the energy derived from its motion as it runs off the land surface. The force of falling raindrops is applied vertically, and force of flowing water is applied horizontally. Although the direction of the forces created is different, they both perform work in detaching and moving soil particles.

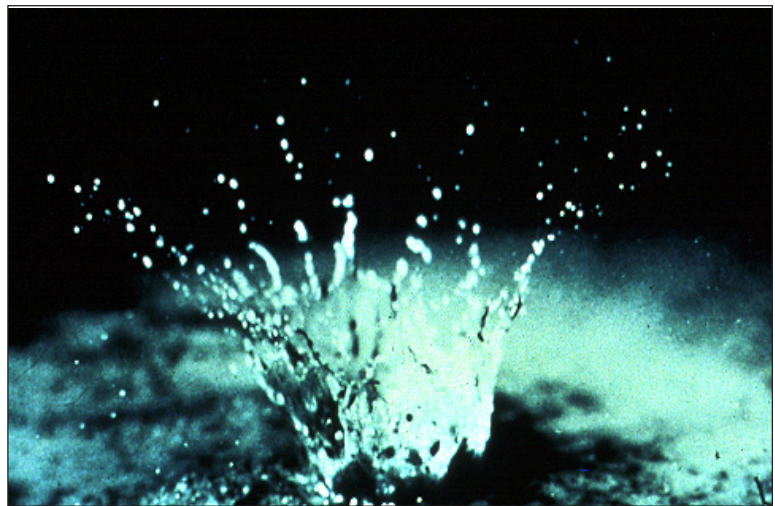
Water-generated erosion can be broken down into the following types:

Raindrop erosion is the first effect of a rainstorm on the soil. Raindrop impact dislodges soil particles and splashes them into the air (**see picture below**). These detached particles are then vulnerable to the next type of erosion.

Sheet erosion is the erosion caused by the shallow flow of water as it runs off the land. These very shallow moving sheets of water are seldom the detaching agent, but the flow transports soil particles which are detached by raindrop impact and splash. The shallow surface flow rarely moves as a uniform sheet for more than a few feet on land surfaces before concentrating in the surface irregularities.

Rill erosion is the erosion which develops as the shallow surface flow begins to concentrate in the low spots of the irregular contours of the surface. As the flow changes from the shallow sheet flow to deeper flow in these low areas, the velocity and turbulence of flow increase. The energy of this concentrated flow is able to both detach and transport soil materials. This action begins to cut small channels of its own. Rills are small but well defined channels which are at most only a few inches in depth. They are easily removed by harrowing or other surface treatments.

Gully erosion occurs as the flow in rills comes together in larger and larger channels. The major difference between gully and rill erosion is a matter of magnitude. Gullies are too large to be repaired with conventional tillage equipment and usually require heavy equipment and special techniques for stabilization.



Channel erosion occurs as the volume and velocity of flow causes movement of the stream bed and bank materials. **Figure 1-1** illustrates the five stages of erosion.

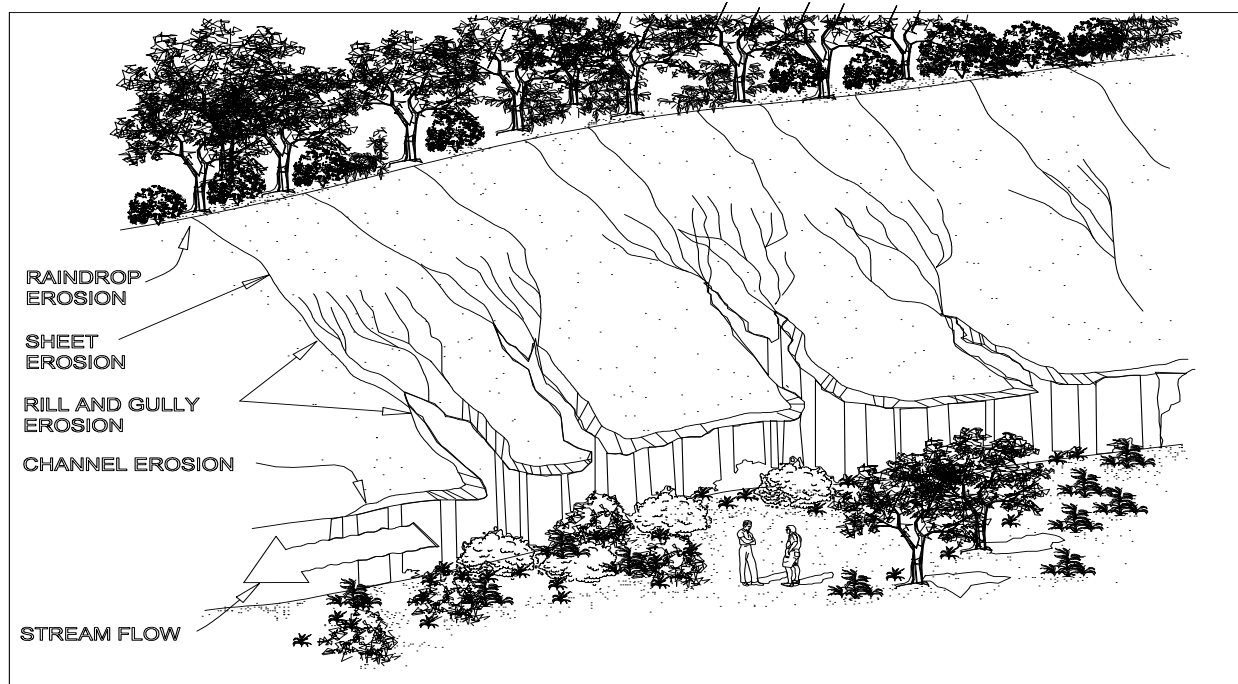


Figure 1-1. Types of erosion
(Source: Michigan Soil Erosion and Sedimentation Guidebook)

1.1.2 FACTORS INFLUENCING EROSION

The erosion potential of any area is determined by four principal factors: the characteristics of its soil, its vegetative cover, its topography and its climate. Although each of these factors is discussed separately herein, they are inter-related in determining erosion potential.

Soil characteristics which influence the potential for erosion by rainfall and runoff are those properties which affect the infiltration capacity of a soil and those which affect the resistance of the soil to detachment and being carried away by falling or flowing water. The following four factors are important in determining soil erodibility:

1. Soil texture (particle size and gradation)
2. Percentage of organic content
3. Soil structure
4. Soil permeability

Soils containing high percentages of fine sands and silt are normally the most erodible. As the clay and organic matter content of these soils increases, the erodibility decreases. Clays act as a binder to soil particles, thus reducing erodibility. However, while clays have a tendency to resist erosion, once eroded, they are easily transported by water. Soils high in organic matter have a more stable structure which improves their permeability. Such soils resist raindrop detachment and infiltrate more rainwater. Clear, well-drained and well graded gravel and gravel-sand mixtures are usually the least erodible soils. Soils with high infiltration rates and permeabilities either prevent or delay and reduce the amount of runoff.

Vegetative cover plays an extremely important role in controlling erosion as it provides the following five benefits:

1. Shields the soil surface from raindrop impact
2. Root systems hold soil particles in place
3. Maintains the soil's capacity to absorb water
4. Slows the velocity of runoff
5. Removes subsurface water between rainfalls through the process of evapotranspiration

By limiting and staging the removal of existing vegetation and by decreasing the area and duration of exposure, soil erosion and sedimentation can be significantly reduced. Special consideration should be given to the maintenance of existing vegetative cover on areas of high erosion potential such as moderately to highly erodible soils, steep slopes, drainageways, and the banks of streams.

Topography. The size, shape, and slope characteristics of a watershed influence the amount and rate of runoff. As both slope length and gradient increase, the rate of runoff increases and the potential for erosion is magnified. Slope orientation can also be a factor in determining erosion potential. For example, a slope that faces south and contains droughty soils may have such poor growing conditions that vegetative cover will be difficult to reestablish.

Climate. The frequency, intensity, and duration of rainfall are fundamental factors in determining the amounts of runoff produced in a given area. As both the volume and velocity of runoff increases, the capacity of runoff to detach and transport soil particles also increases. Where storms are frequent, intense, or of long duration, erosion risks are high. Seasonal changes in temperature, as well as variations in rainfall, help to define the high erosion risk period of the year. When precipitation falls as snow, no erosion will take place. However, when the temperature rises, melting snow adds to runoff, and erosion hazards are high. Because the ground is still partially frozen, its absorptive capacity is reduced. Frozen soils are relatively erosion-resistant. However, soils with high moisture content are subject to uplift by freezing action and are usually very easily eroded upon thawing.

1.1.3 SEDIMENTATION

During a typical storm event, runoff builds up rapidly to a peak and then diminishes. Excessive quantities of soil particles are eroded and transported principally during these higher flows. During lower flows, as the velocity of runoff decreases, the transported materials are deposited to be picked up by later peak flows. In this way, eroded soil can be carried downslope, or downstream, intermittently and progressively from their source or point of origin. This process is known as *sedimentation*.

It must be recognized that sedimentation is a process of dynamic equilibrium. A certain amount of sedimentation and sediment transport occurs in even the most stable streams and rivers. However, when man's activities change the sediment loads and/or the hydrology of a watershed, the streams can quickly go out of equilibrium. Although the stream will eventually adjust to these changes, many more tons of soil will be carried away from the banks and bed in the process, only to be deposited as sediment in downstream receiving waters. The potential environmental and economic impacts of this sediment are discussed in later sections.

1.1.4 EROSION AND SEDIMENT PROBLEMS ASSOCIATED WITH CONSTRUCTION SITES

The principal effect land development activities have on the natural or geologic erosion process consists of exposing disturbed soils to precipitation and to surface storm runoff. Shaping of land for construction or development purposes alters the soil cover and the soil in many ways, often detrimentally affecting on-site drainage and storm runoff patterns and eventually the off-site stream and stream flow characteristics. Protective vegetation is reduced or removed, excavations are made, topography is altered and the removed soil material is stockpiled - often without protective cover. In effect, the physical properties of the soil itself are changed. The development process is such that many citizens of a locality may be adversely affected even by development

of areas of only limited size. Uncontrolled erosion and sediment from these areas often causes considerable economic damage to individuals and to society, in general. Surface water pollution, channel and reservoir siltation and damage to public facilities, as well as to private property, are some of many examples of problems caused by uncontrolled erosion and sedimentation.

Potential hazards associated with development include:

1. A large increase in areas exposed to storm runoff and soil erosion.
2. Increased volumes of storm runoff, accelerated soil erosion and sediment yield and higher peak flows caused by:
 - a. Removal of existing protective vegetative cover.
 - b. Exposure of underlying soil or geologic formations which are less pervious and/or more erodible than original soil surface.
 - c. Reduced capacity of exposed soils to absorb rainfall due to compaction caused by heavy equipment.
 - d. Enlarged drainage areas caused by grading operations, diversions, and street constructions.
 - e. Prolonged exposure of unprotected disturbed areas due to scheduling problems and/or delayed construction.
 - f. Shortened times of concentration of surface runoff caused by altering steepness, distance and surface roughness and through installation of “improved” storm drainage facilities.
 - g. Increased impervious surfaces associated with the construction of streets, buildings, sidewalks and paved driveways and parking lots.
3. Alteration of the groundwater regime that may adversely affect drainage systems, slope stability and survival of existing and/or newly established vegetation.
4. Creation of south and west directional exposure of property which may hinder plant growth due to adverse temperature and moisture conditions.
5. Exposure of subsurface materials that are rocky, acid, droughty or otherwise unfavorable to the establishment of vegetation.
6. Adverse alteration of surface runoff patterns by construction and development.

Although streams and rivers naturally carry sediment loads, erosion from construction sites and runoff from developed areas can elevate these loads to levels well above those in undisturbed watersheds. It is generally acknowledged that erosion rates from construction sites are much greater than from almost any other land use. Results from both field studies and erosion models indicate that erosion rates from construction sites are typically about an order of magnitude larger than row crops, and several orders of magnitude greater than rates from well-vegetated areas such as forests or pastures (USDA, 1970, cited in Dillaha et al., 1982; Meyer et al., 1971). Wolman and Schick (1967) studied the impacts of development on fluvial systems in Maryland and found sediment yields in areas undergoing construction were 1.5 to 75 times greater than detected in natural or agricultural catchments. The authors summarize the potential impacts of construction on sediment yields by stating that “the equivalent of many decades of natural or even agricultural erosion may take place during a single year from areas cleared for construction (Wolman and Schick, 1967).”

Similar impacts from storm water runoff have been reported in a number of other studies. For example, Daniel et al. (1979) monitored three residential construction sites in southeastern Wisconsin and determined that

annual sediment yields were more than 19 times the yields from agricultural areas. Studies have examined the effects of road construction on erosion rates and sediment yields in forested areas. In northern Idaho, the erosion rate per unit area of road surface averaged 220 times the erosion rate of undisturbed areas over a six-year period (Megahan and Kidd, 1972).

Other studies have documented increased surface erosion following road construction, but at increases smaller than the 220-fold increase reported in the 1972 study (Megahan, 1984). A highway construction project in West Virginia disturbed only 4.2% of a 4.75 square mile basin, but this resulted in a three fold increase in suspended sediment yields (Downs and Appel, 1986). During the largest storm event it was estimated that 80% of the sediment in the stream originated from the construction site. As is often the case, the increase in suspended sediment load could not be detected further downstream where the drainage area was over fifty times larger (269 sq. mi.). Another study evaluated the effect of 290 acres of highway construction on watersheds ranging in size from 5 to 38 square miles. Suspended sediment loads in the smallest watershed increased by 250%, and the estimated sediment yield from the construction area was 37 tons/acre over a two-year period (Hainly, 1980). A more recent study in Hawaii showed that highway construction increased suspended sediment loads by 56-76% on three small (1-4 sq. mi.) basins (Hill, 1996). MacDonald et al (in press) estimated that at least 130 tons/acre had eroded in just four months from a newly-constructed and unpaved road network on St. John in the U.S. Virgin Islands.

Yorke and Herb (1978) evaluated nine subbasins in the Maryland portion of the Anacostia watershed for more than a decade in an effort to define the impacts of changing land use/land cover on sediment in runoff. Average annual suspended sediment yields for construction sites ranged from 7 to 100 tons/acre and 0.07 to 0.45 tons/acre respectively. A 1970 study conducted by the National Association of Counties Research Foundation found the potential impacts of urban and suburban development to be even more dramatic, concluding that sediment yields from construction areas can be as much as 500 times the levels detected in rural areas (National Association of Counties Research Foundation, 1970).

Each of these studies identify construction sites as the specific source(s) of sediment. Daniel et al. (1979) identified flow, followed by flow rate, as the most influential factor controlling the sediment loadings from residential construction sites. In evaluating sub-basins at a scale of between 0.35 and 22 square-miles, Yorke and Herb (1978) determined that sediment yields from developed "urban land" were on the upper end of the range for cultivated land (3.7 tons/acre as compared to 0.65 to 4.3 tons/acre). However, the source of most of the sediment in the urban land streams was identified as stream-channel erosion, not the developed properties themselves.

Other studies have shown that stream reaches affected by construction activities often extend well downstream of the construction site. For example, between 4.8 and 5.6 kilometers of stream below construction sites in the Patuxent River watershed were observed to be impacted by sediment inputs (Fox, 1974 as cited in Klein, 1979). The environmental and economic consequences of allowing such activities to go unchecked are discussed in the following sections.

1.1.5 ENVIRONMENTAL IMPACTS OF SEDIMENT

Storm water discharges generated while construction activities are occurring have a potential for serious water quality impacts. The biological, chemical and physical integrity of the waters may become severely compromised. For example, a number of pollutants are preferentially absorbed onto mineral or organic particles found in fine sediment. The erosion and delivery of sediment into aquatic ecosystems is the primary pathway for delivering key pollutants such as nutrients (particularly phosphorous), metals, and organic compounds (e.g., Novotny and Chesters, 1989). It has been estimated that 80% of the phosphorous and 73% of the Kjeldahl nitrogen in streams is associated with eroded sediment (USDA, 1989, cited in Fennessey and Jarrett, 1994). Even more startling is the apparent ability of sediment to act as long term memory or storage media for toxicants. Studies show that pollutants such as DDT, DDE, PCBs and chlordane whose use has been banned or highly restricted, can still be found at detectable levels in sediment deposited years ago in the bottom of streams and rivers.

Where construction activities are intensive, the localized impacts of water quality may be severe because of high pollutant loads, primarily sediments. Siltation is the primary cause of impaired water quality in rivers, and the second largest cause of impaired water quality in lakes (*Managing Nonpoint Source Pollution*, EPA-506/9-90, EPA, 1992; p. 197). Excess sediments are associated with increased turbidity and reduced light penetration in the water column, as well as more long-term effects associated with habitat destruction and increased difficulty in filtering drinking water. Numerous studies have shown that fine sediment (fine sand or smaller) adversely affects aquatic ecosystems by reducing light penetration, impeding sight-feeding, smothering benthic organisms, abrading gills and other sensitive structures, reducing habitat by clogging interstitial spaces within a stream bed, and reducing the intergravel dissolved oxygen by reducing the permeability of the bed material (e.g., Everest et al., 1987; Meehan, 1991). In an aquatic environment, the general effect of fine-graded sediments such as clays, silts, and fine sands is to reduce drastically both the kinds and the amounts of organisms present.

Coarser-grained materials also blanket bottom areas to suppress aquatic life found in these areas. Where currents are sufficiently strong to move the bedload, the abrasive action of these materials in motion accelerates channel scour and has an even more severely deleterious effect upon aquatic life. Introduction of coarse sediment (coarse sand or larger) or large amounts of fine sediment is also a concern because of the potential of filling lakes and reservoirs as well as clogging stream channels (e.g., Paterson et al., 1993). Large inputs of coarse sediment into stream channels will initially reduce stream depth and minimize habitat complexity by filling in pools (MacDonald et al., 1991).

For most construction sites the primary concern is fine sediment, and this is due to the fact that the primary erosion and transport processes are rainsplash, rills (typically less than one foot deep), and sheetwash (Haan et al, 1994). Construction sites in steep areas or along streambanks, however, may initiate landslides, debris flows, or other types of mass wasting events (e.g., Megahan, 1984). In these cases coarse sediment inputs may be of greatest concern. Construction sites can also generate other pollutants associated with wastes onsite such as sanitary wastes or concrete truck washout.

Evidence is now beginning to mount that the ability of a stream to maintain its health is related to the impervious areas within its watershed. Urbanization of a watershed increases the impervious surfaces and increases the pollutant load. One study suggests that once a watershed becomes 12% impervious, the quality of aquatic life has reached a critical threshold.

1.1.6 ECONOMIC IMPACTS OF SEDIMENT

Over four billion tons of sediment are estimated to reach the ponds, rivers, and lakes of our country each year, and approximately one billion tons of this sediment is actually carried all the way to the ocean. Approximately 10 percent of this amount is contributed by erosion from land undergoing highway construction or land development. Although these latter quantities may appear to be small compared to the total, they could represent more than one-half of the sediment load carried by many streams draining small subwatersheds which are undergoing development.

Excessive quantities of sediment cause costly damage to waters and to private and public lands. Obstruction of stream channels and navigable rivers by masses of deposited sediment reduces their hydraulic capacity which, in turn, causes an increase in subsequent flood crests and a consequent increase in the frequency of damaging storm events. The aesthetic attraction of many streams, lakes, and reservoirs used for swimming, boating, fishing, and other water-related recreational activities has been seriously impaired or destroyed by bank cutting and channel scour - accelerated by these higher flood stages induced by sedimentation.

Sediment fills drainage channels, especially along highways and railroads, and plugs culverts and storm drainage systems, thus necessitating frequent and costly maintenance. A 1969 study in Washington, D.C. and Baltimore showed that sediment yields from developing areas could reach 25,000 to 50,000 tons per square mile per year. Annual costs for removing this quantity of sediment from streets alone was estimated to range from \$224,000 to \$448,000 per square mile at that time. Municipal and industrial water supply reservoirs lose storage capacity, the usefulness of recreational impoundments is impaired or destroyed, navigable channels must be continually dredged and the cost of filtering muddy water preparatory to domestic or industrial use becomes excessive - and sometimes exorbitant. The added expense of water purification in the United States, because of sedimentation, amounts to millions of dollars each year.

Every year in the United States about 497 million yd³ of material are dredged by the U.S. Army Corps of Engineers and private operators to create and maintain navigable waterways and harbors. Without such activity, the natural processes of sediment deposition and shoaling would make many waterways and port facilities impassable by most large commercial and defense vessels. The process of keeping these waters passable is an expensive one - approximately \$500 million dollars annually (in 1986 dollars). The State of Delaware also has an active dredging program which is mainly responsible for maintenance of the Inland Waterways system. Approximately 80,000 to 100,000 yd³ of material is dredged each year under this program at an estimated cost of \$3 to \$4 per yd³ (in 1997 dollars). In addition to the financial cost of dredging, the disposal of dredged material has become more difficult with the passage of laws to protect the marine environment and the consequent dwindling supply of suitable places to put it. Thus, consideration of alternatives to dredging has become an issue with serious implications for this nation's maritime trade and naval installations.

In the past, the damage caused by erosion and sedimentation has been quantified in terms of dollars spent to dredge navigational channels, loss of reservoir capacity and so on. More recently, efforts have concentrated on the qualitative cost. It is very difficult to place a dollar figure on damage to the environment; however, we cannot escape the fact that human health and well-being is ultimately related to the environment in which we live. Responsible development requires that steps be taken to control erosion and sedimentation from construction sites in order to minimize the environmental and economic impacts associated with such activities. This Handbook was developed to provide practitioners in the land development and construction industries with the current Best Available Technology (BAT) in order to meet that goal.

1.1.7 OTHER POTENTIAL NONSEDIMENT POLLUTANTS

Research has shown that there are also potential nonsediment pollutants likely to be present in storm water in significant quantities. Potential pollutants which are commonly associated with construction activities include:

1. **Nutrients** - Nitrogen, phosphorus, and potassium are the major plant nutrients used for the fertilizing of new landscape at construction sites. Heavy use of fertilizers can result in the discharge of nutrients to water bodies resulting in excessive algal growth and eutrophication, and under some circumstances may constitute a violation of water quality standards.
2. **Trace Metals** - Galvanized metal, painted surfaces, and pressure-treated lumber comprise many of the surfaces exposed to storm water as a result of construction activity. These coatings and treatments contain metals which enter storm water as the surfaces corrode, flake, dissolve, decay, or leach. Acid rain can accelerate these processes.
3. **Pesticides** - Herbicides, insecticides, and rodenticides are commonly used at construction sites. The unnecessary or improper application of these pesticides may result in direct contamination, indirect pollution through drift, or the transport of soil surfaces into water.

-
4. **Spills and Illegal Dumping of Construction Materials** - Petroleum products, pesticides, and other synthetic organic compounds (glues, sealants, solvents, etc.) are used widely at construction sites and may be improperly stored and disposed. Deliberate dumping of these materials, which can migrate into surface or ground water resources, is a direct violation of the CWA. On parking lot or highway construction projects, the application of diesel fuel to the contact surfaces of the “hot mix asphalt” application and transport vehicles is a common practice that should be discontinued immediately.
 5. **Miscellaneous Wastes** - Miscellaneous wastes include wash from concrete mixers; solid wastes resulting from the clearing and grubbing of vegetation; wood and paper materials derived from packaging of building products; food containers such as paper, aluminum, and steel beverage cans; and sanitary wastes. In addition to erosion and sediment controls, the plan must address the other potential pollutant sources that may exist on a construction site. These controls include proper disposal of construction site waste; compliance with applicable state or local waste disposal, sanitary sewer, or septic system regulations; control of offsite vehicle tracking; and control of allowable nonstorm water discharges.

1.2 REGULATORY AUTHORITY

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1.3 DELAWARE STATE PROGRAM STRUCTURE

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2.0 PRINCIPLES OF EROSION & SEDIMENT CONTROL (ESC)

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3.0 STANDARDS & SPECIFICATIONS FOR EROSION AND SEDIMENT CONTROL (ESC) PRACTICES

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3-A

Standard Symbols

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PRACTICE

SYMBOL

3.1 Sediment Trapping Practices

3.1.1 Straw Bale Barrier

—— **SBB** ——

3.1.2 Silt Fence

3.1.2.1 Standard Silt Fence

—— **SF** ——

3.1.2.2 Reinforced Silt Fence

—— **RSF** ——

3.1.2.3 Super Silt Fence

—— **SSF** ——

3.1.3 Sediment Traps

3.1.3.1 Pipe Outlet Sediment Trap

PST

3.1.3.2 Stone Outlet Sediment Trap

SST

3.1.3.3 Riprap Outlet Sediment Trap

RST

3.1.3.4 Compost Log Sediment Trap

CST

3.1.4 Temporary Sediment Basin

TSB

3.1.5 Storm Drain Inlet Protection

3.1.5.1 Inlet Protection - Type 1











IP-1

3.1.5.2 Inlet Protection - Type 2




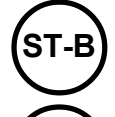



IP-2











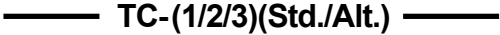
3.1.5.3 Inlet Protection - Type 3

IP-3

<u>PRACTICE</u>	<u>SYMBOL</u>
3.1 <i>Sediment Trapping Practices (cont.)</i>	
3.1.6 Culvert inlet protection	
3.1.7 Compost filter log	
3.1.8 Flocculation	N/A
3.2 <i>Dewatering Practices</i>	
3.2.1 Portable Dewatering Practices	
3.2.1.1 Portable Sediment Tank	
3.2.1.2 Geotextile Dewatering Bag	
3.2.2 Pumping Pit	
3.2.2.1 Pumping Pit - Type 1	
3.2.2.2 Pumping Pit - Type 2	
3.2.3 Dewatering Device	
3.2.3.1 Skimmer Dewatering Device	
3.2.4 Dewatering Basin	
3.2.4.1 Dewatering Basin - Type 1	
3.2.4.2 Dewatering Basin - Type 2	
3.3 <i>Water Control Practices</i>	
3.3.1 Temporary Swale	

PRACTICE**SYMBOL****3.3 Water Control Practices (cont.)****3.3.2 Temporary Earth Berm****———TB - (A/B)(1-4)———****3.3.3 Vegetated Channel****3.3.3.1 Veg. Channel - Parabolic****——— VC- P ——****3.3.3.2 Veg. channel - Triang./Trap.****——— VC- T ——****3.3.3.3 Channel Pipe Drain****———(VC/LC)-(P/T) + PD———****3.3.3.4 Channel Stone Drain****——— VC-(P/T) + SD ——****3.3.4 Lined Channel****3.3.4.1 Lined Channel - Parabolic****——— LC- P ——****3.3.4.2 Lined Channel - Triang./Trap.****——— LC- T ——****3.3.5 Diversion****———(VC/LC)- (P/T)———
————— D —————****3.3.6 Check Dam****3.3.6.1 Stone Check Dam****SCD****3.3.6.2 Compost Log Check Dam****CCD****3.3.7 Subsurface Drain****N/A****3.3.8 Pipe Slope Drain****——— PSD - (Dia.) ——****3.3.9 Chute****3.3.9.1 Riprap Chute****——— RRC ——****3.3.9.2 Gabion Mattress Chute****——— GMC ——**

<u>PRACTICE</u>	<u>SYMBOL</u>
3.3.10 Riprap Outlet Protection	
3.3.10.1 ROP - Type 1	
3.3.10.2 ROP - Type 2	
3.3.11 Riprap Stilling basin	
<i>3.4 Soil Stabilization Practices</i>	
3.4.1 Topsoiling	N/A
3.4.2 Slope Treatment	
3.4.2.1 Slope Treatment - Benching	
3.4.2.2 Slope Treatment - Grooving	
3.4.2.3 Slope Treatment - Serrating	
3.4.2.4 Slope Treatment - EC Log	
3.4.3 Vegetative Stabilization	
3.4.3.1 Soil Testing	N/A
3.4.3.2 Temporary Stabilization	N/A
3.4.3.3 Permanent Stabilization	N/A
3.4.3.4 Sodding	N/A
3.4.4 Streambank & Shoreline Stabilization	N/A
3.4.5 Mulching	N/A

<u>PRACTICE</u>	<u>SYMBOL</u>
3.4.6 Stabilization Matting	
3.4.6.1 Stab. Matting - Slope	
3.4.6.2 Stab. Matting -Channel	
3.4.7 Stabilized Construction Entrance	
3.4.8 Dust Control	N/A
3.5 <i>Waterway Construction Practices</i>	
3.5.1 Temporary Crossing	
3.5.1.1 Temporary Crossing - Culvert	
3.5.1.2 Temp. Crossing - Timber Mat	
3.5.1.3 Temporary Crossing - Brdg.	
3.5.1.4 Temporary Crossing - Ford	
3.5.2 Stream Diversion	
3.5.2.1 Utility Crossing Diversion Pipe	
3.5.2.2 Cofferdam Stream Diversion	
3.5.2.3 Stream Diversion Channel	
3.5.3 Turbidity Curtain	

PRACTICE

SYMBOL

3.6 *Pollution Prevention Practices*

3.6.1 Construction Site Pollution Prevention

N/A

3.6.2 Concrete Washout

CW

3.6.3 Concrete Mixing Operation

CMO

3.6.4 Fueling & Spill Control

N/A

3.7 *Misc. Practices*

3.7.1 ESC for Minor Land Development

N/A

3.7.2 Sensitive Area Protection

SAP

3.7.3 Soil Stockpile

SP

STANDARD AND SPECIFICATIONS FOR STRAW BALE BARRIER

Definition: A temporary barrier of straw or similar material used to intercept sediment laden runoff from small drainage areas of disturbed soil.



Purpose: A bale barrier reduces runoff velocity and effects deposition of the transported sediment load. Straw bale barriers are to be used for no more than three (3) months.

Conditions Where Practice Applies:

- 1. As a secondary practice controlling local areas of minor disturbance and/or minor dewatering operations. **Straw bale barriers shall not be used as a primary perimeter control practice or in areas of concentrated flow.**
- 2. In areas where there is no concentration of water in a channel or other drainageway above the barrier.
- 3. Where erosion would occur in the form of sheet erosion.
- 4. Where length of slope to the straw bale barrier does not exceed these limits.

SLOPE	SLOPE STEEPNESS	SLOPE LENGTH (maximum)	BARRIER LENGTH (maximum)
0% to 2%	Flatter than 50:1	250 feet	1,000 feet
2% to 10%	50:1 to 10:1	125 feet	1,000 feet
10% to 20%	10:1 to 5:1	100 feet	750 feet
20% to 33%	5:1 to 3:1	75 feet	500 feet
33% to 50%	3:1 to 2:1	50 feet	250 feet
Greater than 50%	Greater than 2:1	25 feet	125 feet

Where slope gradient changes through the drainage area, steepness refers to the steepest slope section contributing runoff to the straw bale dike.

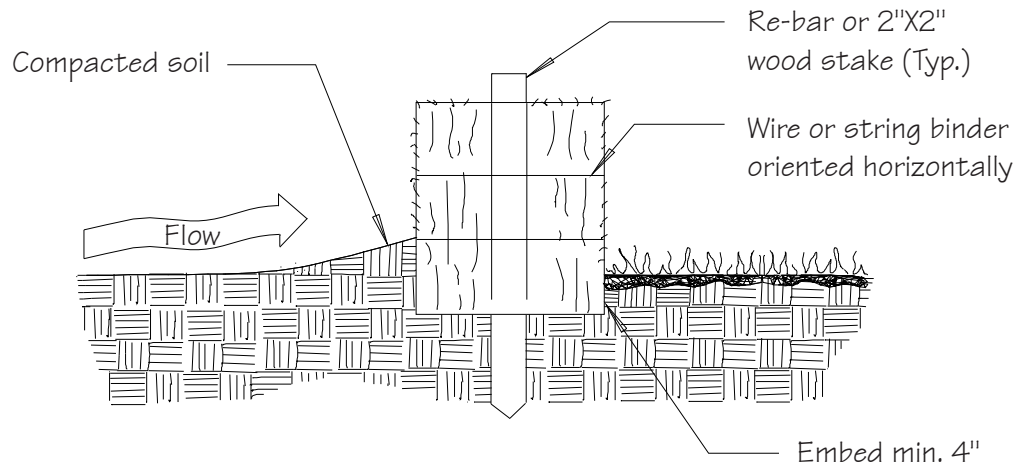
Design Criteria

A design is not required. All bales shall be placed on the contour with the binding string not in contact with the ground.

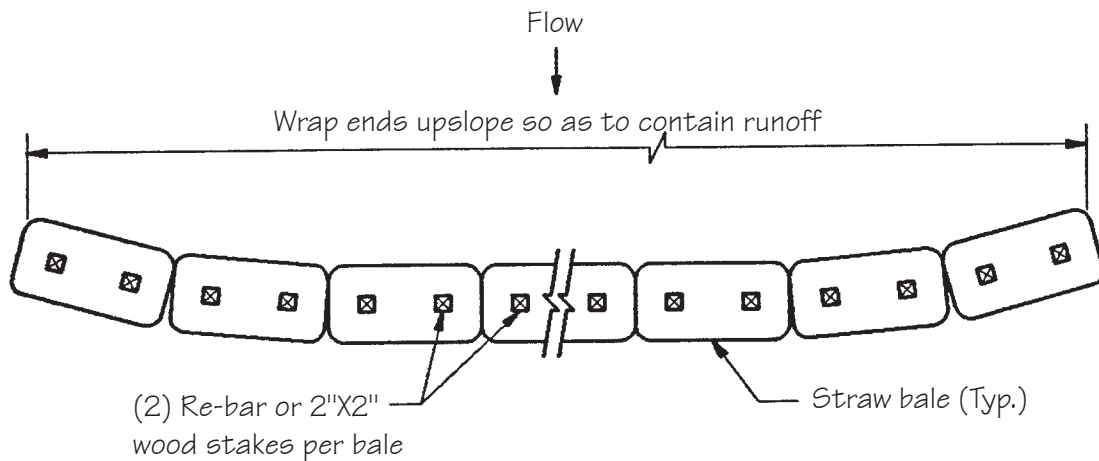
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Standard Detail & Specifications

Straw Bale Barrier



Section



Plan

NOTE: Straw Bale Barrier shall not be used as a primary perimeter control or in areas of concentrated flow.

Source:

Adapted from
VA ESC Handbook

Symbol:

———— **SBB** ————

Detail No.

DE-ESC-3.1.1

Sheet 1 of 2

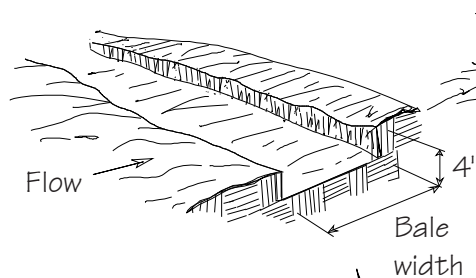
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Standard Detail & Specifications

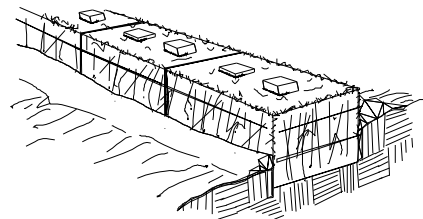
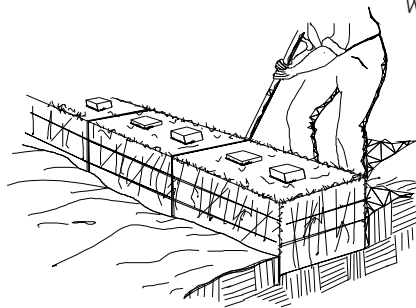
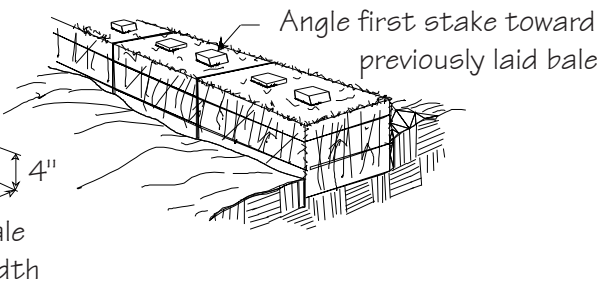
Straw Bale Barrier

Construction Detail

1. Excavate the trench



2. Place and stake straw bales



3. Wedge loose straw between bales

4. Backfill and compact the excavated soil

Construction Notes:

1. Bales shall be placed at the toe of a slope or on the contour and in a row with ends tightly abutting the adjacent bales.
2. Each bale shall be embedded in the soil a minimum of (4) inches, and placed so the bindings are horizontal.
3. Bales shall be securely anchored in place by either two stakes or re-bars driven through the bale. The first stake in each bale shall be driven toward the previously laid bale at an angle to force the bales together. Stakes shall be driven flush with the top of the bale.
4. Inspections shall be frequent and repairs and replacements shall be made promptly as needed.
5. Bales shall be removed when the site has been permanently stabilized.

Source:

Adapted from
VA ESC Handbook

Symbol:

———— **SBB** ————

Detail No.

DE-ESC-3.1.1

Sheet 2 of 2

Effective July 2023

STANDARD AND SPECIFICATIONS FOR SILT FENCE

Definition: A temporary barrier of geotextile fabric (filter cloth) used to intercept sediment laden runoff from small drainage areas of disturbed soil.

Purpose: To temporarily pond sediment laden runoff and allow deposition to occur. Maximum period of use is limited by ultra-violet stability.



Conditions Where Practice Applies:

1. Maximum allowable slope length and fence length will not be exceeded.
2. Erosion would occur in the form of sheet erosion.
3. There is no concentration of water flowing to the barrier.
4. Soil conditions allow proper keying of the skirt (i.e., no large stones or bedrock near the surface).

Design Criteria

Design computations are not required. All silt fence shall be placed as close to the contour as possible and the area below the fence must be undisturbed or stabilized. The type of silt fence specified for each location on the plan shall meet the maximum slope length and maximum fence length requirements shown in the table below:

Slope	Steepness	Max. Slope Length / Max. Fence Length		
		Standard	Reinforced	Super
<2%	<50:1	Unltd / Unltd	N/A	N/A
2 - 10%	50:1 to 10:1	125' / 1000'	250' / 2000'	Unltd / Unltd
10 - 20%	10:1 to 5:1	100' / 750'	150' / 1000'	200' / 1500'
20 - 33%	5:1 to 3:1	60' / 500'	80' / 750'	100' / 1000'
33 - 50%	3:1 to 2:1	40' / 250'	70' / 350'	100' / 500'
> 50%	> 2:1	20' / 125'	30' / 175'	50' / 250'

Installation:

Silt fence shall be installed in accordance with the appropriate detail. Seams shall be overlapped, folded and stapled to provide a continuous section. *Butt joints are not acceptable.*

Specifications for Silt Fence Materials

1. Silt Fence Fabric:

The geotextile material shall meet the specifications contained in **Appendix A-3**. The use of a new material *may* be approved by the appropriate erosion and sediment control plan approval authority on a case-by-case basis. However, such approval shall not constitute statewide acceptance. Statewide acceptability shall depend on in-field and/or laboratory observations and evaluations.

2. Fence Posts:

The length shall be a minimum of 40 inches long. Wood posts will be of sound quality hardwood with a minimum cross sectional area of 4.0 square inches. Steel posts shall be standard "T" or "U" section weighing not less than 1.00 pound per linear foot. Posts for super silt fence shall be standard chain link fence posts.

3. Attachment:

The geotextile material shall be securely attached to the post with staples, nails, ties or other appropriate means. In addition, all silt fence installations shall include a reinforcement strip or other means of reinforcing the attachment of the geotextile material to the post to prevent wind damage.

4. Other materials:

Other materials used for specific types of silt fence installations are indicated on the appropriate detail.

3. Prefabricated Units:

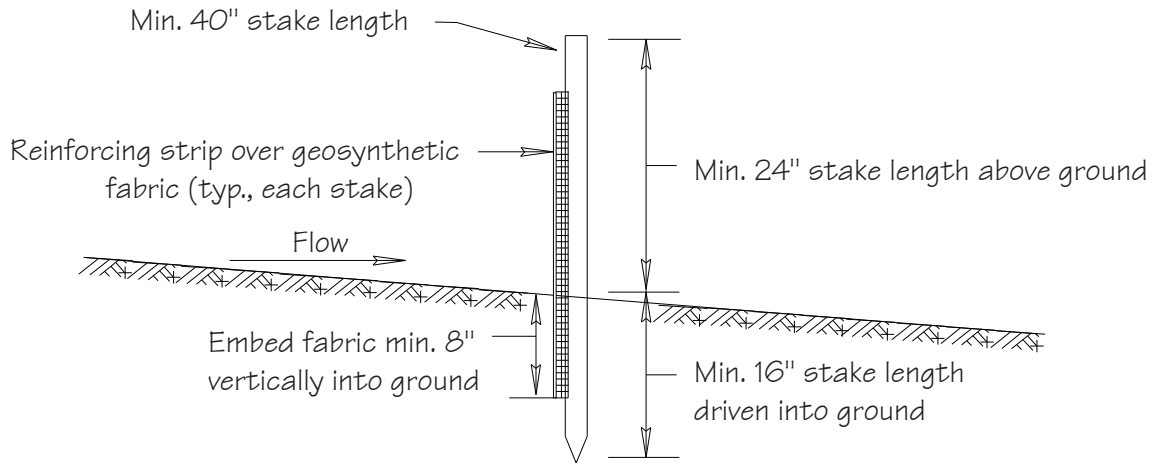
Prefabricated silt fence is acceptable provided all material specifications are met.

Maintenance:

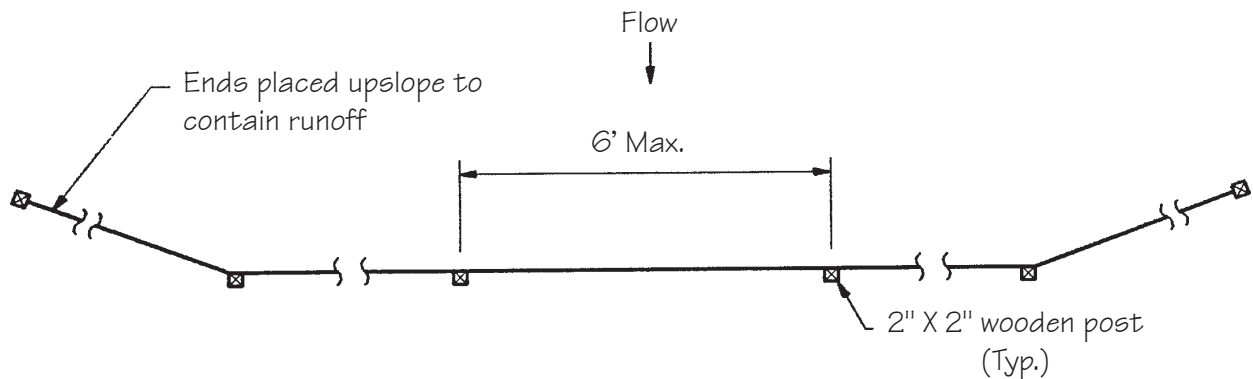
Silt fence must be inspected on a regular basis. Even though a rain event may not have occurred, it should still be inspected for possible wind damage. Repairs should be made immediately. Accumulated sediment should be removed when it has reached 1/2 the exposed height of the fabric.

Standard Detail & Specifications

Silt Fence



Section



Plan

DATA
Max. controlled slope

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:

SF

Detail No.

DE-ESC-3.1.2.1

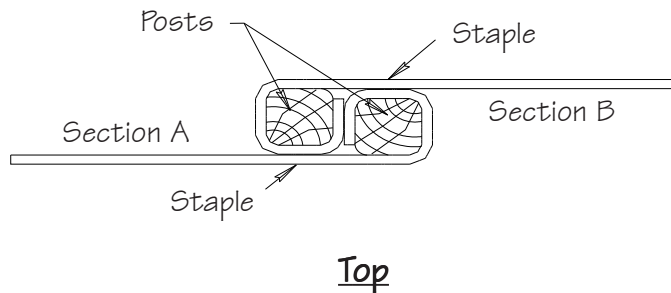
Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Silt Fence

Construction Detail



Method for joining
continuous sections

Construction Notes:

1. Geosynthetic fabric to be fastened securely to fence posts with wire ties or staples.
2. When two sections of filter cloth adjoin each other they shall be overlapped by six inches and folded.
3. Maintenance shall be performed as needed and material removed when “bulges” develop in the silt fence.

Materials:

1. Stakes: Steel (either T or U) or 2" x 2" hardwood
2. Geosynthetic Fabric: Type GD-I
3. Reinforcing strip: Wooden lath or plastic strip

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:

——— **SF** ———

Detail No.

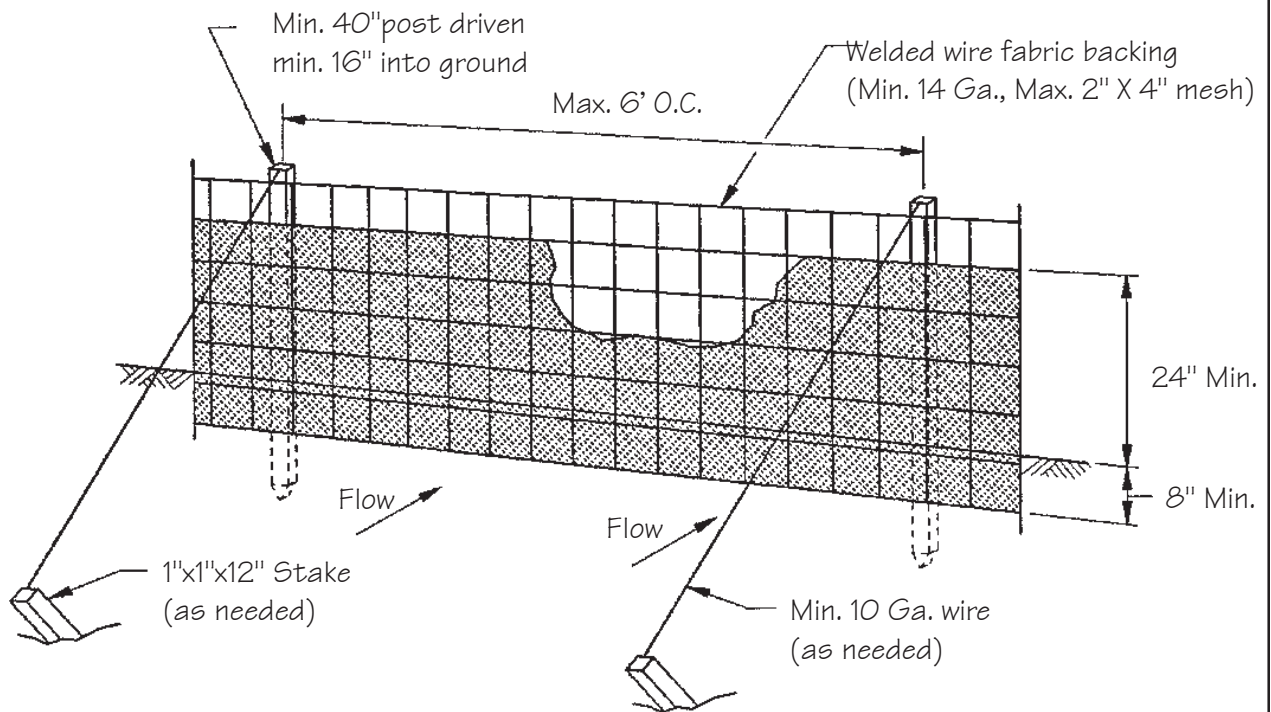
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Sheet 2 of 2

Effective July 2023

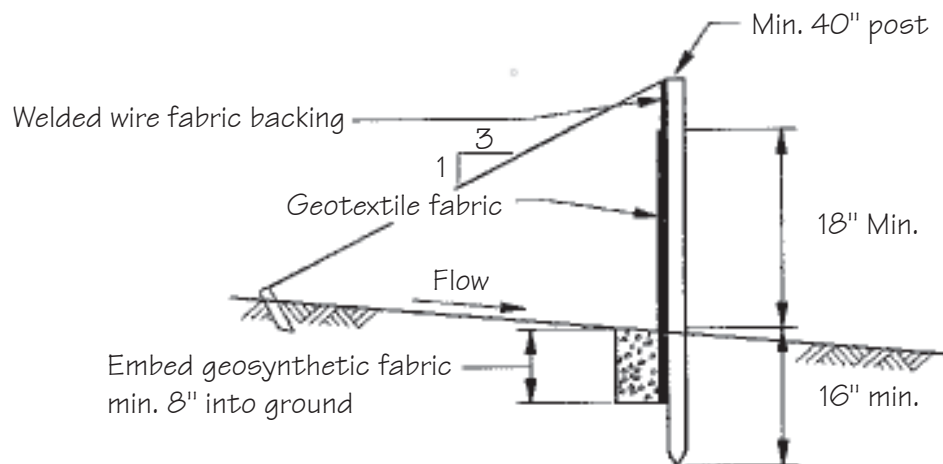
Standard Detail & Specifications

Reinforced Silt Fence



DATA
Max. controlled slope

Perspective



Cross-section

Source:

Adapted from
Transco, Inc.

Symbol:

———— **RSF** ————

Detail No.

DE-ESC-3.1.2.2

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Reinforced Silt Fence

Construction Notes:

1. Welded wire fabric to be fastened securely to the fence posts with wire ties or staples.
2. Filter cloth to be fastened securely to woven wire fence with ties spaced every 24 inches at top and mid-section.
3. When two sections of fabric adjoin each other, they shall be overlapped by six inches and folded.
4. Maintenance shall be performed as needed and material removed when "bulges" develop in the silt fence.

Materials:

1. Posts: Steel either T or U or 2" x 2" hardwood
2. Geotextile Fabric: Type GD-I
3. Backing: Woven welded wire, 14 Ga., 2" X 4" mesh opening

Source:

Adapted from
Transco, Inc.

Symbol:

———— **RSF** ————

Detail No.

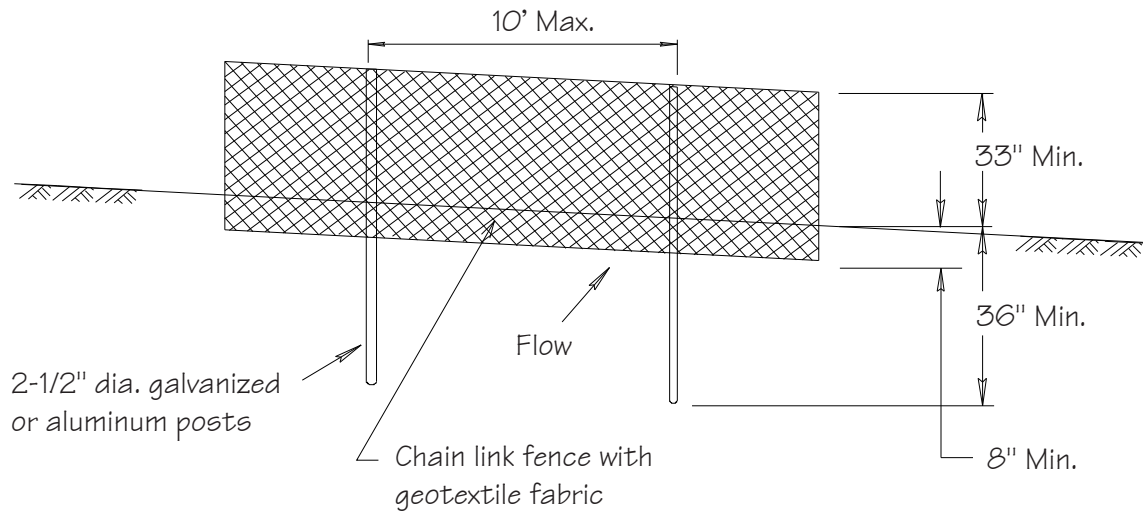
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Sheet 2 of 2

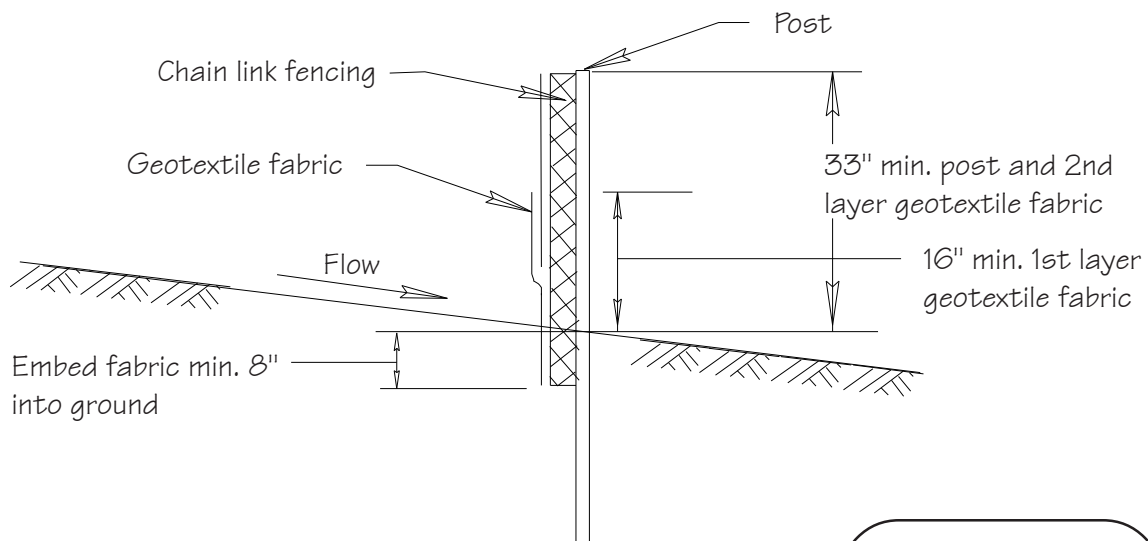
Effective July 2023

Standard Detail & Specifications

Super Silt Fence



Perspective



Section

DATA
Max. controlled slope

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:

—— **SSF** ——

Detail No.

DE-ESC-3.1.2.3

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Super Silt Fence

Construction Notes:

1. The poles do not need to be set in concrete.
2. Chain link fence shall be fastened securely to the fence posts with wire ties or staples.
3. Geotextile fabric shall be fastened securely to the chain link fence with ties spaced every 24" at the top and mid section.
4. Geotextile fabric shall be embedded a minimum of 8" into the ground.
5. When two sections of geotextile fabric adjoin each other, they shall be overlapped by 6" and folded.
6. Maintenance shall be performed as needed and silt buildups removed when "bulges" develop in the silt fence.

Materials:

1. Fencing: Fencing shall be 42 inches in height and constructed in accordance with the latest Delaware Department of Transportation (Del-DOT) Specifications for Chain Link Fencing (Section 727). The Del-DOT specification for a 6 foot fence shall be used, substituting 42 inch fabric and 6 foot length posts.
2. Geosynthetic Fabric: Type GD-I

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:

—— **SSF** ——

Detail No.

DE-ESC-3.1.2.3

Sheet 2 of 2

Effective July 2023

STANDARD AND SPECIFICATIONS FOR SEDIMENT TRAP

Definition: A temporary sediment control device formed by excavation and/or embankment to intercept sediment-laden runoff and to retain the sediment.



Purpose: To intercept sediment-laden runoff and trap the sediment in order to protect drainage ways, properties, and rights-of-way below the sediment trap from sedimentation.

Conditions Where Practice Applies:
A sediment trap is usually installed in a drainageway or at points of discharge from a disturbed area.

Sediment traps should not be used to artificially break up a natural drainage area into smaller sections where a larger device (sediment basin) would be better suited.

TYPES OF SEDIMENT TRAPS
There are four (4) specific types of sediment traps which vary according to their function, location or drainage area. If any of the design criteria presented here cannot be met, see Standard and Specifications for Temporary Sediment Basin.

1.	Pipe Outlet Sediment Trap	See Additional Standard
2.	Stone Outlet Sediment Trap	See Additional Standard
3.	Riprap Outlet Sediment Trap	See Additional Standard
4.	Compost Log Sediment Trap	See Additional Standard

Design Criteria
If any of the design criteria presented here cannot be met, see Standards and Specifications for Temporary Sediment Basin.

Drainage Area
The drainage area for sediment traps shall be in accordance with the specific type of sediment trap used (see Additional Standard for each type).

Location
Sediment traps shall be located so that they can be installed prior to grading or filling in the drainage area they are to protect. Traps must not be located any closer than 20 feet from a proposed building foundation if the trap is to function during building construction. Locate traps to obtain maximum storage benefit from the terrain, for ease of cleanout and disposal of the trapped sediment.

Trap Size

The volume of a sediment trap as measured at the elevation of the crest of the outlet shall be at least 3,600 cubic feet per acre of drainage area. Wet pool storage will enhance performance and should be provided whenever practicable, but may not be used to fulfill the temporary storage requirement. The volume of a constructed trap shall be calculated using standard mathematical procedures. The volume of a natural sediment trap may be approximated by the equation; $\text{Volume (cu ft)} = 0.4 \times \text{surface area (sq ft)} \times \text{maximum depth (ft)}$.

Embankment

All embankments for sediment traps shall not exceed five (5) feet in height as measured at the low point of the original ground along the centerline of the embankment. Embankments shall have a minimum four (4) foot wide top and side slopes of 2:1 or flatter. The embankment shall be compacted by traversing with equipment while it is being constructed.

Excavation

All excavation operations shall be carried out in such a manner that erosion and water pollution shall be minimal. Excavated portions of sediment traps shall have 1:1 or flatter slopes.

Entrance of Runoff Into Trap

Considerable care should be given to the major points of inflow into traps. In many cases the difference in elevation of the inflow and the bottom of the trap is considerable, thus creating potential for severe gullyng and sediment generation. Often a riprap chute at major points of inflow would eliminate gullyng and sediment generation.

Diversions, grade stabilization structures or other water control devices shall be installed as necessary to insure direction of runoff and protect points of entry into the trap. Points of entry should be located so as to insure maximum travel distance of the incoming runoff to point of exit (the outlet) from the trap.

Outlet

The outlet shall be designed, constructed and maintained in such a manner that sediment leaving the trap is minimized and that erosion at or below the outlet does not occur.

Sediment traps must outlet onto stabilized (preferably undisturbed) ground, into a watercourse, stabilized channel, or into a storm drain system.

Dewatering Methods

The method of dewatering each trap shall be indicated on the plan. These methods shall be in accordance with the Standard and Specifications for the various dewatering practices included in Section 3.2 of the Handbook.

Trap Details for Erosion and Sediment Control Plans

Each trap requires specific information to be provided on the plan. The Standard Detail and Specification indicates the data required for each type. Each trap should be identified on the plan and the appropriate data provided.

Maintenance

1. Each trap shall be inspected after each runoff event.
2. Any damage to outlet structures, berms, etc. shall be repaired immediately.
3. Sediment shall be removed and the trap restored to the original dimensions when the sediment has accumulated to 1/2 of the design depth of the trap. Sediment removed from the trap shall be deposited in a protected area and in such a manner that it will not erode.

ADDITIONAL STANDARD AND SPECIFICATIONS FOR PIPE OUTLET SEDIMENT TRAP

Design Criteria: Pipe Outlet Sediment Trap consists of a trap formed by an embankment or excavation. The outlet for the trap is through a perforated riser and a pipe through the embankment. The outlet pipe and riser shall be made of corrugated metal. The top of the embankment shall be at least 1 1/2 feet above the crest of the riser. The top 2/3 of the riser shall be perforated with one (1) inch nominal diameter holes or slits spaced six (6) inches vertically and horizontally placed in the concave portion of the corrugated pipe.

No holes or slits will be allowed within six (6) inches of the top of the horizontal barrel. All pipe connections shall be watertight. The riser shall be wrapped with 1/2 to 1/4 inch hardware clothwire then wrapped with filter cloth at least six (6) inches above the highest hole and six (6) inches below the lowest hole. The top of the riser pipe shall not be covered with filter cloth. The riser shall have a base with sufficient weight to prevent flotation of the riser. Two approved bases are: (1) A concrete base 12" thick with the riser embedded 9" into the concrete base, or (2)- 1/4" minimum thickness steel plate attached to the riser by a continuous weld around the circumference of the riser to form a watertight connection. The plate shall have 2.5 feet of stone, gravel, or earth placed on it to prevent flotation. In either case, each side of the square base measurement shall be the riser diameter plus 24 inches.

Sizes of Pipe Needed

Pipe outlet sediment traps shall be limited to a five (5) acres maximum drainage area. Pipe outlet sediment traps may be interchangeable in the field with stone outlet or riprap sediment traps provided that these sediment traps are constructed in accordance with the detail and specifications for that trap.

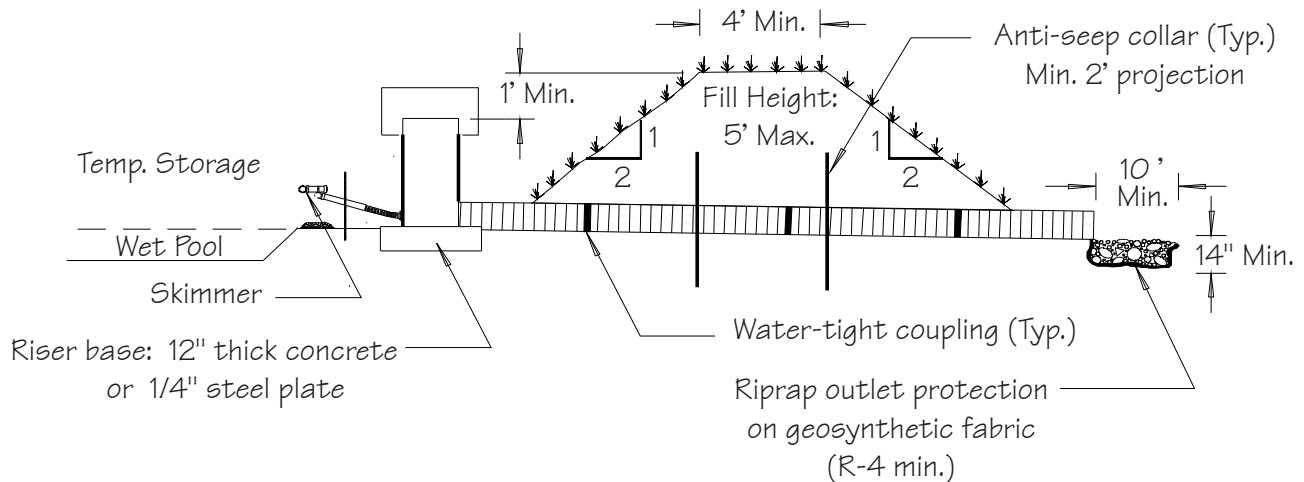
Select pipe diameter from the following table:

Barrel Diameter*	Minimum Sizes	
	Riser Diameter	Max.Drainage Area
(inches)	(inches)	(acres)
12"	15"	1
15"	18"	2
18"	21"	3
21"	24"	4
21"	27"	5

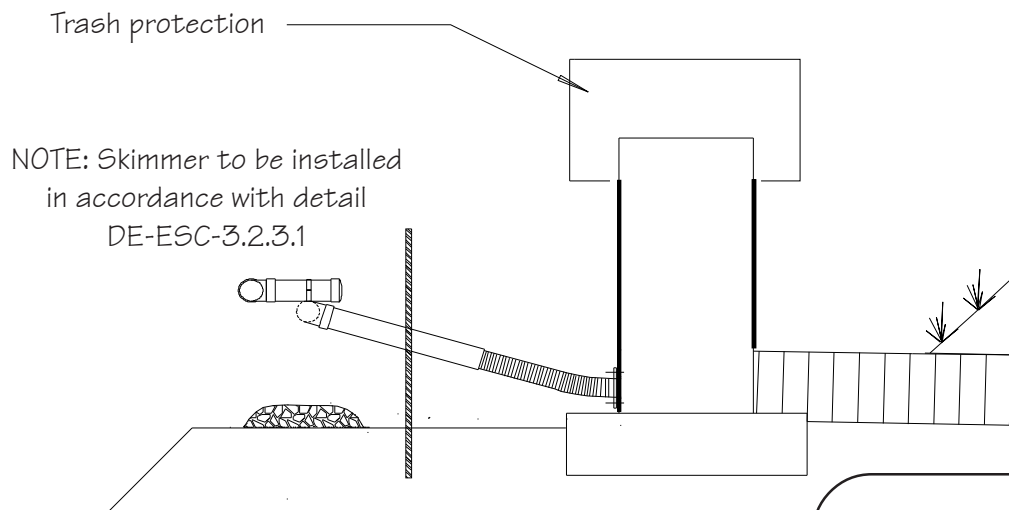
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Standard Detail & Specifications

Pipe Outlet Sediment Trap



Profile thru Pipe Outlet



Riser Detail

DATA

Drainage area (D.A.)
 Required storage (V_s)
 Design dimensions (L x W x D)
 Riser diameter
 Pipe diameter

Source:

DE ESC Handbook

Symbol:

PST

Detail No.

DE-ESC-3.1.3.1

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Pipe Outlet Sediment Trap

Construction Notes

1. The area under embankment shall be cleared, grubbed and stripped of any vegetation and root mat. The pool area shall be cleared.
2. The fill material for the embankment shall be free of roots or other woody vegetation as well as oversized stones, rocks, organic material, or other objectionable material. The embankment shall be compacted by traversing with equipment while it is being constructed.
3. All fill slopes shall be 2:1 or flatter; cut slopes 1:1 or flatter.
4. All pipe connections shall be watertight.
5. Fill material around the pipe spillway shall be hand compacted in four (4) inch layers. A minimum of two (2) feet of hand-compacted backfill shall be placed over the pipe spillway before crossing it with construction equipment.
6. The riser shall be anchored with either a concrete base or steel plate base to prevent flotation. Concrete bases shall be 12 inches thick with the riser embedded nine (9) inches. Steel plate bases will be 1/4 inch minimum thickness attached to the riser by a continuous weld around the bottom to form a watertight connection. The plate shall have 2.5 feet of stone, gravel or tamped earth placed on it.
7. Volume of temporary storage shall be 3,600 cubic feet per acre of drainage area. Wet pool storage should be provided whenever practicable, but shall not be used to fulfill the temporary storage volume requirement.
8. Sediment shall be removed and trap restored to its original dimensions when the sediment has accumulated to 1/2 the design depth of the trap. Removed sediment shall be deposited in a suitable area and in such a manner that it will not erode.
9. The structure shall be inspected after each rain and repairs made as needed.
10. **A skimmer dewatering device shall be considered an integral part of the trap. Any additional dewatering operations for the wet pool shall be conducted in accordance with any and all regulatory requirements.**
11. Construction operations shall be carried out in such a manner that erosion and water pollution are minimized. Disturbed areas shall be stabilized in accordance with the Standards and Specifications for Vegetative Stabilization contained in this Handbook.
12. The structure shall be removed and area stabilized when the drainage area has been properly stabilized.

MAXIMUM DRAINAGE AREA: 5 ACRES

Source: DE ESC Handbook	Symbol: 	Detail No. DE-ESC-3.1.3.1 Sheet 2 of 2 Effective July 2023
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ADDITIONAL STANDARD AND SPECIFICATIONS FOR STONE OUTLET SEDIMENT TRAP

Design Criteria

Stone Outlet Sediment Trap consists of a trap formed by an embankment or excavation. The outlet of this trap is over a stone section placed on level ground.

1. The minimum length (feet) of the outlet shall be equal to four (4) times the drainage area (acres).
2. The outlet crest (top of stone in weir section) shall be level, at least one (1) foot below top of embankment and no more than one (1) foot above ground beneath the outlet. Stone used in the outlet shall be small riprap (R-4). To provide a more efficient trapping effect, a layer of filter cloth should be embedded one (1) foot back into the upstream face of the outlet stone or a one (1) foot thick layer of DE #3 aggregate shall be placed on the upstream face of the outlet.
3. The temporary storage for this trap shall be computed using 3,600 cubic feet of required storage for each acre of drainage area over and above any storage provided as a wet pool. The temporary storage volume provided is determined by computing the volume of storage available behind the outlet structure up to the elevation of the crest of the stone outlet. Additional wet pool storage can be provided by excavating below the elevation required to fulfill the temporary storage volume.
4. The maximum height of embankment shall not exceed four (4) feet.
5. The elevation of the top of any berm directing water to a riprap outlet sediment trap shall equal or exceed the minimum elevation of the embankment along the entire length of this trap.

Stone Outlet Sediment Traps may be interchangeable in the field with pipe or riprap outlet sediment traps provided they are constructed in accordance with the standard and specifications for those traps. Stone outlet sediment traps shall be limited to a five (5) acre maximum drainage area.

The use of the Stone Outlet Sediment Trap is the preferred sediment control device when traps are used.

MAXIMUM DRAINAGE AREA: 5 ACRES

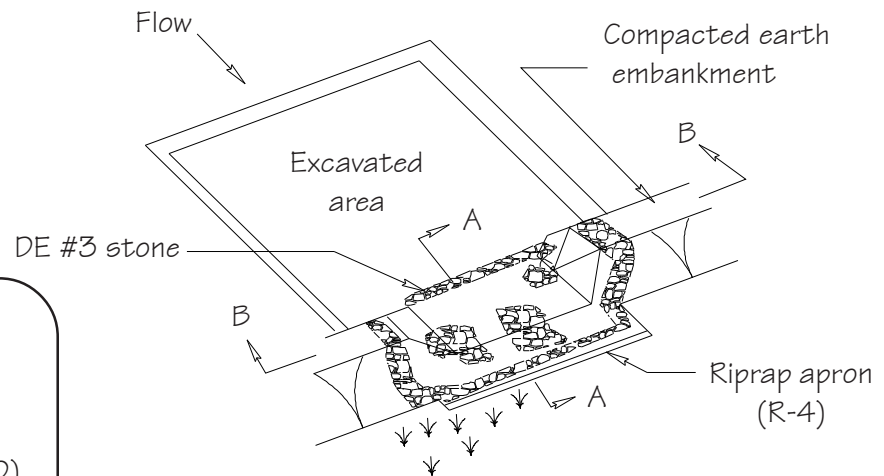
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Standard Detail & Specifications

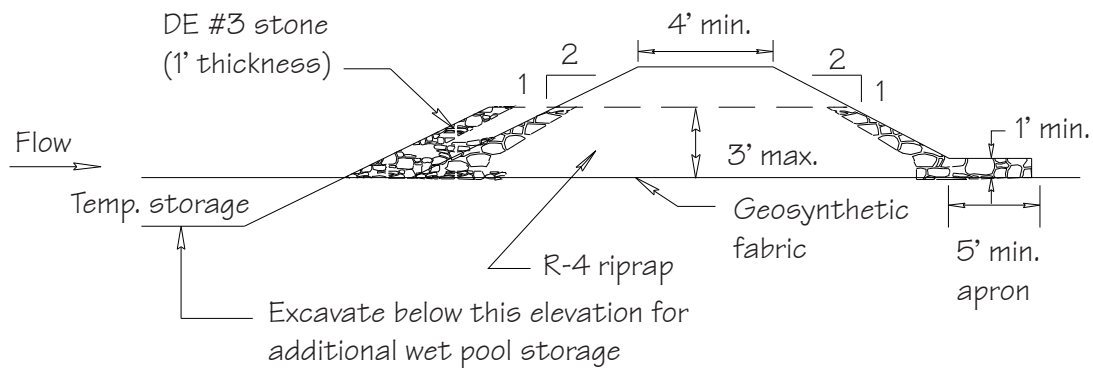
Stone Outlet Sediment Trap

DATA

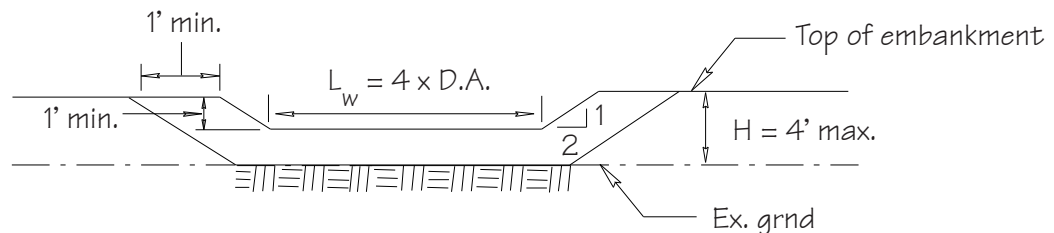
Drainage area (D.A.)
 Required storage (V_s)
 Design dimensions ($L \times W \times D$)
 Embankment height (H)
 Weir length (L_w)



Perspective



Section A-A



Section B-B

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:



Detail No.

DE-ESC-3.1.3.2

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Stone Outlet Sediment Trap

Construction Notes:

1. The area under embankment shall be cleared, grubbed and stripped of any vegetation and root mat. The pool area shall be cleared.
2. The fill material for the embankment shall be free of roots and other woody vegetation as well as over-sized stones, rocks, organic material or other objectionable material. The embankment shall be compacted by traversing with equipment while it is being constructed.
3. The volume of sediment storage shall be 3600 cubic feet per acre of drainage area in addition to any storage provided in the form of a permanent wet pool. The plan shall include an approved means of dewatering the wet pool for necessary maintenance or removal.
4. All fill slopes shall be 2:1 or flatter, cut slopes 1:1 or flatter.
5. The stone used in the outlet shall be small riprap (R-4) along with a 1' thickness of DE #3 aggregate placed on the up-grade side on the small riprap or embedded filter cloth in the riprap.
6. Sediment shall be removed and trap restored to its original dimensions when the sediment has accumulated to 1/2 the design depth of the trap.
7. The structure shall be inspected after each rain and repairs made as needed.
8. **An approved dewatering device shall be considered an integral part of the trap. Dewatering operations shall be conducted in accordance with any and all regulatory requirements.**
9. Construction operations shall be carried out in such a manner that erosion and water pollution are minimized. Disturbed areas shall be stabilized in accordance with the Standards and Specifications for Vegetative Stabilization contained in this Handbook.
10. The structure shall only be removed when the contributing drainage area has been properly stabilized.
11. OPTIONAL: A one foot layer of DE #3 stone may be placed on the upstream side of the riprap in place of the embedded filter cloth.

MAXIMUM DRAINAGE AREA: 5 ACRES

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:

SST

Detail No.

DE-ESC-3.1.3.2

Sheet 2 of 2

Effective July 2023

ADDITIONAL STANDARD AND SPECIFICATIONS FOR RIPRAP OUTLET SEDIMENT TRAP

Design Criteria

Riprap Outlet Sediment Trap consists of a trap formed by an excavation and embankment. The outlet for this trap shall be through a partially excavated channel lined with riprap. This outlet channel shall discharge onto a stabilized area or to a stable watercourse. The riprap outlet sediment trap may be used for drainage areas of up to a maximum of 15 acres.

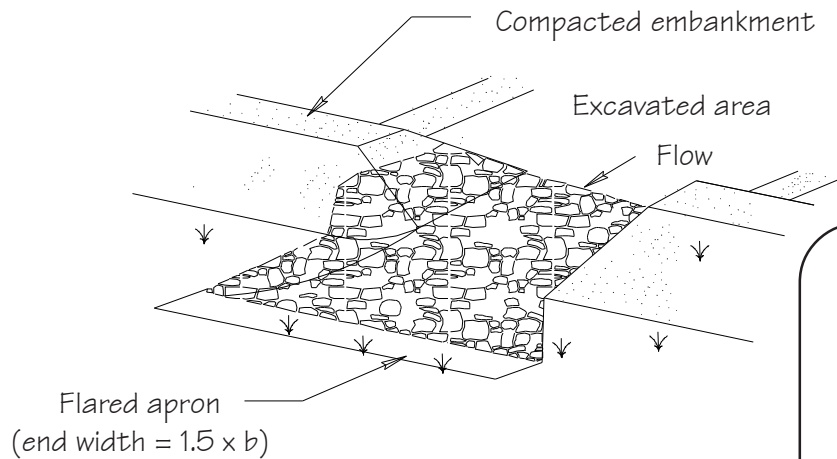
1. The total drainage area shall not exceed 15 acres.
2. The storage needs for this trap shall be computed using 3,600 cubic feet of required storage for each acre of drainage area in addition to any storage provided as a wet pool. The temporary storage volume provided is determined by computing the volume of storage available behind the outlet structure up to the elevation of the crest of the riprap outlet channel. Additional wet pool storage can be provided by excavating below the elevation required to fulfill the temporary storage volume.
3. The maximum height of embankment shall not exceed four (4) feet.
4. The elevation of the top of any dike directing water to a riprap outlet sediment trap shall equal or exceed the minimum elevation of the embankment along the entire length of this trap.

Riprap Outlet Sediment Trap - Design Guidelines

Contributing Drainage Area (Acres)	Depth of Channel (a) (Feet)	Length of Weir (b) (Feet)
1	1.5	4.0
2	1.5	5.0
3	1.5	6.0
4	1.5	10.0
5	1.5	12.0
6	1.5	14.0
7	1.5	16.0
8	2.0	10.0
9	2.0	10.0
10	2.0	12.0
11	2.0	14.0
12	2.0	14.0
13	2.0	16.0
14	2.0	16.0
15	2.0	18.0

Standard Detail & Specifications

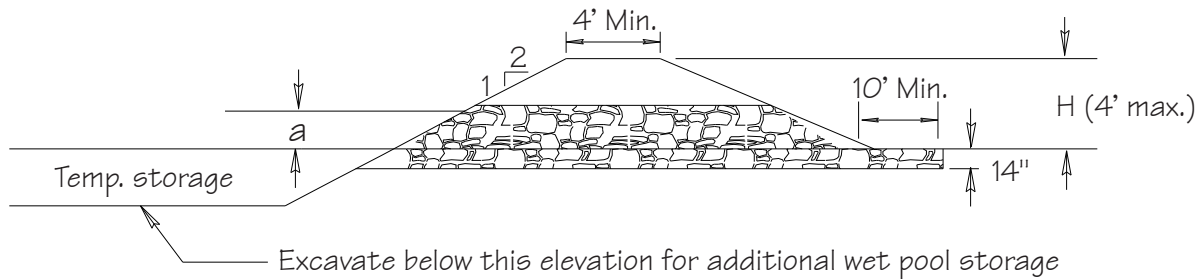
Riprap Outlet Sediment Trap



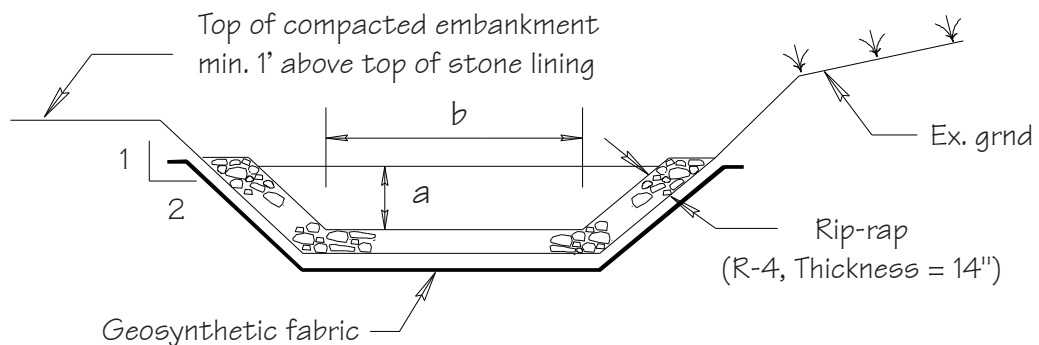
Perspective

DATA

Drainage area (D.A.)
Required storage (V_s)
Design dimensions (L x W x D)
Embankment height (H)
Channel depth (a)
Weir length (b)



Profile thru Outlet



Cross-section of Outlet

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:



Detail No.

DE-ESC-3.1.3.3

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Riprap Outlet Sediment Trap

Construction Notes:

1. The area under embankment shall be cleared, grubbed and stripped of any vegetation and root mat. The pool area shall be cleared.
2. The fill material for the embankment shall be free of roots or other woody vegetation as well as over-sized stones, rocks, organic material or other objectionable material. The embankment shall be compacted by traversing with equipment while it is being constructed. Maximum height of embankment shall be four (4) feet, measured at centerline of the embankment.
3. All fill slopes shall be 2:1 or flatter; cut slopes 1:1 or flatter.
4. Elevation of the top of any dike directing water into trap must equal or exceed the height of embankment.
5. Storage area provided shall be figured by computing the volume available behind the outlet channel up to the elevation of the crest of the outlet weir channel.
6. Filter cloth shall be placed over the bottom and sides of the outlet channel prior to placement of stone. Sections of fabric must overlap at least one (1) foot with section nearest the entrance placed on top. Fabric shall be embedded at least six (6) inches into existing ground at entrance of outlet channel.
7. Stone used in the outlet shall be R-4 riprap with a thickness of 14".
8. **An approved dewatering device shall be considered an integral part of the trap. Dewatering operations shall be conducted in accordance with any and all regulatory requirements.**
9. Sediment shall be removed and trap restored to its original dimensions when the sediment has accumulated to 1/2 the design depth of the trap. Removed sediment shall be deposited in a suitable area and in such a manner that it will not erode.
10. The structure shall be inspected after each rain and repaired as needed.
11. Construction operations shall be carried out in such a manner that erosion and water pollution are minimized. Disturbed areas shall be stabilized in accordance with the Standards and Specifications for vegetative Stabilization contained in this Handbook.
12. The structure shall be removed and the area stabilized when the contributing drainage area has been properly stabilized.

MAXIMUM DRAINAGE AREA: 15 ACRES

Source: Adapted from MD Stds. & Specs. for ESC	Symbol: <div style="border: 2px solid black; padding: 10px; text-align: center; width: 100px; margin: 0 auto;">RST</div>	Detail No. DE-ESC-3.1.3.3 Sheet 2 of 2 Effective July 2023
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ADDITIONAL STANDARD AND SPECIFICATIONS FOR COMPOST LOG SEDIMENT TRAP

Design Criteria:

Compost Log Sediment Trap consists of a trap formed by enclosing a designated area with compost logs. The sediment and pollutant containment process characteristic to Sediment traps combines both filtering and deposition of suspended solids. Because a compost log sediment trap is a *dry pond* system there is little or no re-suspension of settled particulates with successive runoff events and maintenance is generally lower relative to wet pond systems.

1. Compost log sediment traps shall have a minimum effective height of three (3) feet. Additional height and runoff-sediment storage volume can be attained by excavating directly upslope from the Sediment trap. Excavation shall not undermine the structure and integrity of the sediment trap system.
2. Runoff flow and ponding depth shall maintain a minimum 12 inch vertical distance from the maximum waterline (freeboard) to the top of the sediment trap.
3. The temporary storage for this trap shall be computed using 3,600 cubic feet of required storage for each acre of drainage area. The temporary storage volume provided is determined by computing the volume of storage available within the compost log enclosure up to the maximum waterline.
4. For stability and ballast against constant water pressure (head), compost log sediment traps shall have a 1H:1V construction ratio, although the base may be wider for additional ballast. Larger diameter compost logs (18 in, 24 in, 32 in) shall be used at the base of the sediment trap system with increasingly smaller diameter logs (8 in, 12 in, 18 in) placed on top of the layer below.
5. Where compost logs are sleeved to join other logs for long sediment trap designs, material overlap shall be a minimum of 4 ft and shall be staked where material overlaps using 2 stakes, 2 ft apart. Sediment trap logs shall not be joined (sleeved) where concentrated flow contacts the sediment trap logs or enters the sediment trap system. Additionally, sleeved joints shall not be located at elevation low points within the sediment trap.
6. If concentrated flow is directed or channeled to the sediment trap, energy flow dissipaters shall be used at the base of the channel/concentrated flow prior to contact with the sediment trap compost logs. Dissipaters shall be placed at a minimum distance of 20 ft from the base course of the sediment trap.

Materials:

Compost logs used for the construction of Compost Log Sediment Traps shall meet the requirements of **3.1.7 Standards & Specifications for Compost Filter Log.**

Site preparation:

Sediment traps should be placed on low grade or level contours to maximize runoff-sediment volume containment. Flow of water should be perpendicular to the Sediment trap at impact. Placing Sediment traps on compacted or undisturbed soil will reduce the potential for undermining. Sediment traps shall not be placed on fill soil or slopes.

Installation:

Compost logs are stacked so the horizontal base width is at least equivalent to the effective height (1H:1V), traps shall be installed so the effective height is at least 3 feet, and the log configuration will be designated by the design engineer. Stakes shall be installed through the middle of the compost logs using 2 inches by 2 inches by 3 feet wooden hardwood stakes on 10 feet centers. Stakes shall be placed in a pyramid configuration perpendicular to compost logs where stakes cross at the apex of the compost log trap. Stakes shall be joined and secured with wire wrapping at apex using 16 gauge or multi-strand 20 gauge wire allowing 12 inches of stake above the compost log trap. All base layers shall be staked on 5 feet centers; placed opposite the pyramid staking; where staking is present every 2.5 feet Half inch rebar may also be used when ground is frozen or extremely compacted. Staking depth for all soil types shall be a minimum 12 inches into native soil.

Slope interruption may be installed upslope and within the runoff flow path to reduce flow energy entering the compost traps. Concentrated flows, channels, or ditches directing flow into the trap shall employ energy flow dissipaters prior to flow contact with the trap compost logs or entry into the trap system. Dissipaters shall be placed at a minimum distance of 20 feet from the base course of the trap.

In order to prevent water flowing around the ends of the sediment trap, the ends of the trap must be constructed pointing upslope so the ends are at a minimum 1 foot higher elevation than the lowest point (mid-section) of the sediment trap. The mid-section of the sediment trap shall be the point of lowest elevation. A minimum of 10 linear feet per end each placed at a 30 degree angle is recommended.

Spillway:

Though the sediment trap is designed to pond stormwater and filters the stormwater through the compost barrier, a spillway must be designed to handle a worst-case scenario. The design engineer will determine the location of a controlled outfall which will also serve as the minimum freeboard location for the trap. Erosion control matting or appropriately sized riprap shall be installed under the first row of compost logs and extend from the trap a distance no less than 30 feet.

Safety:

State and local requirements shall be met concerning fencing and signs, warning the public of hazards of soft sediment and possible flood water.

Maintenance:

The compost log sediment trap must be reviewed on a regular basis to ensure that it is in a functional condition at all times. Remove the sediment at the base of the upslope side of the sediment trap when accumulation has reached one half (1/2) of the effective height of the trap.

Final Disposal:

The compost medium in the logs will be dispersed on site once the upgrade disturbed area has been permanently stabilized and approval is granted by the local delegated agency to remove the trap. The compost medium may be dispersed with a loader, rake, bulldozer or similar device and may be incorporated into the soil as an amendment or left on the soil surface to aid in permanent seeding or landscaping. The compost log mesh netting must be extracted and disposed of properly. In the case where biodegradable mesh netting has been used, the netting may remain incorporated with the compost medium when being spread on site.

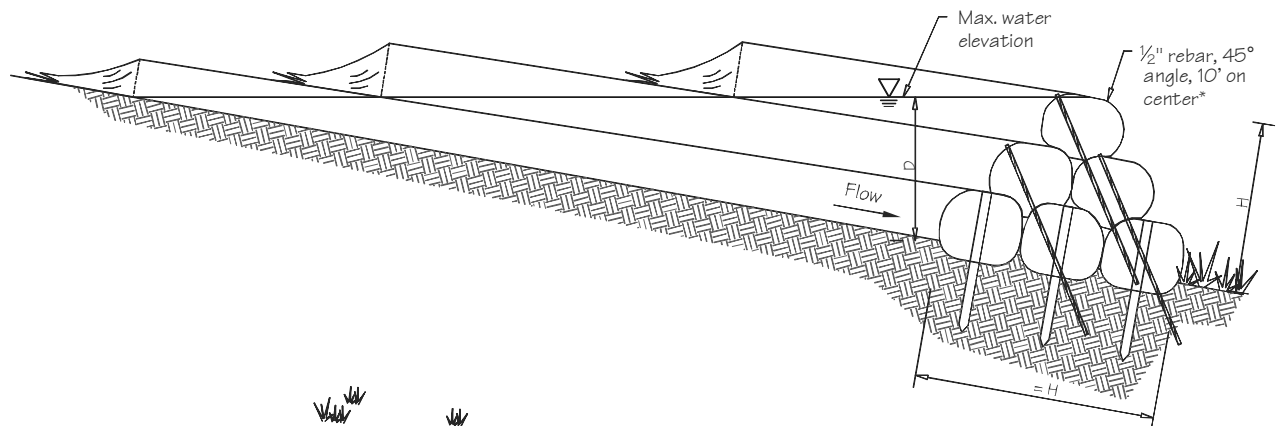
Compost Log Sediment Traps may be interchangeable in the field with pipe, stone outlet or riprap outlet sediment traps provided they are designed and constructed in accordance with the standard and specifications for those traps. Compost Log Sediment Traps shall be limited to a five (5) acre maximum drainage area.

MAXIMUM DRAINAGE AREA: 5 ACRES

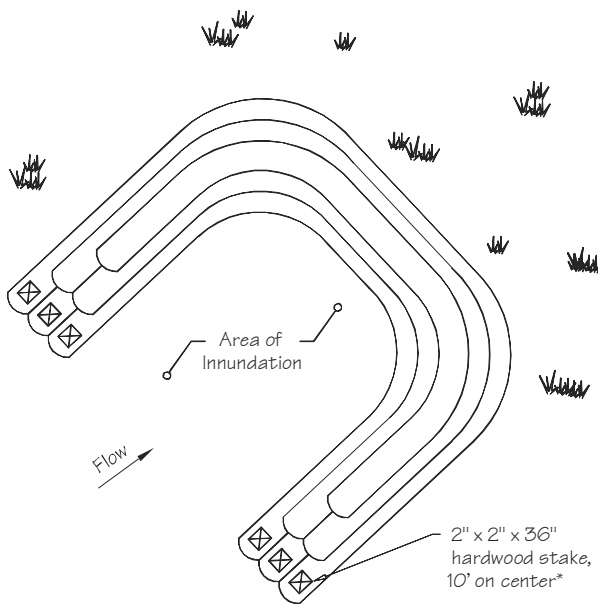
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Standard Detail & Specifications

Compost Log Sediment Trap



* Staking per
manufacturer
recommendation



DATA TO BE PROVIDED

Spillway Location
Spillway Weir Elevation
Sediment Trap Volume

Source:

Adapted from
Filtrexx™ International

Symbol:

CST

Detail No.

DE-ESC-3.1.3.4

Sheet 1 of 3

Effective July 2023

Standard Detail & Specifications

Compost Log Sediment Trap

Construction Notes:

1. Compost log sediment traps should be placed on low grade or level contours to maximize runoff-sediment volume containment.
2. Compost logs are stacked so the horizontal base width is at least equivalent to the effective height (1H:1V); traps shall be installed so the effective height is at least 3 feet.
3. The volume of sediment storage shall be 3600 cubic feet per acre of drainage area.
4. Stakes shall be installed through the middle of the compost logs using 2 inches by 2 inches by 3 feet wooden hardwood stakes on 10 feet centers. Stakes shall be placed in a pyramid configuration perpendicular to compost logs where stakes cross at the apex of the compost log trap. Stakes shall be joined and secured with wire wrapping at apex using 16 gauge or multi-strand 20 gauge wire allowing 12 inches of stake above the compost log trap.
5. All base layers shall be staked on 5 feet centers; placed opposite the pyramid staking; where staking is present every 2.5 feet Half inch rebar may also be used when ground is frozen or extremely compacted. Staking depth for all soil types shall be a minimum 12 inches into native soil.
6. Concentrated flows, channels, or ditches directing flow into the trap shall employ energy flow dissipaters prior to flow contact with the trap compost logs or entry into the trap system. Dissipaters shall be placed at a minimum distance of 20 feet from the base course of the trap.
7. In order to prevent water flowing around the ends of the sediment trap, the ends of the trap must be constructed pointing upslope so the ends are at a minimum 1 feet higher elevation than the lowest point (mid-section) of the sediment trap. The mid-section of the sediment trap shall be the point of lowest elevation. A minimum of 10 linear feet per end each placed at a 30 degree angle is recommended.
8. The design engineer will determine the location of a controlled outfall which will also serve as the minimum freeboard location for the trap. Erosion control matting or appropriately sized riprap shall be installed under the first row of compost logs and extend from the trap a distance no less than 30 feet.
9. The compost log sediment trap must be reviewed on a regular basis to ensure that it is in a functional condition at all times. Remove the sediment at the base of the upslope side of the sediment trap when accumulation has reached one half (1/2) of the effective height of the trap.

Source:

Adapted from
Filtrexx™ International

Symbol:

CST

Detail No.

DE-ESC-3.1.3.4

Sheet 2 of 3

Effective July 2023

Standard Detail & Specifications

Compost Log Sediment Trap

10. The compost medium in the logs will be dispersed on site once the upgrade disturbed area has been permanently stabilized and approval is granted by the local delegated agency to remove the trap. The compost medium may be dispersed with a loader, rake, bulldozer or similar device and may be incorporated into the soil as an amendment or left on the soil surface to aid in permanent seeding or landscaping. The compost log mesh netting must be extracted and disposed of properly. In the case where biodegradable mesh netting has been used, the netting may remain incorporated with the compost medium when being spread on site.

Materials

1. Stakes: 2" x 2" x 36" hardwood.
2. Compost media : See requirements in Standard Detail and Specifications for Compost Logs (DE-ES-3.1.7).
3. Filter sock: See requirements in Standard Detail and Specifications for Compost Logs (DE-ES-3.1.7).
4. Rebar: 1/2" nominal.

MAXIMUM DRAINAGE AREA: 5 ACRES

Source:

Adapted from
Filtrexx™ International

Symbol:

CST

Detail No.

DE-ESC-3.1.3.4

Sheet 3 of 3

Effective July 2023

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STANDARD AND SPECIFICATIONS FOR TEMPORARY SEDIMENT BASIN

Definition: A temporary barrier or dam constructed across a drainageway or at other suitable locations to intercept sediment-laden runoff and to trap and retain the sediment.



Purpose: The purpose of a sediment basin is to intercept sediment-laden runoff and reduce the amount of sediment leaving the disturbed area in order to protect drainageways, properties, and rights-of-way below the sediment basin.

Scope: This standard applies to the installation of temporary sediment basins on sites where:

1. Failure of the structure would not result in loss of life, damage to homes or buildings, or interruption of use or service of public roads or utilities;
2. The drainage area does not exceed 100 acres;
3. The basin is to be removed within 36 months after the beginning of construction of the basin.

Permanent (to function more than 36 months) sediment basins or structures that temporarily function as a sediment basin but are intended for use as a permanent stormwater management facility shall be classified as permanent structures and shall conform to criteria appropriate for permanent structures. These structures shall be designed and constructed to conform to State criteria, local requirements, and/or U.S.D.A. Natural Resource Conservation Service Standards and Specifications No. 378 for ponds; whichever is more restrictive. The total volume of permanent sediment basins shall equal or exceed the capacity requirements for temporary basins contained herein.

Criteria for Temporary Sediment Basins For the purpose of this standard, sediment basins must meet the following minimum criteria:				
Max.Drainage Area, acres	Max.Height* of Dam, Ft.	Min.Embankment Top Width, Ft.	Embankment Side Slopes	Anti-Seep Collar Req'd
100	15	10	2:1 Inside 3:1 Outside	Yes
* Height is measured from the low point of original ground along the centerline of dam to the top of the dam.				

Conditions Where Practice Applies:

A sediment basin is appropriate where physical site conditions or land ownership restrictions preclude the installation of other erosion control measures to adequately control runoff, erosion, and sedimentation. It may be used below construction operations which expose critical areas to soil erosion. The basin shall be maintained until the disturbed area is protected against erosion by permanent stabilization.

Design Criteria for Temporary Sediment Basins:

Standard designs have been established for temporary sediment basins having drainage areas less than 20 acres. The data for these standard designs are shown in Figure 3.1.4a for drainage areas less than 10 acres and in Figure 3.1.4b for drainage areas from 10 to 20 acres. Basins which have drainage areas greater than 20 acres or which have special circumstances which preclude the use of a standard design shall have a site specific design. A worksheet has been provided based on the recommended design procedure (see Figure 3.1.4c). The following discussion outlines additional criteria to be considered in the design process.

Compliance with Laws and Regulations

Design and construction shall comply with state and local laws, ordinances, rules and regulations.

Location

The sediment basin should be located to obtain the maximum storage benefits from the terrain and for ease of cleanout of the trapped sediment. It should be located to minimize interference with construction activities and construction of utilities. Whenever possible, sediment basins should be located so that storm drains may outfall or be diverted into the basin.

Size of the Basin

The volume of the sediment basin, as measured from the bottom of the base to the elevation of the crest of the principal spillway shall be at least 3,600 cubic feet per acre of drainage area. This 3,600 cubic feet is equivalent to 1.0 inch of sediment per acre of drainage area. Additional storage in the form of a permanent wet pool shall be provided whenever practicable, but may not be used to fulfill the temporary storage volume requirement.

Sediment basins shall be cleaned out when the volume remaining as described above is reduced by sedimentation to 1,800 cubic feet per acre of drainage area (50 percent full). In no case shall the sediment level be permitted to build up higher than one foot below the principal spillway crest. At this elevation, cleanout shall be performed to restore the original design volume to the sediment basin. The elevation of the maximum allowable sediment level shall be determined and shall be stated in the design data as a distance below the top of the riser and be clearly marked on the riser.

The basin dimensions necessary to obtain the required basin volume as stated above shall be clearly shown on the plans to facilitate plan review, construction and inspection.

Shape of the Basin

It is recommended that the designer of a sediment basin strive to incorporate the following features:

- ◆ Length to width ratio greater than 2:1, where length is the distance between the inlet and outlet.
- ◆ A wedge shape with the inlet located at the narrow end.

In cases where site conditions prevent the use of the recommended shape, function can sometimes be improved by installing baffles in the basin pool area. A procedure for the design of these structures is discussed later in this standard and specification.

Spillway Design

Peak rates of runoff values used in spillway design shall be based on USDA-NRCS methodology as outlined in TR 55 Urban Hydrology and/or TR 20 Project Formulation - Hydrology. Special situations which warrant a different methodology require approval from the Department. Runoff computations shall be based upon the worst soil-cover conditions expected to prevail in the contributing drainage area during the anticipated effective life of the structure. The combined capacities of the principal and emergency spillway shall be sufficient to pass the peak rate of runoff from a 10-year frequency, 24-hour NRCS Type II rainfall event or a higher frequency corresponding to the hazard involved.

1. **Principal spillway** - A spillway consisting of a vertical pipe or box type riser joined (watertight connection) to a pipe (barrel) which shall extend through the embankment and outlet beyond the downstream toe of the fill. The minimum capacity of the principal spillway shall be 0.2 cfs per acre of drainage area when the water surface is at the emergency spillway crest elevation. For those basins with no emergency spillway, the principal spillway shall have the capacity to handle the peak flow from a ten year frequency rainfall event. The minimum size of the barrel shall be 8 inches in diameter. ***See Figures 3.1.4d, 3.1.4e, and 3.1.4f for principal spillway sizes and capacities.***
 - a. **Crest elevation** - When used in combination with an emergency spillway, the crest elevation of the riser shall be a minimum one foot below the elevation of the control section of the emergency spillway.
 - b. **Watertight riser and barrel assembly** - The riser and all pipe connections shall be completely watertight except for the inlet opening at the top or a dewatering opening and shall not have any other holes, leaks, rips or perforations in it.

-
- c. *Dewatering the basin* - There are two stages of dewatering the basin: (1) the detention pool which is below the crest of the riser and above the surface of the trapped sediment; and (2) the sediment itself which will have a high water content to the point of being "soupy."
- i. Individual dewatering methods may be dictated by the intended use of the basin, i.e., sediment, flyash, or other special materials, that are to be trapped and retained within the basin. If a dewatering device is needed it shall be included in the sediment basin plans submitted for approval and shall be installed during construction of the basin. Dewatering shall be done in such a manner as to remove the relatively clean water without removing any of the sediment that has settled out and without removing any appreciable quantities of floating debris. Dewatering sediments trapped in a basin are often advantageous to the developer or contractor. Relatively dry material can be handled with on-site equipment rather than the expensive draglines often needed to handle wet (underwatered) sediments. Usually, the detention pool may be dewatered by a siphon installed on the riser, mechanical pumping, and surface or subsurface drains. For details on these methods of dewatering, see Section 3.2 of the Handbook.
 - ii. Dewatering the sediment is not required but some local ordinances may require some methods to dewater the basin and facilitate the cleanout process. One very successful means of doing this is by use of a dewatering device.
- d. *Anti-vortex device and trash rack* - An anti-vortex device and trash rack shall be securely installed on top of the riser and shall be the concentric type as shown on Sheet 3 of the Standard Detail and Specification for Temporary Sediment Basin.
- e. *Base* - The riser shall have a base attached with a watertight connection and shall have sufficient weight to prevent flotation of the riser. Two approved bases for risers ten feet or less in height are: (1) a concrete base 18" thick with the riser embedded 9" in the base, and (2) a 1/4" minimum thickness steel plate attached to the riser by a continuous weld around the circumference of the riser to form a watertight connection. The plate shall have 2.5 feet of stone, gravel, or compacted earth placed on it to prevent flotation. In either case, each side of the square base shall be twice the riser diameter.
- For risers greater than ten feet high computations shall be made to design a base which will prevent flotation. The minimum factor of safety shall be 1.20 (Downward forces = 1.20 x upward forces).
- f. *Anti-Seep Collars* - anti-seep collars shall be installed around all conduits through earth fills of impoundment structures according to the following criteria:
- i. Collars shall be placed to increase the seepage length along the conduit by a minimum of 15 percent of the pipe length located within the saturation zone.
 - ii. Collar spacing shall be between 5 and 14 times the vertical projection of each collar.
 - iii. All collars shall be placed within the saturation zone.
 - iv. The assumed normal saturation zone (phreatic line) shall be determined by projecting a line at a slope of 4 horizontal to 1 vertical from the point where the normal water (riser crest) elevation touches the

the upstream slope of the fill to a point where this line intersects the invert of the pipe conduit. All fill located within this line may be assumed as saturated.

When anti-seep collars are used, the equation for revised seepage length becomes:

$$2(N)V = 0.15(L_s) \text{ or } N = \frac{0.075(L_s)}{V}$$

Where: L_s = saturated length is length, in feet, of pipe between riser and intersection of phreatic line and pipe invert.

N = number of anti-seep collars.

V = vertical projection of collar from pipe, in feet.

v. All anti-seep collars and their connections shall be watertight.

- g. *Outlet* - An outlet shall be provided, including a means of conveying the discharge in an erosion-free manner to an existing stable channel. Where discharge occurs at the property line, drainage easements will be obtained in accordance with local ordinances. Adequate notes and references will be shown on the erosion and sediment control plan.

Protection against scour at the discharge end of the pipe spillway shall be provided. Measures may include impact basin, riprap, revetment, excavated plunge pools, or other approved methods. See the Standard and Specifications for Riprap Outlet Protection or Riprap Stilling Basin.

2. **Emergency Spillways** - The entire flow area of the emergency spillway shall be constructed in undisturbed ground (not fill). The emergency spillway cross-section shall be trapezoidal with a minimum bottom width of eight feet. This spillway channel shall have a straight control section of at least 20 feet in length; and a straight outlet section of at least 25 feet in length.

- a. *Capacity* - The minimum capacity of the emergency spillway shall be that required to pass the peak rate of runoff from the 10-year 24-hour frequency storm, less any reduction due to flow in the pipe spillway.
- b. *Velocities* - The velocity of flow in the exit channel shall not exceed 5 feet per second for vegetated channels during a 10 year runoff event. For channels with erosion protection other than vegetation, velocities shall be within the non-erosive range for the type of protection used.
- c. *Erosion Protection* - Erosion protection shall be provided for by vegetation as prescribed in this publication or by other suitable means such as riprap, asphalt or concrete.
- d. *Freeboard* - Freeboard is the difference between the design high water elevation in the emergency spillway and the top of the settled embankment. If there is no emergency spillway it is the difference between the water surface elevation required to pass the design flow through the pipe and the top of the settled embankment. *The freeboard shall be at least one foot.*

Embankment Cross-Section

The minimum top width shall be ten feet. The inside slopes shall be 2:1 or flatter, outside slopes shall be 3:1 or flatter.

Entrance of Runoff Into Basin

Points of entrance of surface runoff into excavated basins shall be protected to prevent erosion. Considerable care should be given to the major points of inflow into basins. In many cases the difference in elevation of the inflow and the bottom of the basin is considerable, thus creating potential for severe gullying and sediment generation. Often a riprap chute at major points of inflow would eliminate gullying and sediment generation.

Diversions, grade stabilization structures or other water control devices shall be installed as necessary to insure direction of runoff and protect points of entry into the basin. Points of entry should be located so as to insure maximum travel distance of the incoming runoff to point of exit (the riser) from the basin.

Procedure for Determining or Altering Sediment Basin Shape

As specified in the Standard and Specification, the pool area at the elevation of the crest of the principal spillway shall have a length to width ratio of at least 2.0 to 1. The purpose of this requirement is to minimize the "short-circuiting" effect of the sediment laden inflow to the riser and thereby increase the effectiveness of the sediment basin. The purpose of this procedure is to prescribe the parameters, procedures and methods of determining and modifying the shape of the basin.

The length of the flow path (L) is the distance from the point of inflow to the riser (outflow point). The point of inflow is the point that the stream enters the normal pool (pool level at the riser crest elevation). The pool area (A) is the area of the normal pool. The effective width (W_e) is found by the equation:

$$W_e = A/L_e \quad \text{and} \quad L:W \text{ ratio} = L/W_e$$

In the event there is more than one inflow point, any inflow point which conveys more than 30 percent of the total peak inflow rate shall meet the length-width ratio criteria.

The required basin shape may be obtained by proper site selection, by excavation or by constructing a baffle in the basin. The purpose of the baffle is to increase the effective flow length from the inflow point to the riser. Baffles shall be placed mid-way between the inflow point and the riser. The baffle length shall be as required to provide the minimum 2:1 length-width ratio. The effective length (L_e) shall be the shortest distance the water must flow from the inflow point around the end of the baffle to the outflow point. Then:

$$W_e = A/L_e \quad \text{and} \quad L:W \text{ ratio} = L_e/W_e$$

Three examples are shown on Sheet 9 of the Standard Detail and Specification for Temporary Sediment Basin. Note that for the special case in Example C, the water is allowed to go around both ends of the baffle and the effective length, $L_e = L_1 + L_2$. Otherwise, the length-width ratio computations are the same as shown above. This special case procedure for computing L_e is allowable only when the two flow paths are equal, i.e., when $L_1 = L_2$. A baffle detail is also shown.

Disposal

The sediment basin plans shall indicate the method(s) of disposing of the sediment removed from the basin. The sediment shall be placed in such a manner that it will not erode from the site. The sediment shall not be deposited downstream from the basin, or adjacent to a stream, or floodplain. Disposal sites will be stabilized as required by an approved erosion and sediment control plan.

The sediment basin plans shall also show the method of removing the sediment basin after the drainage area is stabilized, and shall include the stabilization of the sediment basin site. The basin shall be dewatered in accordance with the approved plan prior to removing or breaching the embankment. Sediment shall not be allowed to flush into a stream or drainageway.

Safety

Sediment basins are attractive to children and can be very dangerous. Local ordinances and regulations must be adhered to regarding health and safety. The developer or owner shall check with local building officials on applicable safety requirements. If temporary fencing of sediment basins is required, the location of and type of fence shall be shown on the plan.

Final Disposal

When temporary structures have served their intended purpose and the contributing drainage area has been properly stabilized, the embankment and resulting sediment deposits are to be leveled or otherwise disposed of in accordance with the approved sediment control plan. The proposed use of a sediment basin site will often dictate final disposition of the basin and any sediment contained therein. If the site is scheduled for future construction, then the basin material and trapped sediments must be removed, safely disposed of, and backfilled with a structural fill. When the basin area is to remain open space the pond may be pumped dry, graded and back filled.

INFORMATION TO BE SUBMITTED

Temporary sediment basin designs and construction plans submitted for review to the regulatory authority shall include the completed hydrologic design computation worksheet (Figure 3.1.4c) and the data required on the Standard Detail and Specification. (NOTE: Standard designs discussed previously do not require hydrologic computations.)

Conditions Where Practice Applies:

1. Drainage area to the basin is less than 10 acres.
2. An emergency spillway is required: $Q_{ES} = Q_{PEAK} - Q_{PIPE} = 52 - 11 = 41$ cfs
3. Volume of storage computed as 3,600 C.F./acre of drainage area.
4. $A/Q_{10} \geq .01$

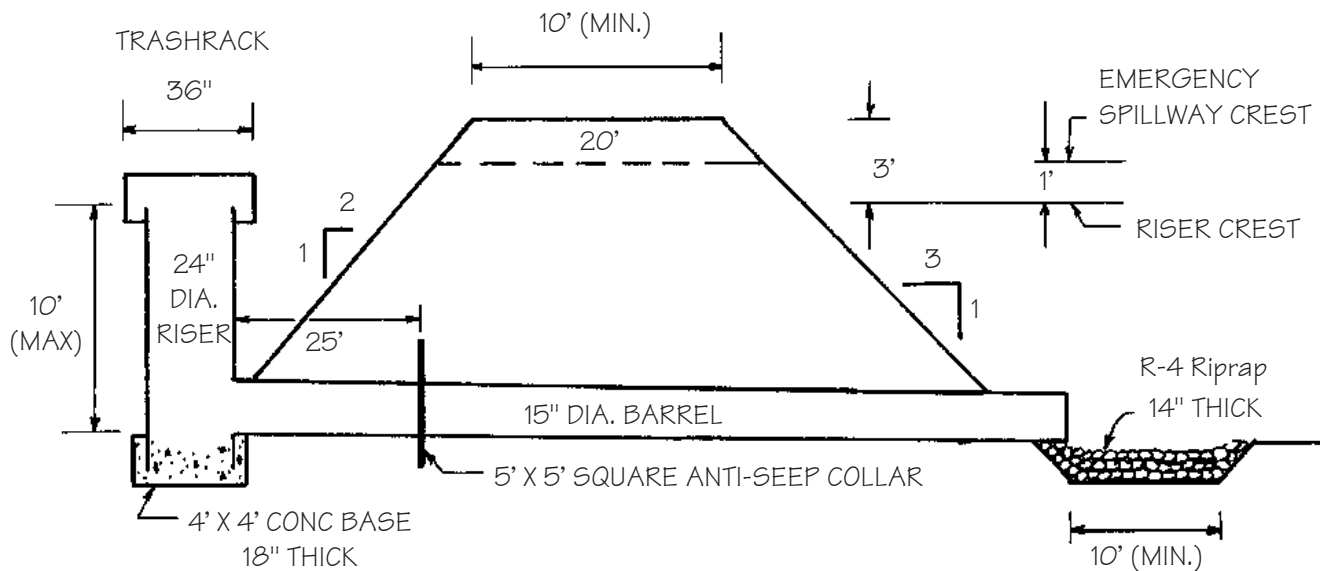


Figure 3.1.4a Standard sediment basin design for drainage areas less than 10 acres

NOTE: This graphic is for informational purposes only.
Data must be transferred to Standard Detail and Specifications for construction purposes.

Conditions Where Practice Applies:

1. Drainage area to the basin is 10 to 20 acres.
2. An emergency spillway is required: $Q_{ES} = Q_{PEAK} - Q_{PIPE} = 88 - 35 = 53$ cfs
3. Volume of storage computed as 3,600 C.F./acre of drainage area.
4. $A/Q_{10} \geq .01$

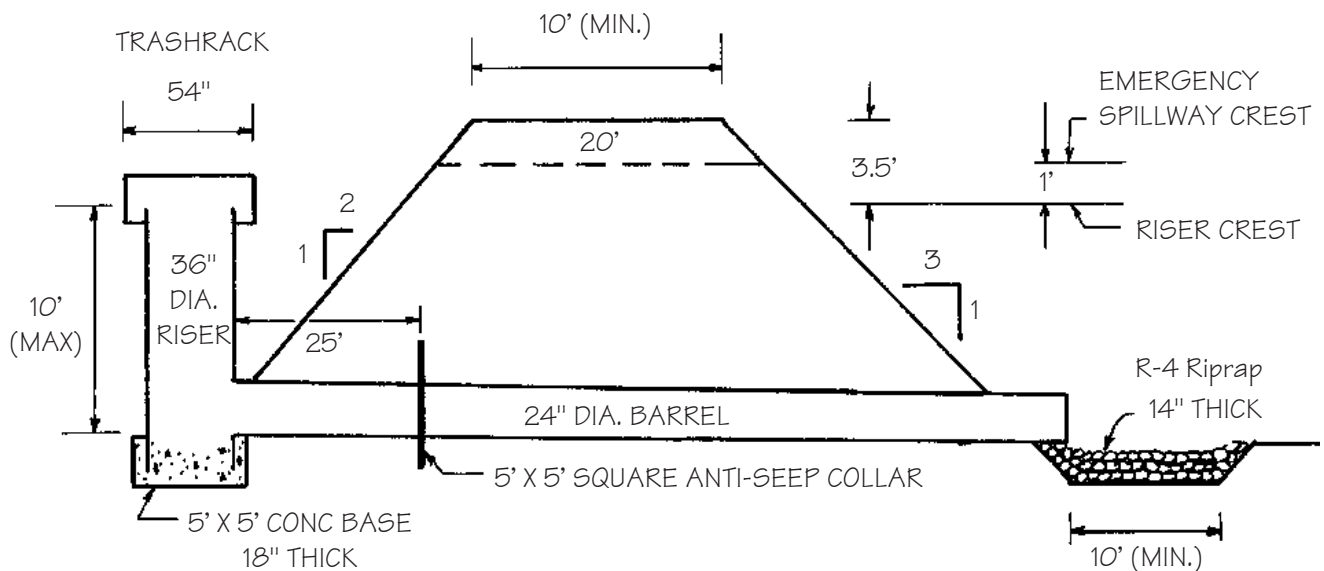


Figure 3.1.4b Standard sediment basin design for drainage areas from 10 to 20 acres.

NOTE: This graphic is for informational purposes only.
Data must be transferred to Standard Detail and Specifications for construction purposes.

Computed by _____ Date _____
 Checked by _____ Date _____
 Project _____
 Basin ID _____ Location _____
 Total area draining to basin, _____ Acres.

BASIN VOLUME DESIGN

1. Min. required volume = 134 cu. yds. x _____ ac. drainage = _____ cu. yds.
2. Volume of basin* = _____ = _____ cu. yds.
3. Excavate _____ cu. yds. to obtain required capacity.
 Min. vol. before cleanout = 67 cu. yds. x _____ ac. drainage = _____ cu. yds.
 Elevation corresponding to scheduled time to clean out: _____
 Distance below top of riser (ft): _____

DESIGN OF SPILLWAYS

Runoff

4. $Q_{p_{10}}$ = _____ cfs (TR-55 or other appropriate method, attach runoff computation sheet).

Pipe Spillway (Qps)

5. Min. pipe spillway capacity, $Q_{ps} = 0.2 \times$ _____ ac. drainage = _____ cfs.
 Note: If there is no emergency spillway, then req'd. $Q_{ps} = Q_{p_{10}} =$ _____ cfs.
6. H = _____ ft. Barrel length = _____ ft.
7. Barrel: Diam. _____ inches; $Q_{ps} = (Q)$ _____ x (cor.fac.) _____ = _____ cfs.
8. Riser: Diam. _____ inches; Length _____ ft.; h = _____ ft.
9. Trash Rack: Diam. _____ inches; H = _____ inches.

Emergency Spillway Design

10. Emergency Spillway Flow, $Q_{es} = Q_{p_{10}} - Q_{ps} =$ _____ - _____ = _____ cfs.
11. Width _____ ft. Hp _____ ft.
 Entrance channel slope _____ %
 Exit channel slope _____ %

ANTI-SEEP COLLAR DESIGN

12. y = _____ ft.; z = _____ :1; pipe slope = _____ %, Ls = _____ ft.
 Use _____ collars, _____' - _____" square; projection = _____ ft.

DESIGN ELEVATIONS

13. Riser Crest = _____ Design High Water = _____
 Emergency Spillway Crest = _____ Top of Dam = _____

*Surface area criteria: Pond Surface Area (A)/10 Year Peak Discharge (Q_{10}) $\geq .01$

Figure 3.1.4c Temporary sediment basin design worksheet

TEMPORARY SEDIMENT BASIN DESIGN DATA SHEET

INSTRUCTIONS FOR USE OF FORM

1. Minimum required detention volume is 134 cubic yards per acres from each acre of drainage area. Values larger than 134 cubic yards per acre may be used for greater protection. Compute volume using entire contributing drainage area, even if only part may be disturbed.
2. Surface area criteria is established such that the pond surface area (ac) during a 10-year frequency storm divided by the peak discharge (cfs) of the 10-year frequency storm shall have a ratio of at least 0.01.
3. If volume of basin is not adequate for required storage, excavate to obtain the required volume.
4. Peak rates of runoff values shall be based on USDA-NRCS methodology as outlined in TR 55 Urban Hydrology and/or TR 20 Project Formulation - Hydrology.
5. The principal spillway shall be designed to carry 0.2 cfs per acre of drainage area. The pipe shall be designed to carry $Q_{p_{10}}$ if site conditions preclude installation of an emergency spillway to protect the structure.
6. Determine value of "H" from field conditions. ("H" is the interval between the centerline of the barrel pipe at the outlet and the emergency spillway crest or, if there is no emergency spillway, to the design high water.)
7. See Pipe Spillway Design Charts (Figure 3.1.4d or Figure 3.1.4e).
8. See Riser Inflow curves (Figure 3.1.4f).
9. See Trash Rack and Anti-Vortex Device Design Table (Figure 3.1.4g).
10. Compute Q_{es} by subtracting actual flow carried by the pipe spillway from the total inflow, Q_p .
11. Use Figure 3.1.4h to obtain values of design depth of flow (H_p), bottom width, and design Q_{es} . If no emergency spillway is to be used, so state, giving reason(s).
12. See Anti-Seep Collar Design Graph (Figure 3.1.4j).
13. Fill in design elevations. The emergency spillway crest must be set no closer to riser crest than value of "h" which causes pipe spillway to carry the minimum required Q. Therefore, the elevation difference between spillways shall be equal to the value of "h", or one foot, whichever is greater. Design high water is the elevation of the emergency spillway crest plus the value of H_p , or if there is no emergency spillway, it is the elevation of the riser crest plus "h" required to handle the 10-year storm. Minimum top of dam elevation requires 1.0 ft. of freeboard above design high water.

NOTE: A method for dewatering shall be incorporated into the design.

PIPE FLOW CHART (Full flow assumed)

For Corrugated Metal Pipe Inlet $K_e + K_b = 1.0$ and 70 feet of Corrugated Metal Pipe Conduit
 $n = 0.025$. Note correction factors for other pipe lengths.

Dia. H	12"	15"	18"	21"	24"	30"	36"	42"
2	2.84	4.92	7.73	11.30	15.60	26.60	40.77	58.12
3	3.48	6.03	9.47	13.84	19.10	32.58	49.93	71.19
4	4.02	6.96	10.94	15.98	22.06	37.62	57.66	82.20
5	4.49	7.78	12.23	17.87	24.66	42.06	64.46	91.90
6	4.92	8.52	13.40	19.57	27.01	46.07	70.60	100.65
7	5.32	9.21	14.47	21.14	29.19	49.77	76.28	108.75
8	5.68	9.84	15.47	22.60	31.19	53.19	81.53	116.23
9	6.03	10.44	16.41	23.97	33.09	56.43	86.49	123.30
10	6.36	11.00	17.30	25.26	34.88	59.48	91.16	129.96
11	6.67	11.54	18.14	26.50	36.59	62.39	95.63	136.33
12	6.96	12.05	18.95	27.68	38.21	65.16	99.87	142.37
13	7.25	12.55	19.72	28.81	39.77	67.83	103.96	148.21
14	7.52	13.02	20.47	29.90	41.27	70.39	107.88	153.80
15	7.78	13.48	21.19	30.95	42.72	72.85	111.66	159.18
16	8.04	13.92	21.88	31.96	44.12	75.24	115.32	164.40
17	8.29	14.35	22.55	32.94	45.48	77.55	118.87	169.46
18	8.53	14.77	23.21	33.90	46.80	79.81	122.33	174.39
19	8.76	15.17	23.84	34.83	48.08	81.99	125.67	179.15
20	8.99	15.56	24.46	35.73	49.33	84.12	128.93	183.80
21	9.21	15.95	25.07	36.62	50.55	86.21	132.13	188.36
22	9.43	16.32	25.65	37.47	51.73	88.22	135.21	192.76
23	9.64	16.69	26.23	38.32	52.90	90.21	138.27	197.12
24	9.85	17.05	26.80	39.14	54.04	92.15	141.24	201.35
25	10.05	17.40	27.35	39.95	55.15	94.05	144.15	205.50
L	Correction Factors For Other Pipe Lengths							
40	1.23	1.22	1.20	1.19	1.16	1.14	1.13	1.11
50	1.14	1.13	1.12	1.11	1.10	1.09	1.08	1.07
60	1.07	1.06	1.06	1.05	1.05	1.04	1.04	1.03
70	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
80	0.95	0.95	0.95	0.96	0.96	0.96	0.97	0.97
90	0.90	0.91	0.91	0.92	0.92	0.93	0.94	0.94
100	0.86	0.87	0.88	0.89	0.89	0.90	0.91	0.92

Figure 3.1.4d Pipe flow chart for corrugated pipe drop inlet spillway
 (Source: NRCS Engineering Field Manual, Chapter 6)

PIPE FLOW CHART (Full Pipe flow assumed)

For R/C Drop Inlet, $K_e + K_b = 0.65$ with 70 feet of R/C conduit, $n = .013$. Note correction factors for other pipe lengths.

Dia. H	12"	15"	18"	21"	24"	30"	36"	42"
2	4.54	8.01	11.74	16.60	22.44	36.74	54.65	76.02
3	5.56	9.81	14.39	20.33	27.49	45.00	66.94	93.11
4	6.42	11.33	16.61	23.48	31.74	51.96	77.30	107.52
5	7.18	12.66	18.57	26.25	35.49	58.09	86.42	120.21
6	7.87	13.86	20.34	28.75	38.87	63.63	94.65	131.66
7	8.50	14.98	21.98	31.06	41.99	68.74	102.27	142.25
8	9.08	16.01	23.49	33.20	44.88	73.47	109.30	152.03
9	9.64	17.00	24.92	35.22	47.61	77.94	115.95	161.28
10	10.16	17.91	26.26	37.12	50.18	82.15	122.21	169.99
11	10.65	18.78	27.55	38.94	52.64	86.18	128.20	178.32
12	11.13	19.62	28.77	40.67	54.97	89.99	133.88	186.22
13	11.58	20.42	29.95	42.33	57.23	93.68	139.37	193.86
14	12.01	21.18	31.07	43.93	59.37	97.19	144.59	201.12
15	12.44	21.93	32.17	45.47	61.46	100.62	149.69	208.21
16	12.85	22.65	33.22	46.96	63.48	103.92	154.60	215.04
17	13.24	23.35	34.24	48.40	65.43	107.12	159.35	221.65
18	13.63	24.03	35.24	49.81	67.34	110.23	163.99	228.10
19	14.00	24.68	36.21	51.17	69.18	113.25	168.48	234.34
20	14.36	25.32	37.14	52.50	70.97	116.18	172.84	240.41
21	14.72	25.95	38.07	53.80	72.73	119.07	177.13	246.38
22	15.06	26.56	38.96	55.06	74.43	121.85	181.27	252.13
23	15.40	27.16	39.84	56.31	76.11	124.60	185.36	257.83
24	15.73	27.74	40.69	57.51	77.75	127.28	189.35	263.37
25	16.06	28.32	41.53	58.70	79.35	129.90	193.25	268.80
L	Correction Factors For Other Pipe Lengths							
40	1.15	1.13	1.11	1.09	1.08	1.06	1.06	1.05
50	1.09	1.08	1.07	1.06	1.05	1.04	1.04	1.03
60	1.04	1.04	1.04	1.03	1.03	1.02	1.02	1.02
70	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
80	0.96	0.96	0.97	0.97	0.98	0.98	0.98	0.99
90	0.93	0.94	0.94	0.95	0.95	0.96	0.97	0.97
100	0.90	0.91	0.92	0.93	0.93	0.95	0.95	0.96

Figure 3.1.4e Pipe flow chart for smooth pipe drop inlet spillway
(Source: NRCS, Engineering Field Manual, Chapter 6)

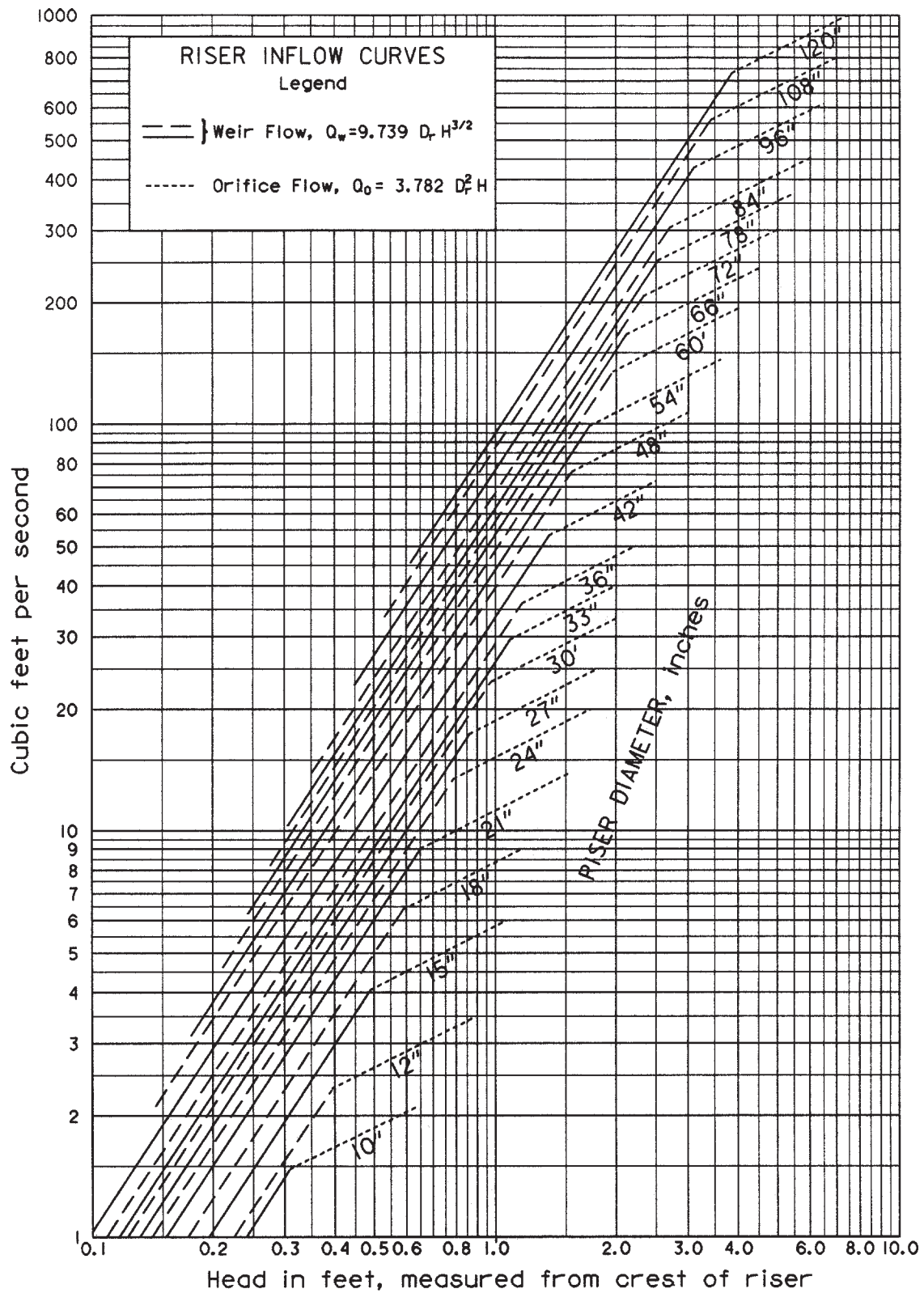


Figure 3.1.4f Riser inflow curves
 (Source: USDA-NRCS-MD)

CONCENTRIC TRASH RACK AND ANTI-VORTEX DESIGN TABLE

Riser Diameter, inches	Cylinder		Height, inches	Minimum Size Support Bar	Minimum Top	
	Diameter	Thickness, gage			Thickness	Stiffener
12	18	16	6	#6 Rebar or 1.5 x 1.5 x 3/16 angle	16 ga. (F&C)	-
15	21	16	7	" "	" "	-
18	27	16	8	" "	" "	-
21	30	16	11	" "	16 ga.(C), 14 ga. (F)	-
24	36	16	13	" "	" "	-
27	42	16	15	" "	" "	-
36	54	14	17	#8 Rebar	14 ga.(C), 12 ga. (F)	-
42	60	16	19	" "	" "	-
48	72	16	21	1.25" pipe or 1.25 x 1.25 x 0.25 angle	14 ga.(C), 10 ga. (F)	-
54	78	16	25	" "	" "	-
60	90	14	29	1.5" pipe or 1.5 x 1.5 x 0.25 angle	12 ga.(C), 8 ga. (F)	-
66	96	14	33	2" pipe or 2 x 2 x 3/16 angle	12 ga.(C), 8 ga. (F) w/stiffener	2 x 2 x 0.25 angle
72	102	14	36	" "	" "	2.5 x 2.5 x 0.25 angle
78	114	14	39	2.5" pipe or 2 x 2 x 0.25 angle	" "	" "
84	120	12	42	2.5" pipe or 2.5 x 2.5 x 0.25 angle	" "	2.5 x 2.5 x 5/16 angle
<p>Note 1: The criterion for sizing the cylinder is that the area between the inside of the cylinder and the outside of the riser is equal to or greater than the area inside the riser. Therefore, the above table is invalid for use with concrete pipe risers.</p> <p>Note 2: Corrugation for 12"-36" pipe measures 2 2/3" x 1/2"; for 42"-84" the corrugation measures 5" x 1" or 8" x 1".</p> <p>Note 3: C = corrugated; F = flat.</p>						

Figure 3.1.4g Trash rack and anti-vortex design table
(Source: USDA-NRCS-MD)

Emergency Spillway Widths (feet)		
cfs	Depth of Flow (feet)	
	1.0	1.5
15	10	
20	13	
25	17	
30	20	
35	24	9
40	27	10
45	30	11
50	33	12
60	40	15
70	47	17
80	54	19
90	60	22
100	67	24
125	84	30
150	100	36
175	117	42
200	134	48
250	167	60
300	200	72
The exit slopes for emergency spillways with flow depths of 1.0 and 1.5 feet must fall within the following ranges for this table to be used.		
Flow depth	Exit slope (%)	
	Minimum	Maximum
1.0	5	15
1.5	4	8

Figure 3.1.4h Emergency spillway design table
(Source: NRCS, Engineering Field Manual, Chapter 11)

Anti-Seep Collar Design

This procedure provides the anti-seep collar dimensions for only temporary sediment basins to increase the seepage length by 15% for various pipe slopes, embankment slopes and riser heights.

The first step in designing anti-seep collars is to determine the length of pipe within the saturated zone of the embankment. This can be done graphically or by the following equation, assuming that the upstream slope of the embankment intersects the invert of the pipe at its upstream end. (See Figure 3.4.1i below for embankment-invert intersection.)

$$L_s = Y(z + 4) \left[1 + \frac{S_p}{0.25 - S_p} \right]$$

Where: L_s = length of pipe in the saturated zone (ft.)

Y = distance in feet from upstream invert of pipe to highest normal water level expected to occur during the life of the structure, usually the top of the riser.

Z = slope of upstream embankment as a ratio of z ft. horizontal to one ft. vertical.

S_p = slope of pipe in feet per foot.

This procedure is based on the approximation of the phreatic line as shown in Figure 3.1.4i below:

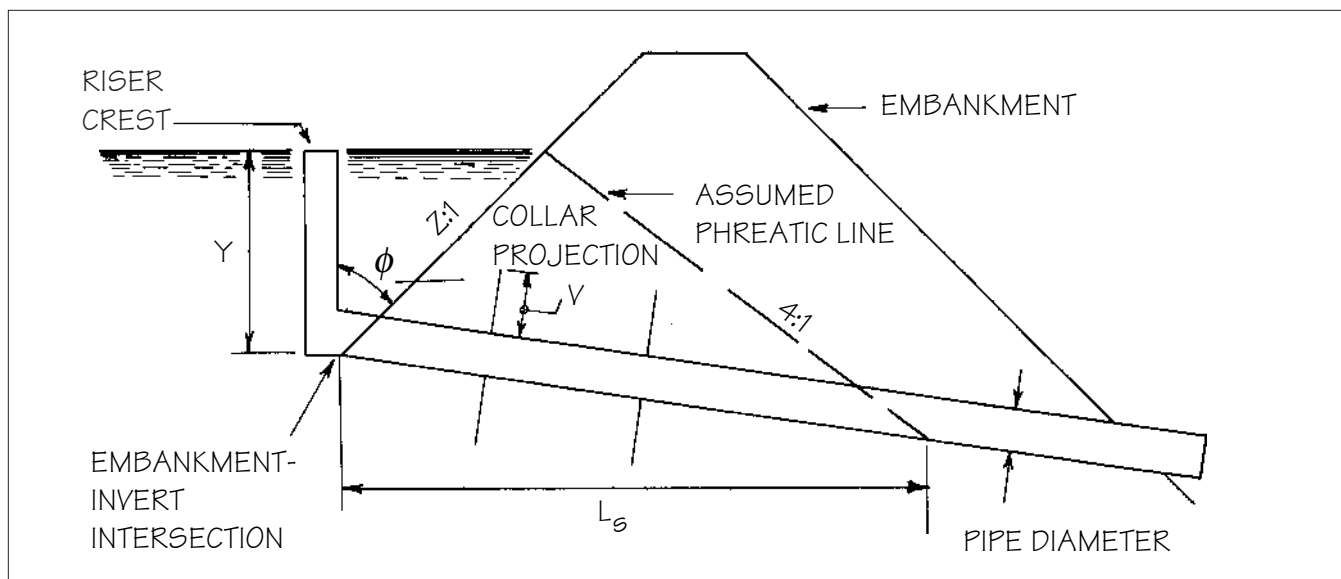


Figure 3.1.4i Terminology for anti-seep collar design

ANTI-SEEP COLLAR DESIGN

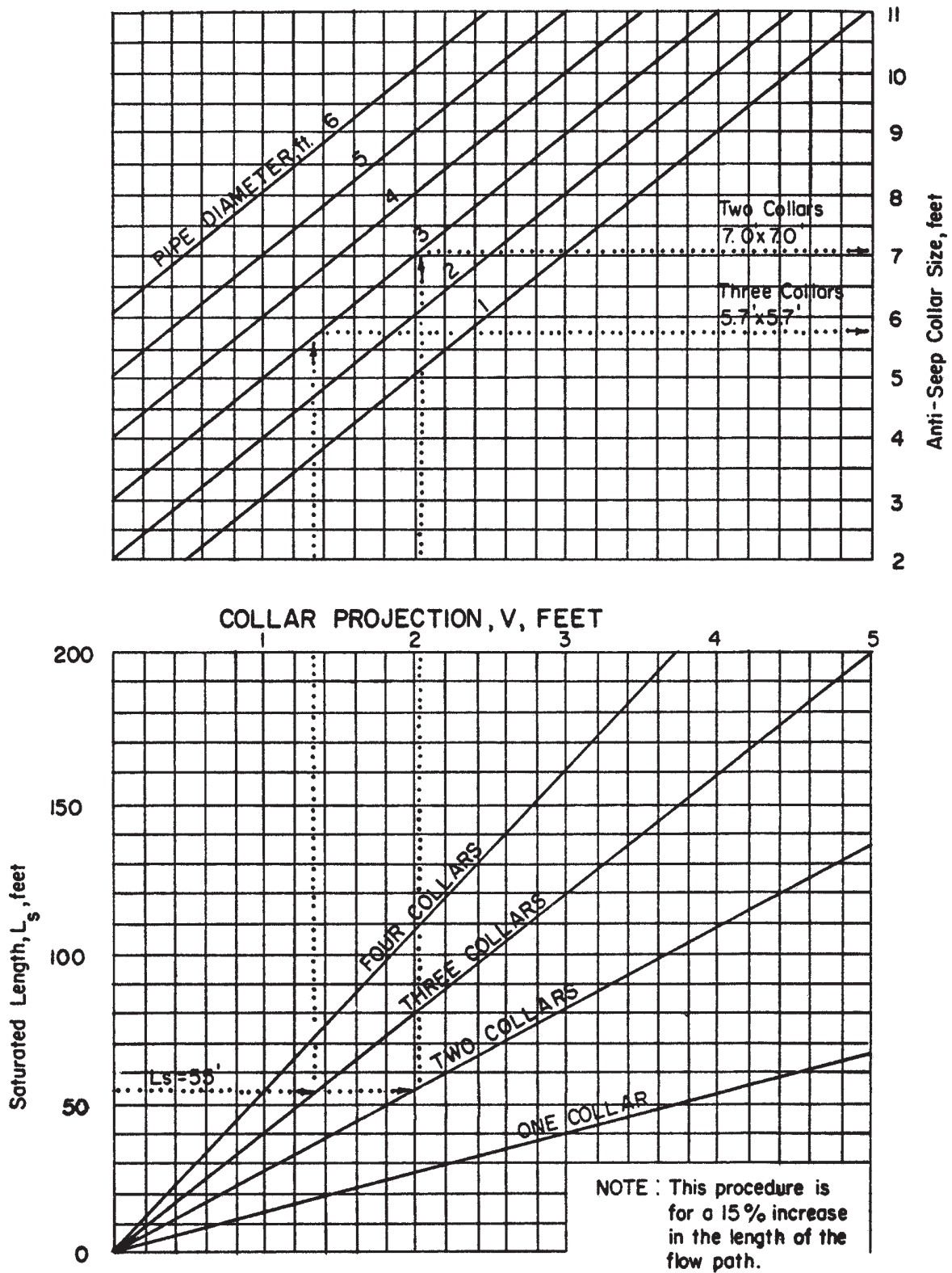
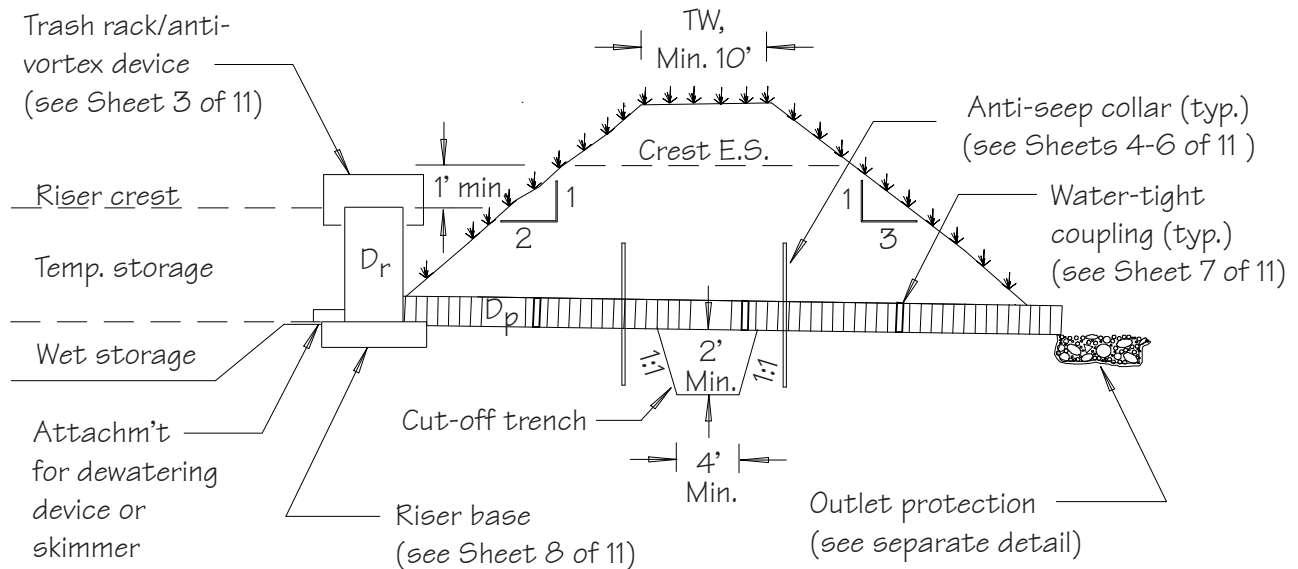


Figure 3.1.4j Anti-seep collar design graph
(Source: USDA-NRCS-MD)

Standard Detail & Specifications

Temporary Sediment Basin



Section thru Principal Spillway

DATA

Drainage area (D.A.)	Crest of riser (EI)	Crest of e.s. (EI)
Required storage (V_s)	Riser dia. (D_r)	E.S. depth (d)
Design dimensions ($L \times W \times D$)	Pipe material	E.S. width (b)
Clean-out elev. (EI)	Length of pipe (L)	Anti-seep collars (No.)
Embankment top width (TW)	Pipe dia. (D_p)	Collar dim. ($L \times W$)
Top of embankment (EI)	Pipe inverts (EI)	Collar spacing (Ft)
Angle of pipe at riser (Deg.)		

See Sheet 3 of 11 for req'd trash rack/anti-vortex device data

Source:

DE ESC Handbook

Symbol:

TSB

Detail No.

DE-ESC-3.1.4

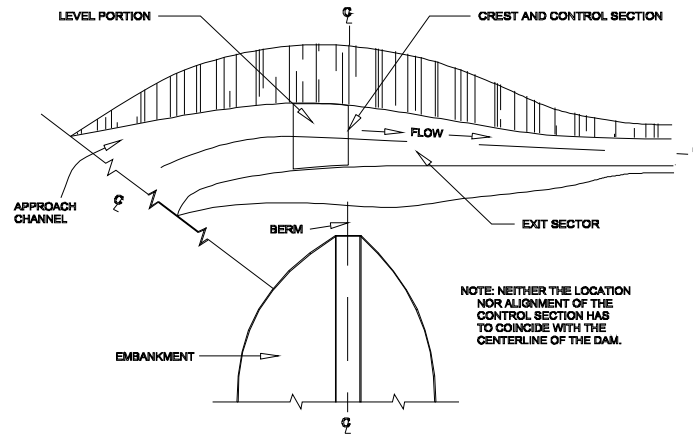
Sheet 1 of 11

Effective July 2023

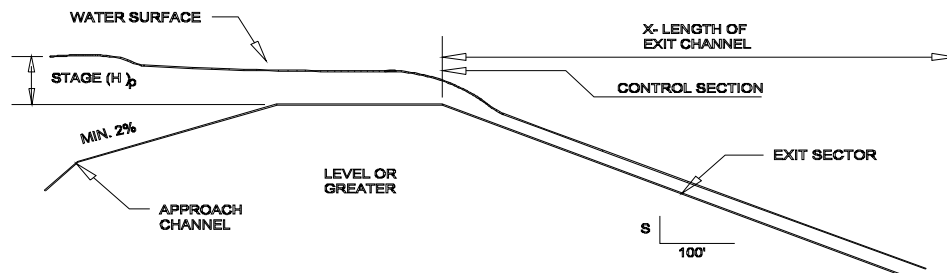
Standard Detail & Specifications

Temporary Sediment Basin

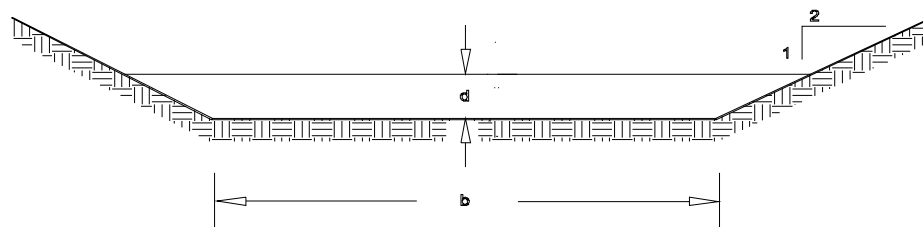
Emergency Spillway Details



Plan



Profile



Cross-section

Source:

Adapted from
USDA-NRCS

Symbol:

TSB

Detail No.

DE-ESC-3.1.4

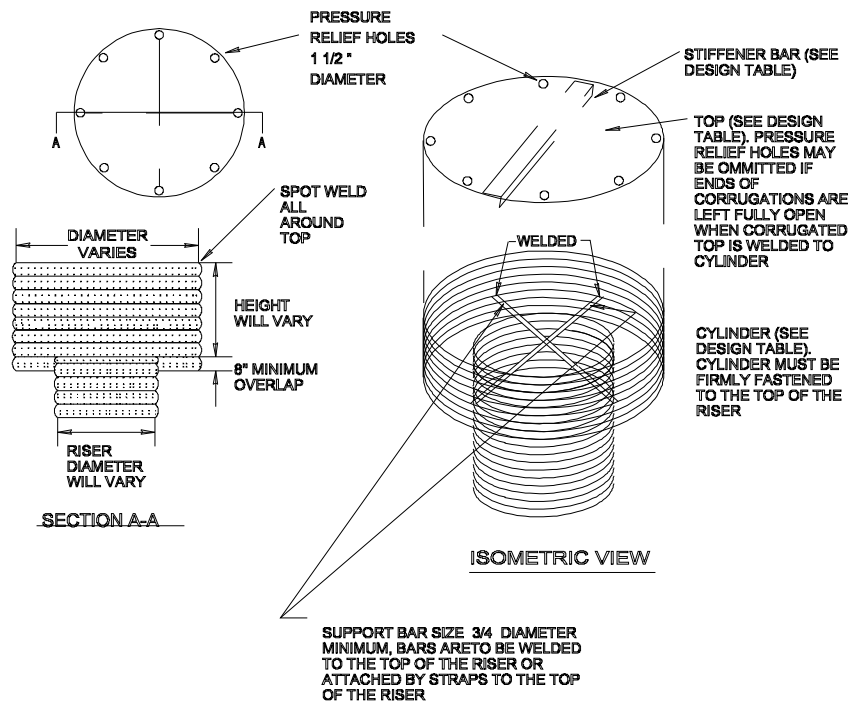
Sheet 2 of 11

Effective July 2023

Standard Detail & Specifications

Temporary Sediment Basin

Detail - Trash Rack and Anti-Vortex Device



Data

Top stiffener (if required) is ____ x ____ x ____ angle welded to top and oriented perpendicular to corrugations.

Top is ____ gage corrugated metal or 1/8" steel plate. Pressure relief holes may be omitted, if ends of corrugations are left fully open when corrugated top is welded to cylinder.

Cylinder is ____ gage corrugated metal pipe or fabricated from 1/8" steel plate.

Dia. = _____

H = _____

- Notes: 1. The cylinder must be firmly fastened to the top of the riser.
2. Support bars are welded to the top of the riser or attached by straps bolted to top of riser.

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:

TSB

Detail No.

DE-ESC-3.1.4

Sheet 3 of 11

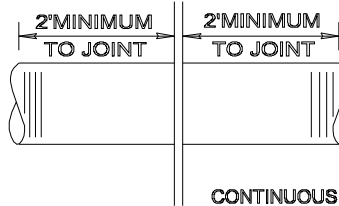
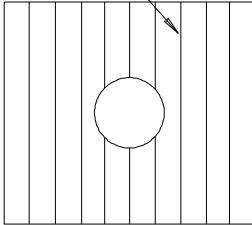
Effective July 2023

Standard Detail & Specifications

Temporary Sediment Basin

Detail - One-Piece Metal Anti-Seep Collar

INSTALL COLLAR WITH
CORRUGATIONS
VERTICAL

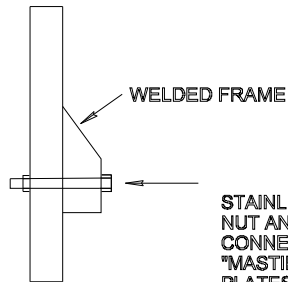


MINIMUM LAST
TWO
CORRUGATIONS
ON EACH END
MUST BE
ANNULAR OR
FLANGE

CONTINUOUS WELD THE FULL
CIRCUMFERENCE OF THE
COLLAR ON BOTH SIDES

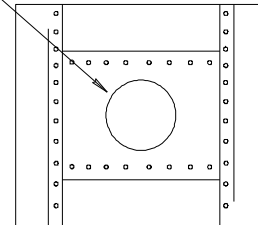
COLLAR WELDED IN PLACE ON BARREL SECTION

PLATES TO BE PRE-
CUT, CLAMPED
TOGETHER, PRE-
DRILLED AND
LABELLED TO
FACILITATE
WATERTIGHT FIELD
ASSEMBLY



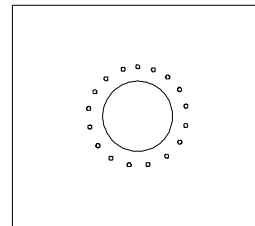
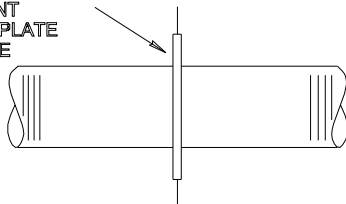
CONTINUOUS WELD THE FULL
CIRCUMFERENCE OF THE
COLLAR ON BOTH SIDES

STAINLESS STEEL
NUT AND BOLT
CONNECTION WITH
"MASTIK" BETWEEN
PLATES



ANTI-SEEP COLLAR DESIGN

USE "MASTIK" OR
EQUIVALENT
BETWEEN PLATE
AND FRAME



COLLAR FOR FLANGE JOINT PIPE

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:

TSB

Detail No.

DE-ESC-3.1.4

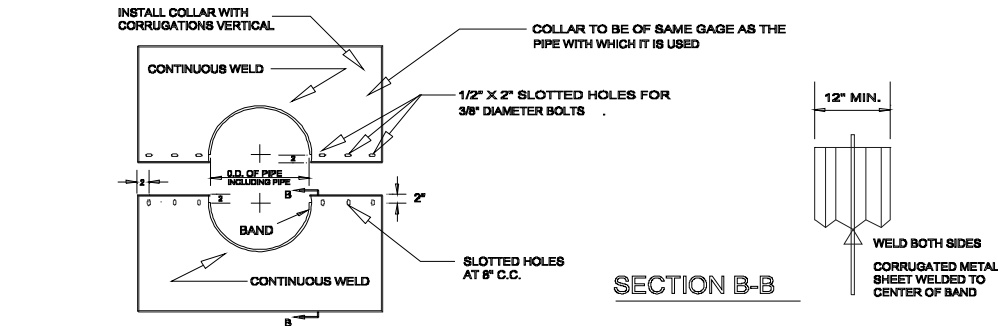
Sheet 4 of 11

Effective July 2023

Standard Detail & Specifications

Temporary Sediment Basin

Detail - Two-Piece Corrugated Metal Anti-Seep Collar

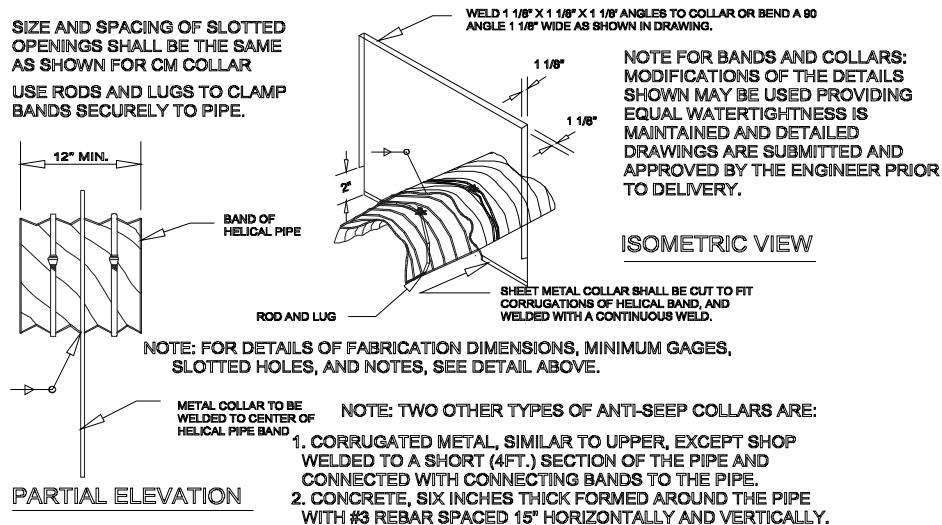


ELEVATION OF UNASSEMBLED COLLAR

NOTES FOR COLLARS:

1. ALL MATERIALS TO BE IN ACCORDANCE WITH CONSTRUCTION AND CONSTRUCTION MATERIAL SPECIFICATIONS.
2. WHEN SPECIFIED ON THE PLANS, COATING OF COLLARS SHALL BE IN ACCORDANCE WITH CONSTRUCTION AND CONSTRUCTION MATERIAL SPECIFICATIONS.
3. UNASSEMBLED COLLARS SHALL BE MARKED BY PAINTING OR TAGGING TO IDENTIFY MATCHING PAIRS.
4. THE LAP BETWEEN THE TWO HALF SECTIONS AND BETWEEN THE PIPE AND CONNECTING BAND SHALL BE CAULKED WITH ASPHALT MASTIC AT TIME OF INSTALLATION.
5. EACH COLLAR SHALL BE FURNISHED WITH TWO 1/2" DIAMETER RODS WITH STANDARD TANK LUGS FOR CONNECTING COLLARS TO PIPE.

Detail - Two-Piece Helical Pipe Anti-Seep Collar



PARTIAL ELEVATION

ISOMETRIC VIEW

Source:

Adapted from
VA ESC Handbook

Symbol:

TSB

Detail No.

DE-ESC-3.1.4

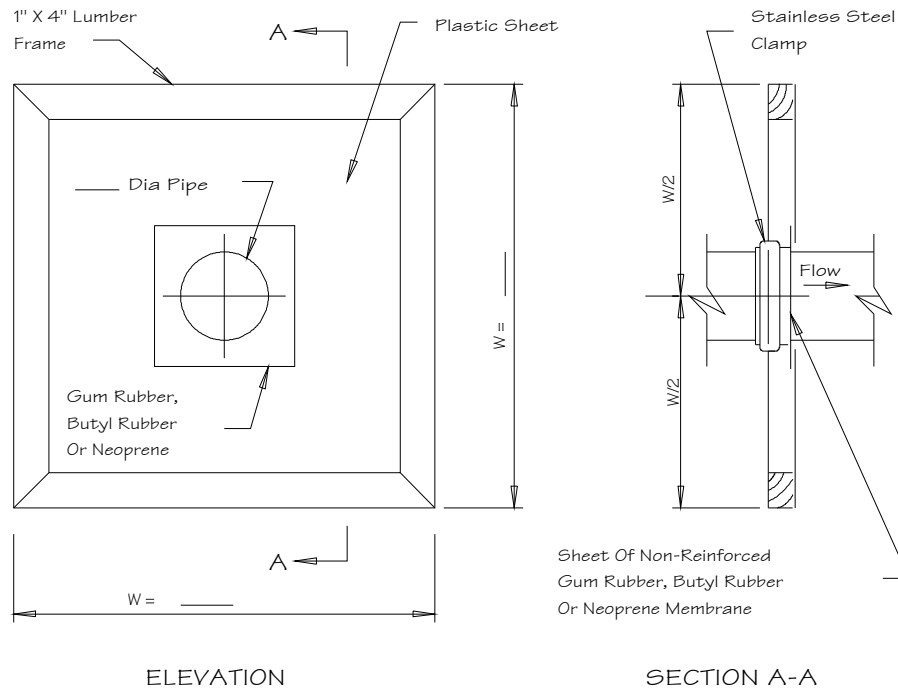
Sheet 5 of 11

Effective July 2023

Standard Detail & Specifications

Temporary Sediment Basin

Detail - Flexible Anti-Seep Collar



NOTES:

1. Helical pipe shall have a mastic sealer applied at the collar location. The sealer will not be required for PVC or annular pipe.
2. The center membrane section may be 1/16 inch gum rubber, butyl rubber or neoprene. The entire antiseep may be made of these materials.
3. The outer portion of the antiseep collar, away from the pipe, may be made of a minimum 20 mil plastic sheet.
4. Cut a hole, 3 inches smaller than the diameter of the pipe, centered on the material used at the pipe and force it over the end of the pipe.
5. The antiseep material shall be fastened to the pipe using a stainless steel clamp.
6. Completed installation must be watertight.
7. Care must be taken to back fill equally on both sides of the antiseep collar.

Source:

Adapted from
IL Urban Manual

Symbol:

TSB

Detail No.

DE-ESC-3.1.4

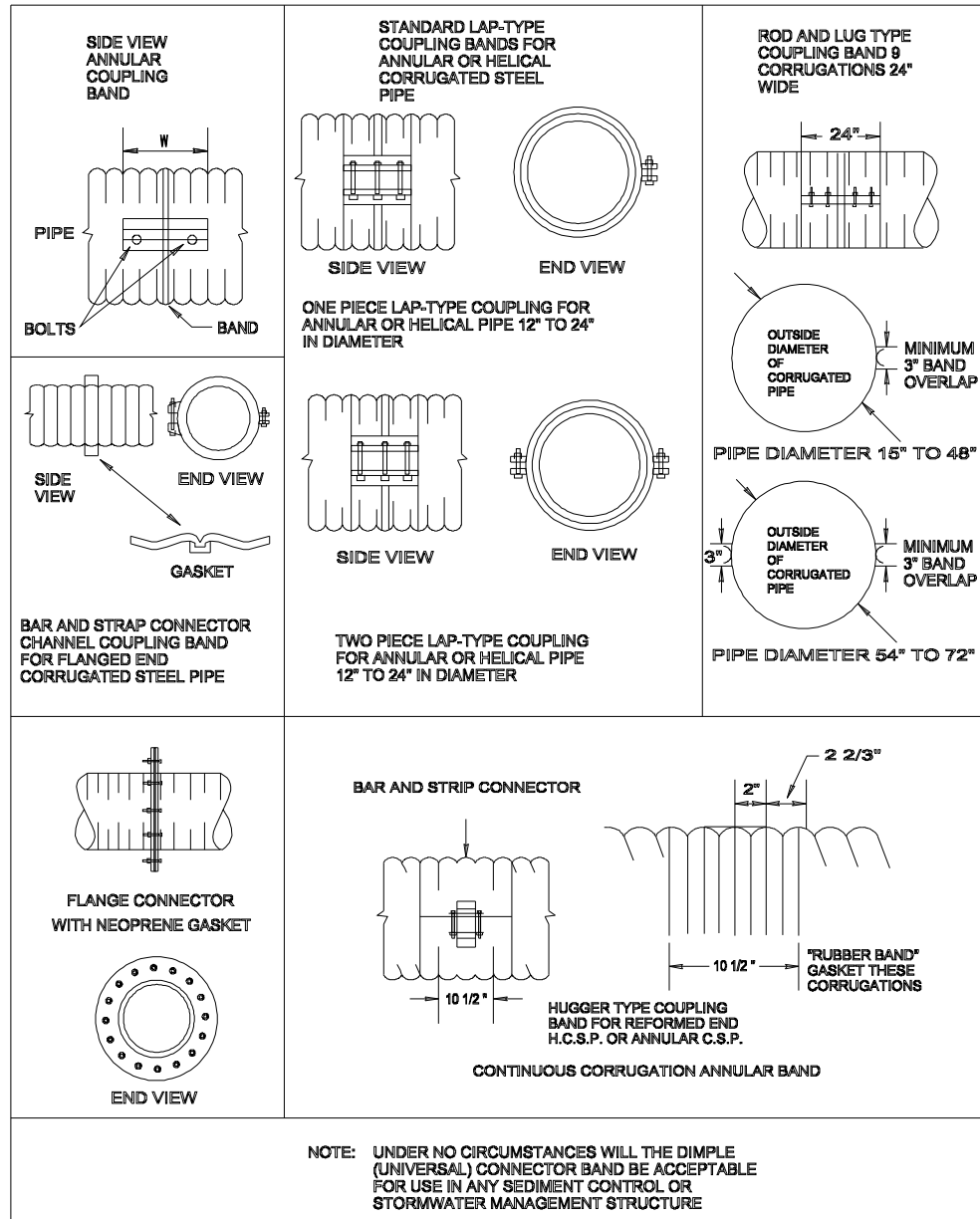
Sheet 6 of 11

Effective July 2023

Standard Detail & Specifications

Temporary Sediment Basin

Detail - Water-Tight Connectors



Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:



Detail No.

DE-ESC-3.1.4

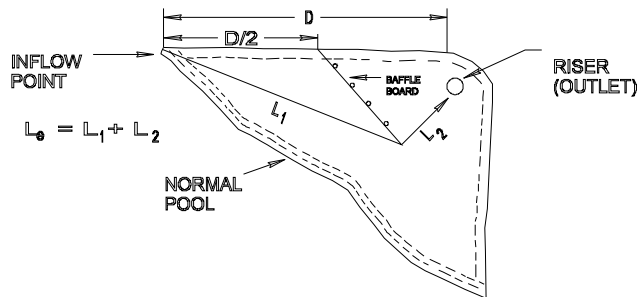
Sheet 7 of 11

Effective July 2023

Standard Detail & Specifications

Temporary Sediment Basin

Example Baffle Configurations



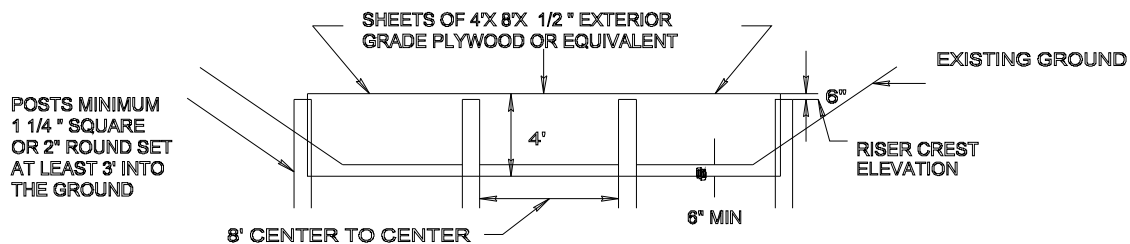
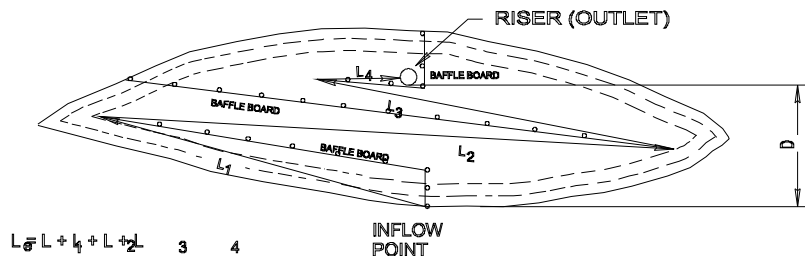
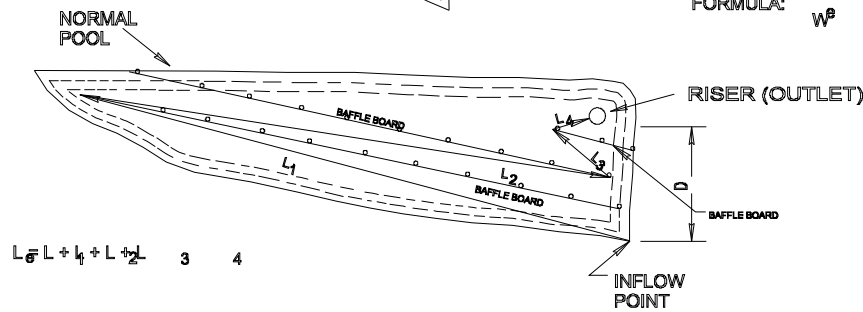
D = DISTANCE BETWEEN INFLOW AND OUTFLOW

A = AREA OF NORMAL POOL

W^p = EFFECTIVE WIDTH = A/D

L^p = TOTAL DISTANCE FROM THE INFLOW POINT AROUND THE BAFFLES TO THE RISER

FORMULA: $\frac{L^p}{W^p} \geq 2$



Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:

TSB

Detail No.

DE-ESC-3.1.4

Sheet 9 of 11

Effective July 2023

Standard Detail & Specifications

Temporary Sediment Basin

Construction Notes:

1. Site Preparation

Areas under the embankment shall be cleared, grubbed, and stripped of topsoil. In order to facilitate clean-out and restoration, the pool area (measured at the top of the pipe spillway) will be cleared of all brush, trees, and other objectionable materials.

2. Cut-off-trench

A cut-off trench shall be excavated along the centerline of earth fill embankments. The minimum depth shall be two feet. The cut-off trench shall extend up both abutments to the riser crest elevation. The minimum bottom width shall be four feet, but wide enough to permit operation of excavation and compaction equipment. The side slopes shall be no steeper than 1:1. Compaction requirements shall be the same as those for embankment. The trench shall be dewatered during the backfilling and compaction operations.

3. Embankment

The fill material shall be taken from approved areas shown on the plans. It shall be clean mineral soil free of roots, woody vegetation, oversized stones, rocks, or other objectionable material. Relatively pervious materials such as sand or gravel (Unified Soil Classes GW, GP, SW & SP) shall **not** be placed in the embankment. Areas on which fill is to be placed shall contain sufficient moisture so that it can be formed by hand into a ball without crumbling. If water can be squeezed out of the ball, it is too wet for proper compaction. Fill material shall be placed in six-inch to eight-inch thick continuous layers over the entire length of the fill. Compaction shall be obtained by routing and hauling the construction equipment over the fill so that the entire surface of each layer of the fill is traversed by at least one wheel or tread track of the equipment or by the use of a compactor. The embankment shall be constructed to an elevation 10 percent higher than the design height to allow for settlement.

4. Pipe Spillways

The riser shall be securely attached to the barrel or barrel stub by welding the full circumference making a watertight connection. The barrel stub must be attached to the riser at the same percent (angle) of grade as the outlet conduit. The connection between the riser and the riser base shall be water tight. All connections between barrel sections must be achieved by approved watertight band assemblies. The barrel and riser shall be placed on a firm, smooth foundation of impervious soil. Pervious materials such as sand, gravel, or crushed stone shall not be used as backfill around the pipe or anti-seep collars. The fill material around the pipe spillway shall be placed in four inch layers and compacted by means of a manually directed power tamper under and around the pipe to at least the same density as the adjacent embankment. A minimum depth of two feet of hand compacted backfill shall be placed over the pipe spillway before crossing it with construction equipment. Steel base plates on risers shall have at least 2-1/2 feet of compacted earth, placed over it to prevent flotation.

Source:

DE ESC Handbook

Symbol:

TSB

Detail No.

DE-ESC-3.1.4

Sheet 10 of 11

Effective July 2023

Standard Detail & Specifications

Temporary Sediment Basin

Construction Notes (cont.):

5. Emergency Spillway

The emergency spillway shall be installed in undisturbed ground. The achievement of planned elevations, grades, design width, entrance and exit channel slopes are critical to the successful operation of the emergency spillway and must be constructed within a tolerance of + 0.2 feet.

6. Vegetative Treatment

Stabilize the embankment and emergency spillway in accordance with the appropriate Vegetative Standard and Specifications immediately following construction. In no case shall the embankment remain unstabilized for more than seven (7) days.

7. Safety

State and local requirements shall be met concerning fencing and signs, warning the public of hazards of soft sediment and floodwater.

8. Maintenance

- a. Repair all damages caused by soil erosion and construction equipment at or before the end of each working day.
- b. **An approved dewatering device shall be considered an integral part of the basin. Dewatering operations shall be conducted in accordance with any and all regulatory requirements.**
- c. Sediment shall be removed from the basin when it reaches the specified distance below the top of the riser. This sediment shall be placed in such a manner that it will not erode from the site. The sediment shall not be deposited downstream from the embankment, or adjacent to a stream or floodplain.

9. Final Disposal

When temporary structures have served their intended purpose and the contributing drainage area has been properly stabilized, the embankment and resulting sediment deposits are to be leveled or otherwise disposed of in accordance with the approved sediment control plan. The proposed use of a sediment basin site will often dictate final disposition of the basin and any sediment contained therein. If the site is scheduled for future construction, then the basin material and trapped sediments must be removed, safely disposed of, and backfilled with a structural fill. When the basin area is to remain open space the pond may be pumped dry, graded and backfilled.

Source:

DE ESC Handbook

Symbol:

TSB

Detail No.

DE-ESC-3.1.4

Sheet 11 of 11

Effective July 2023

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STANDARD AND SPECIFICATIONS FOR STORM DRAIN INLET PROTECTION

Definition: A barrier installed around inlets or across an opening to temporarily pond sediment-laden water, thereby reducing the sediment content.



Purpose: To prevent sediment-laden water from entering a storm drain system through inlets.

Conditions Where Practice Applies

This practice shall be used where the drainage area to an inlet is disturbed, it is not possible to temporarily divert the storm drain outfall into a sediment trapping device and watertight blocking of inlets is not advisable. It is not to be used in place of sediment trapping devices. There are two (2) general types of inlet protection:

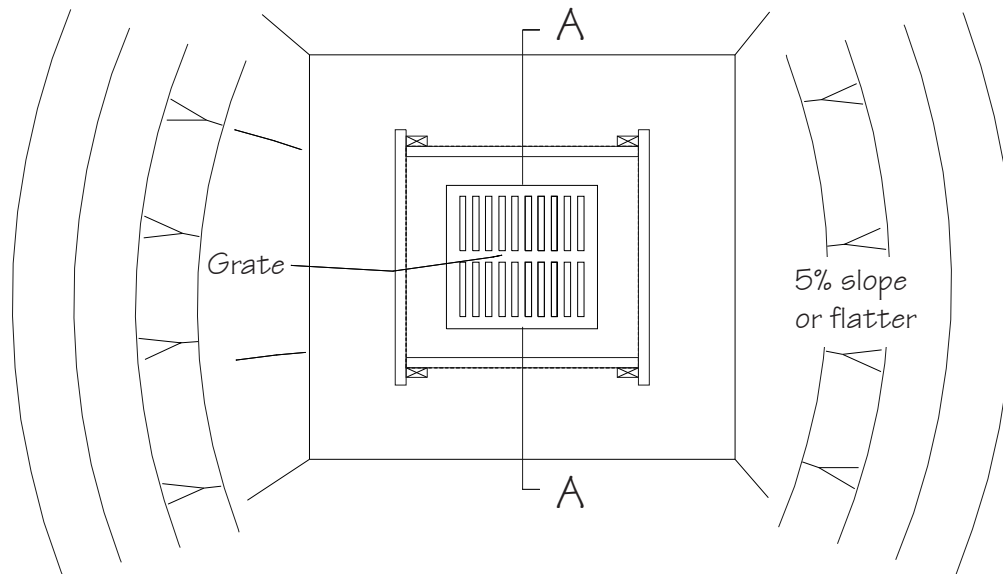
1. **Type 1** - This type of inlet protection is typically used in open space areas and is the preferred type when site conditions allow. Optimal performance requires some temporary ponding of water to allow sedimentation to occur.
2. **Type 2** - This type of inlet protection shall only be used in situations in which the Type 1 inlet protection can not be installed, such as impervious surfaces, partially completed roads, etc. Since there is no temporary ponding of sediment-laden runoff, this type of inlet protection is inherently less effective than the Type 1 inlet protection.
3. **Type 3** - This type of inlet protection should be used for roadway inlets that have a throat or curb opening, where standard Type 2 protection would allow untreated runoff to bypass through the throat or cannot be used if a grate is not present. The application should only be used for the curb opening; i.e., if both a curb opening and a grate exist on the same structure, then both Type 2 and Type 3 inlet protection shall be utilized.

It may be necessary to change from one type of inlet protection to the other during the normal course of construction. The designer should be aware of this and allow the necessary flexibility in the sequence of construction.

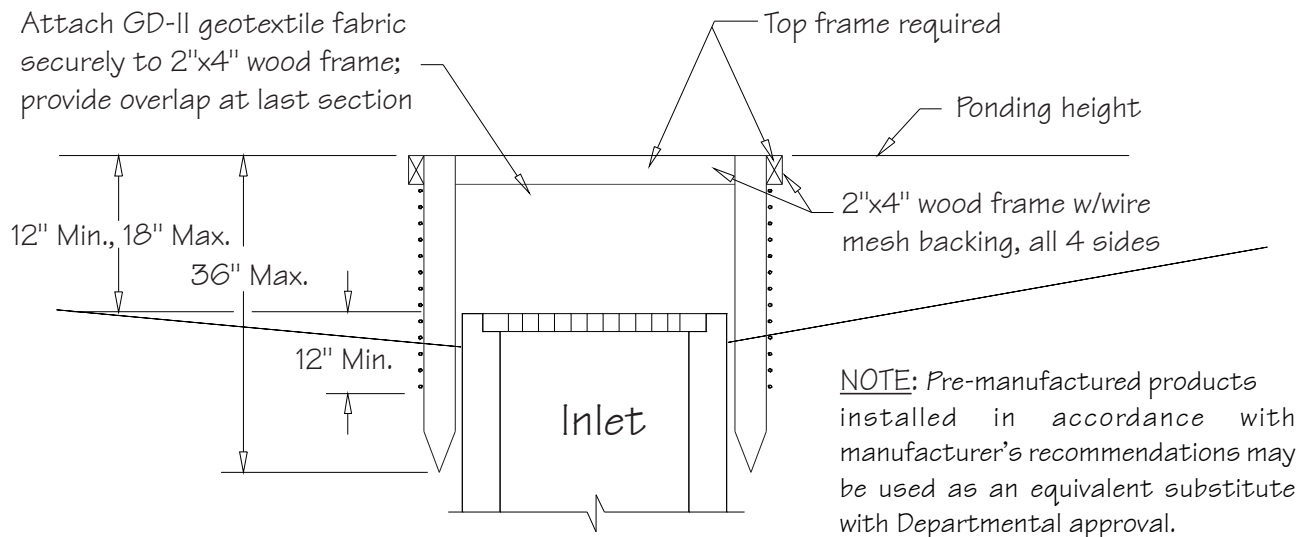
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Standard Detail & Specifications

Inlet Protection - Type 1



Attach GD-II geotextile fabric securely to 2"x4" wood frame; provide overlap at last section



Section A-A

Source:

Adapted from
Erosion Draw Manual
J. McCullah & Assoc.

Symbol:



Detail No.

DE-ESC-3.1.5.1

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Inlet Protection - Type 1

Construction Notes:

1. Excavate completely around inlet to a depth of 18" below grate elevation.
2. Drive 2" x 4" post 1' into ground at four corners of inlet. Place nail strips between posts on ends of inlet. Assemble top portion of 2" x 4" frame using overlap joint shown. Top of frame (weir) must be 6" below edge of roadway adjacent to inlet.
3. Stretch wire mesh tightly around frame and fasten securely. Ends must meet at post.
4. Stretch geotextile fabric tightly over wire mesh, the cloth must extend from top of frame to 18" below inlet grate elevation. Fasten securely to frame. Ends must meet at post, be overlapped and folded, then fastened down.
5. Backfill around inlet in compacted 6" layers until at least 12" of geotextile fabric is buried.
6. If the inlet is not in a low point, construct a compacted earth dike in the ditchline below it. The top of this dike is to be at least 6" higher than the top of frame (weir).
7. This structure must be inspected frequently and the filter fabric replaced when clogged.

Materials:

1. Wooden frame is to be constructed of 2" x 4" construction grade lumber.
2. Wire mesh must be of sufficient strength to support filter fabric with water fully impounded against it.
3. Geotextile fabric: Type GD-II

Source:

Adapted. from
Erosion Draw Manual
J. McCullah & Assoc.

Symbol:



Detail No.

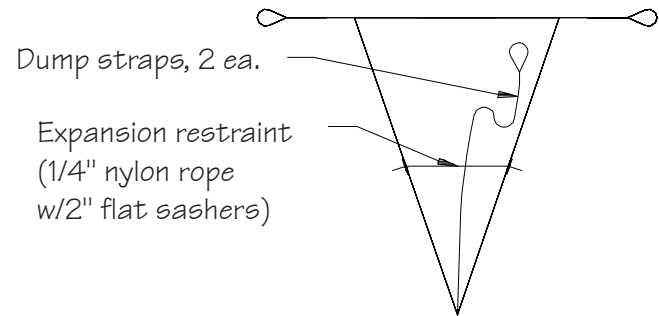
DE-ESC-3.1.5.1

Sheet 2 of 2

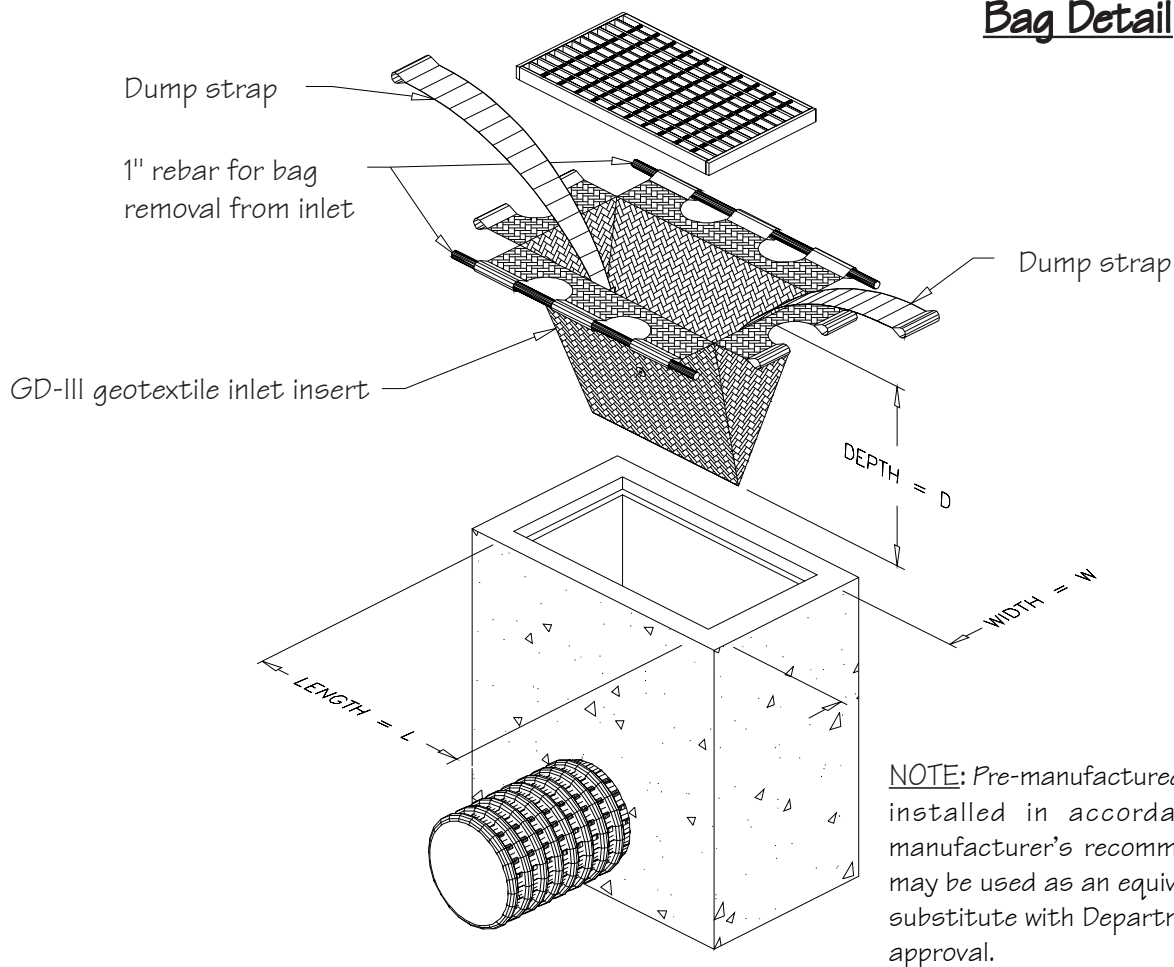
Effective July 2023

Standard Detail & Specifications

Inlet Protection - Type 2



Bag Detail



Perspective

Source:

Adapted from
ACF Products, Inc.

Symbol:



Detail No.

DE-ESC-3.1.5.2

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Inlet Protection - Type 2

Notes:

1. This practice shall only be used in situations in which Inlet Protection - Type 1 cannot be used due to site constraints. These include, but are not limited to partially completed parking areas, streets, roads, etc.
2. It may be necessary to transition from Type 1 to Type 2 Inlet Protection as construction proceeds.
3. For areas where there is a concern for oil run-off or spills, insert shall meet one of the above specifications with an oil-absorbant pillow or shall be made completely from an oil-absorbant material with a woven pillow.

Materials:

The geotextile inlet insert shall meet or exceed the specifications of Type GD-III geotextile in accordance with Appendix A-3 of the Delaware Erosion & Sediment Control Handbook.

Source:

Adapted from
ACF Products, Inc.

Symbol:



Detail No.

DE-ESC-3.1.5.2

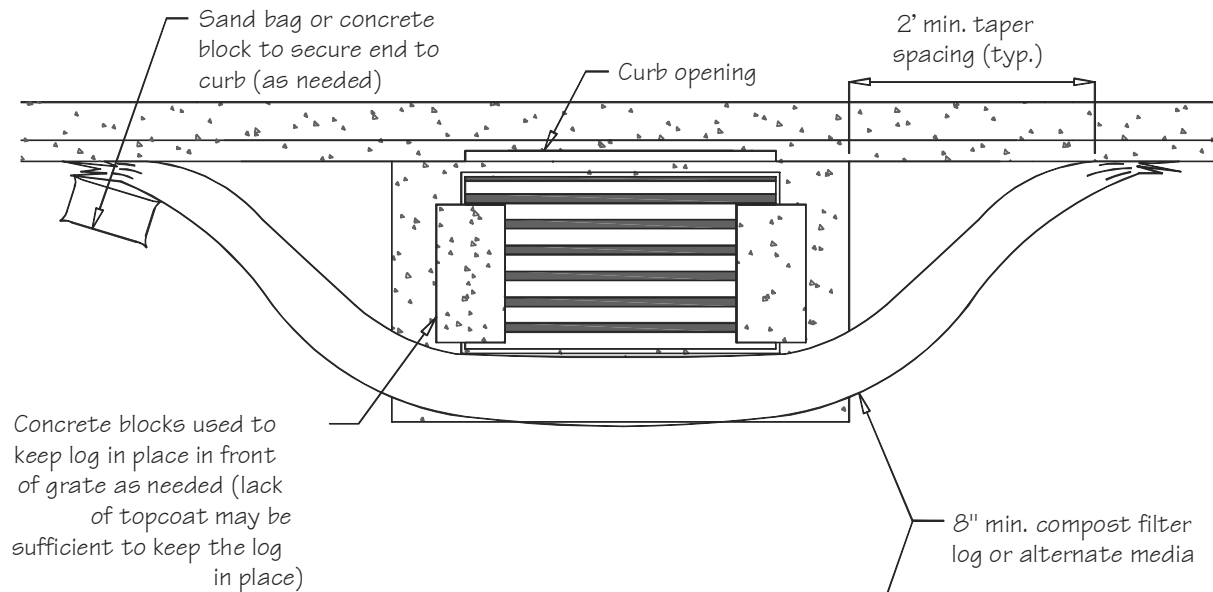
Sheet 2 of 2

Effective July 2023

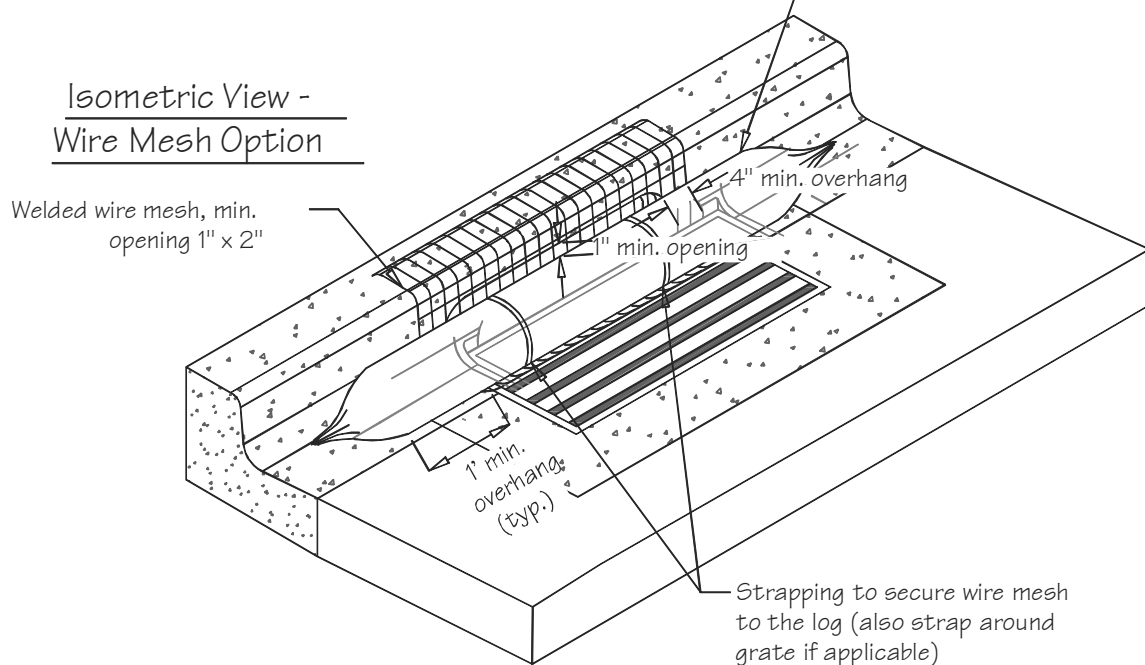
Standard Detail & Specifications

Inlet Protection - Type 3

Plan View - Concrete Block Option



Isometric View - Wire Mesh Option



Source:

Adapted from
Filtrexx™ International

Symbol:



Detail No.

DE-ESC-3.1.5.3

Sheet 1 of 3

Effective July 2023

Standard Detail & Specifications

Inlet Protection - Type 3

Notes:

1. This practice shall only be used in situations in which Inlet Protection – Type 1 cannot be used due to site constraints. These include, but are not limited to partially complete parking areas, streets, roads, etc., having a throat or curb opening. It should be used in conjunction with Type 2 Inlet Protection when a grate is also present.
2. The filter log sock fabric shall be high durability netting material to resist puncture and wear in the traffic areas. If compost media is used to fill the sock it must meet the Standards and Specifications for Compost Material in the Appendix, except that the maximum pass through for a 3/8" screen shall be 20% to allow for higher flow through. Additives, such as soluble phosphorus and petroleum hydrocarbons, can be mixed with the compost media to aid in pollutant removal, if desired. Reference the Compost Filter Log design guidelines for additional requirements on the high durability netting material, compost media, and sock filling and installation procedures. Reference the design alternatives below for additional log media options.
3. The maximum contributing drainage area shall be 3 acres, or as recommended by the manufacturer. 8" diameter socks shall be used for standard roadway applications. If in a highly disturbed area, the Engineer or Site Reviewer may opt for larger socks, either 12" or 18" depending on the need. (If used as a replacement for Type 1 Inlet Protection with special approval, minimum 12" diameter socks shall be used.) The top of the log may need to be flattened so that it is always below the top of curb elevation with a minimum 1" opening in order to prevent localized flooding.
4. Concrete blocks shall be used to aid in the log shape and prevent it from entering into the throat. They should be placed between the log and the throat opening, and used to secure the ends of the log against the curb if needed. The end of the log shall extend a minimum of 2 feet past the end of the throat opening. If a grate is also present in addition to the throat opening, the concrete blocks can either be laid perpendicular to the curb (recommended) so that the log lies on the outside of the grate, or parallel to the curb so that the log lies on top of the grate (note, Type 2 Inlet Protection is also used in conjunction with Type 3 if a grate is present). Sand bags can be used as an alternate to the concrete blocks at the end of the log to secure the log against the curb.

Source:

Adapted from
FiltrexTM International

Symbol:



Detail No.

DE-ESC-3.1.5.3

Sheet 2 of 3

Effective July 2023

Standard Detail & Specifications

Inlet Protection - Type 3

5. If concrete blocks are not desired due to high traffic volumes, a welded wire screen in an "S" shape can be fitted over the length of the opening and secured to the log with straps, such as zip-ties. This will prevent the sock from falling into the opening. In this case, the log only needs to extend past the curb opening a minimum of 1 foot.
6. In all cases, the log shall provide a physical barrier to the catchbasin to allow for ponding and sedimentation along the upstream side of the log. The logs shall be placed on flat surfaces and maintain constant contact with the paved surface. Any daylight will allow for untreated discharge and is not permitted.
7. All structures must be inspected frequently (24 hours after a storm event and weekly) for proper function. Accumulated sediment shall be removed to avoid future failure, and must not exceed half of the effective height of the log. Reference manufacturer's recommendations for additional maintenance.

Alternatives:

1. In lieu of the compost filter log, crushed DE #3 stone with a fractured face on all sides that is double wrapped in 1" chicken wire made from 10 gauge wire may be used. The wire should be secured using hog rings or wire ties on 6" centers along the length of the joint, and on 1" center on the ends of the rock sock. All installation and maintenance criteria are the same as the compost log above.
2. In lieu of the compost filter media, 100% shredded rubber (typically from tires) can be used.
3. For applications that have a grate and a throat inlet, some Type 2 Inlet Protection manufacturers have developed a catchbasin sack insert that also have a tubular attachment which rests above the grate and against the throat. As long as the sack meets the requirements of Type 2 Inlet Protection, and the provided throat protection extends a minimum of 1' past the limits of the curb opening, without any daylight along the edges, these combination Type 2 and Type 3 devices may be used upon approval of the Department or Delegated Agency.

Source:

Adapted from
Filtrexx™ International

Symbol:



Detail No.

DE-ESC-3.1.5.3

Sheet 3 of 3

Effective July 2023

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STANDARD AND SPECIFICATIONS FOR CULVERT INLET PROTECTION

Definition: A barrier installed across a culvert entrance to temporarily pond sediment-laden water, thereby reducing the sediment content.



Purpose: To prevent sediment-laden water from entering a culvert and being conveyed downstream.

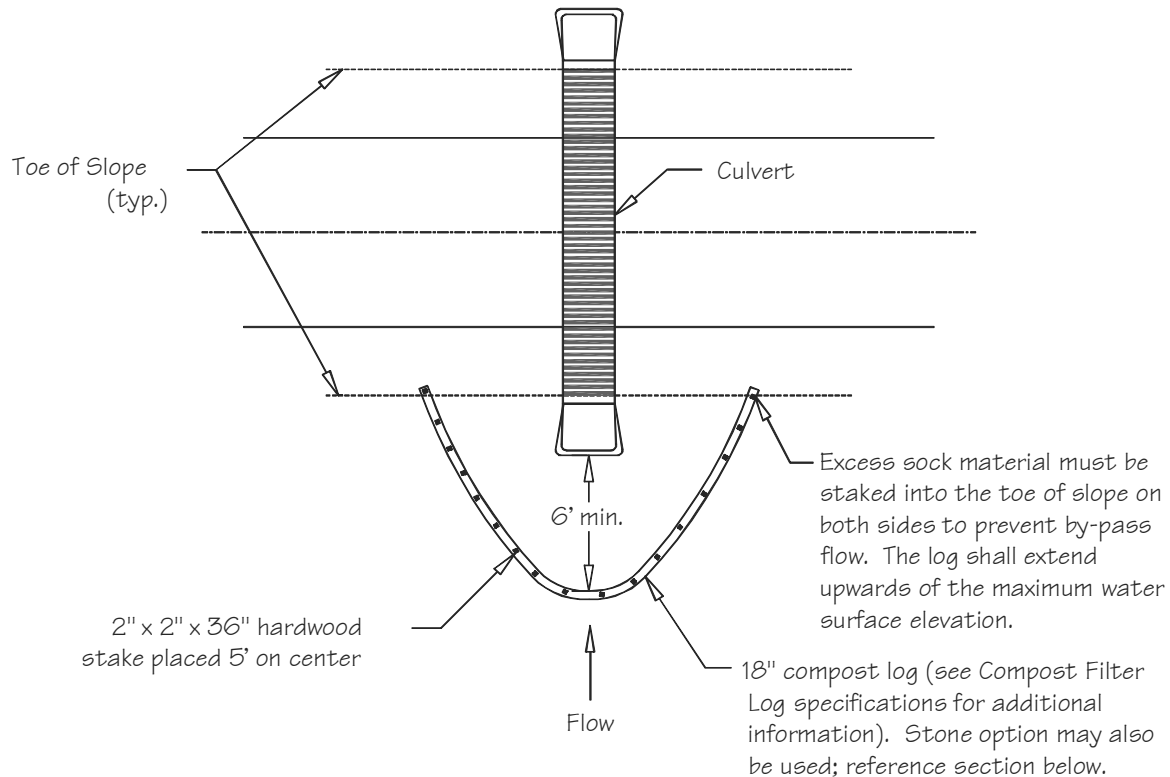
Conditions Where Practice Applies

This practice shall be used where the drainage area to a culvert is disturbed, it is not possible to temporarily divert the runoff into a sediment trapping device and watertight blocking of the culvert is not advisable. It is not to be used in place of sediment trapping devices.

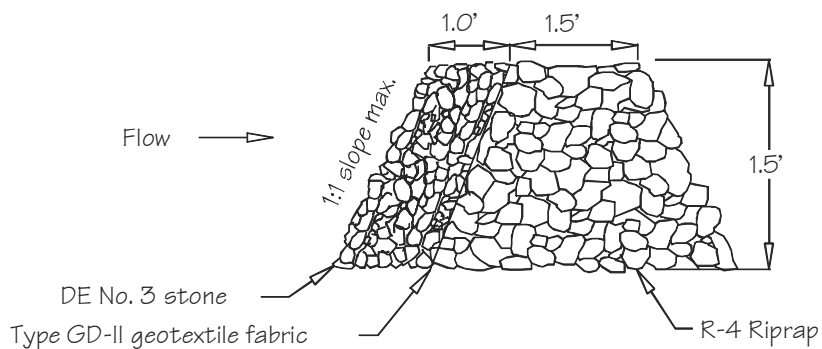
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Standard Detail & Specifications

Culvert Inlet Protection



Plan View - Compost Log Option



Section View - Stone Option

Source:

Adapted from
VA ESC Handbook
& Filtrexx™ International

Symbol:



Detail No.

DE-ESC-3.1.6

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Culvert Inlet Protection

Construction Notes

1. Compost logs shall be designed and installed in accordance with the Standard Detail and Specifications for Compost Logs (DE-ES-3.1.7).
2. If compost logs can not be installed properly or flow conditions exceed the design capabilities of the compost logs, the stone option shall be employed. Additional filtration may be provided by using a Type GD-II geotextile incorporated into the design as an option.
3. Placement of the compost log or stone barrier should be in a "horseshoe" shape and provide a minimum of 6 feet of clearance from the culvert inlet.

Materials

1. Stakes: 2" x 2" x 36" hardwood.
2. Compost media : See requirements in Standard Detail and Specifications for Compost Logs (DE-ES-3.1.7).
3. Filter sock: See requirements in Standard Detail and Specifications for Compost Logs (DE-ES-3.1.7).
4. Geotextile: Type GD-II for stone/riprap option.
5. Stone: DE No. 3 for stone/riprap option.
6. Riprap: R-6 for stone/riprap option.

Source:

Adapted from
VA ESC Handbook
& Filtrexx™ International

Symbol:



Detail No.

DE-ESC-3.1.6

Sheet 2 of 2

Effective July 2023

STANDARD AND SPECIFICATIONS FOR COMPOST FILTER LOG

Definition: A three-dimensional tubular sediment control device comprised of a filter sock that is filled with compost media to intercept sediment laden runoff from small drainage areas of disturbed soils.

The media may include additives that can trap pollutants, such as soluble phosphorus or petroleum hydrocarbons, as the runoff is filtered through the compost filter sock.



Purpose: To temporarily pond sediment laden runoff, allowing deposition to occur, and the filtering of runoff through the compost media eliminating additional pollutants. Required longevity, loading and application determine the specifications for the two compost filter log components: the compost media and the filter sock material. The compost logs may be used for many applications including, but not limited to, perimeter control, stockpile control, inlet protection, and slope and channel interruption. The below Standard and Specifications are in general for use as a perimeter control, but variations for alternate applications are noted. If a specific detail exists for the alternate applications, that Standard and Specifications should also be referenced.

Conditions Where Practice Applies: Compost logs for sediment control may be installed downslope from any disturbed area requiring erosion and sediment control and filtration of soluble pollutants. Compost logs are effective when installed perpendicular to sheet or low concentrated flow, and in areas that silt fence is normally considered appropriate. Although compost logs can withstand occasional crossing with construction equipment, it is not recommended and any such areas must be inspected immediately and repaired if necessary.

Design Criteria:

Location

Place the compost filter log on undisturbed soil to reduce the potential for undermining, and locate downstream of future disturbed areas. Runoff flow shall be perpendicular to the filter sock and relatively unconcentrated. The log should not be placed on any large protrusions or gullies in the ground in order to keep constant contact with the surface; gaps underneath or around the compost filter log will allow runoff to flow through untreated and are not allowed.

At the base of a slope, place the filter log a minimum of 5' away from the toe of the slope to allow for ponding without overtopping of the sock. If 5' separation is not possible, then a larger sock diameter shall be considered to allow for additional ponding at the base of the slope. For steep slopes with a contributing area at the top of the slope, an additional compost filter sock can be located at the top of the slope to slow down the runoff and to act as a level spreader.

Securing

The ends of the compost filter log should be angled upslope to prevent runoff from washing around the ends; minimum 1' elevation difference. Stakes shall be installed through the middle of the compost log, maximum 8' on center. The stakes shall be minimum 2" by 2" by 36" hardwood stakes, and set a minimum 12" below grade (depth can be reduced to 8" for dense clay areas). For areas where stakes are not feasible, such as on impervious surfaces, concrete blocks shall be placed behind the log every 8' on center, and limited to applications of 4% slope or less.

Sizing and Characteristics

The below sizing guides shall be used to determine the diameter of the filter sock. The engineer shall specify the size of the filter sock on the plans.

Design Diameter	8"	12"	18"	24"	32"
Effective Height	6.5"	9.5"	14.5"	19"	26"
Effective Circumference	25"	38"	57"	75"	100"
Density (lbs/ft)	13	32	67	133	200
Max. Slope Length for <2% Slope	600'	750'	1,000'	1,300'	1,650'
Max. Slope Length for 2 -5% Slope	400'	500'	550'	650'	750'
Max. Slope Length for 5 -10% Slope	200'	250'	300'	400'	500'
Max. Slope Length for 10 -20% Slope	100'	125'	140'	260'	400'
Max. Slope Length for 20 -30% Slope	60'	75'	90'	130'	200'
Max. Slope Length for >30% Slope	40'	50'	55'	65'	75'
Max. Length	N/A	N/A	N/A	N/A	N/A
Hydraulic Flow Through Rate (gpm/ft)	7.5	11.3	15	22.5	30

Note: Specifications are adapted from the Filtrexx Low Impact Design Manual.

Materials

The material of the filter sock shall be determined based on the location of the sock and the longevity required. The engineer shall specify the type of filter sock by thickness and degradation type on the plans and specifications.

Material Type	3 mil HDPE	5 mil HDPE	5 mil HDPE	Multi-Filament Polypropylene	Multi-Filament Polypropylene – High Durability
Degradation	Photodegradable	Photodegradable	Biodegradable	Photodegradable	Photodegradable
Longevity	6 mo to 2 yrs	9 mo to 3 yrs	6 to 12 mo	1 to 4 yrs	2 to 5 yrs
Application	8" to 18" socks	8" to 32" socks	8" to 32" socks	8" to 32" socks	8" to 32" socks
Min. Tensile Strength (psi)	N/A	26	26	44	202
% Original Strength after 1000 Hours of UV Exposure	23%	23%	N/A	100%	100%
Mesh Opening	3/8"	3/8"	3/8"	3/8"	1/8"
Special Considerations				Used for long duration, non-vegetated applications	Used in all traffic applications (i.e., Type 3 Inlet Protection)

Note: Specifications are adapted from the Filtrex Low Impact Design Manual.

The compost media used within the logs shall be a plant derived compost that complies with the Compost Material Standards and Specifications detailed in the Appendix, including being produced from a Certified facility through the U.S. Composting Seal of Testing Assurance (STA) program . As stated in the Standard and Specification, a maximum of 40% of the particles shall pass through a 3/8" screen for standard compost log applications. In high flow through situations, such as using the compost logs as inlet protection within the roadway, the percent passing through the 3/8" screen can be reduced to 20%. In low flow situations, such as using the compost logs to create a sediment trap, the percent passing through the 3/8" screen can be increased to 60%.

Installation

The compost filter logs are assembled by tying a knot in one end of the filter sock, filling the sock with the composted material (usually using a pneumatic blower), then knotting the other end once the desired length

is reached. The compost must be uniform throughout the sock and not have any gaps or the presence of large materials that would impede flow and/or create gaps. A filter sock the length of the slope shall be used when possible. In cases when multiple socks are needed, the socks shall be interlocked by overlapping the socks a minimum of 12" prior to filling; placing filled logs end-to-end is not allowed. For shorter applications, the socks may be supplied pre-filled and simply rolled out in place.

Maintenance:

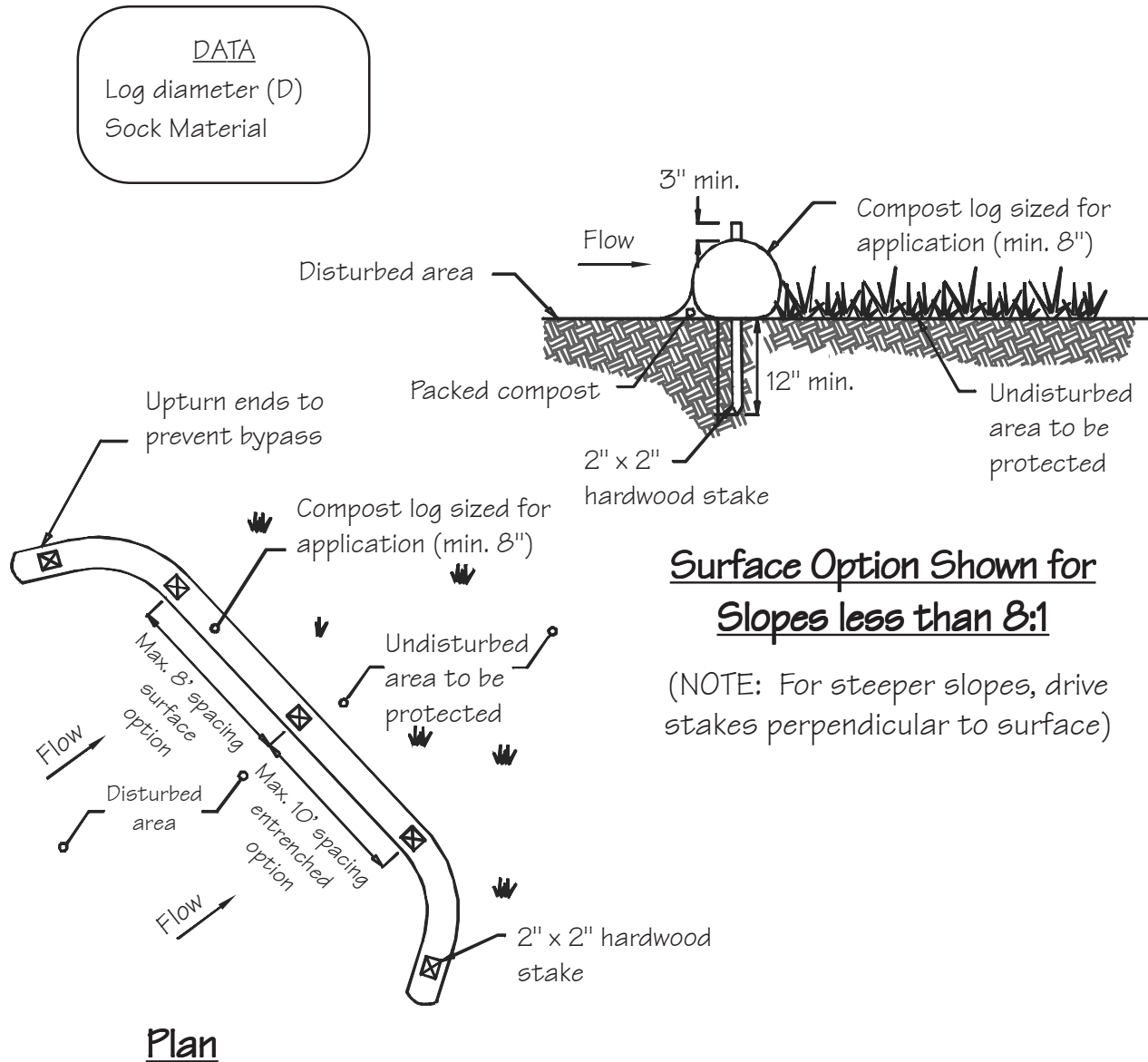
The compost filter logs shall be inspected after storm events and on a weekly basis. Accumulated sediment shall be removed when it reaches half of the effective height of the sock, and disposed of in an appropriate manner. If the sock fabric is degrading prior to completion of the project, it shall be vegetated to help secure the compost in place, and/or an additional compost filter sock added. If the sock has been flattened due to equipment or vehicular traffic, it shall be "fluffed" back to proper dimensions. If the effective height cannot be restored, than the log shall be replaced.

Disposal:

Once the contributing upstream area is completely stabilized, the compost filter sock may be removed, and depending on the longevity remaining for the sock fabric, it may be reused elsewhere. Another removal technique is to slice the sock fabric, dispose of the fabric, and spread or mix the compost with the soil to act as a soil amendment. The compost filter sock can also be vegetated, by either initially adding seed into the compost mix or seeding the sock post installation, and left permanently in place as a safeguard against future erosion onsite. The engineer shall specify a seed mixture if the compost filter sock is to be left permanently in place, and for maximum longevity can utilize a photodegradable filter sock fabric since the vegetation will aid to reduce the photo-degradation.

Standard Detail & Specifications

Compost Filter Log



NOTE: Manufacturer's recommendations supersede any installation details shown for this practice

Source:

Adapted from
MD Stds & Specs for ESC &
FiltrexTM International

Symbol:

— CFL —

Detail No.

DE-ESC-3.1.7

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Compost Filter Log

Construction Notes:

1. Prior to installation, clear bedding area of obstructions including rocks or debris larger than 1 inch and fill in any sharp depression areas.
2. If socks are prepared on-site, fill the sock fabric using a pneumatic blower so that the logs are rigid and do not deform. Terminate at the desired length.
3. For trenched applications, excavate 2 to 4 inches below grade along the width and length of the compost filter log.
4. Install the compost filter logs perpendicular to the flow direction and parallel to the slope with the beginning and end of the installation pointing up the slope a minimum of 1 foot elevation difference. On sites where this is not possible, upturn at a minimum length of 10' at a 30 degree angle to prevent runoff bypass.
5. For untrenched applications, blow or hand pack soil, mulch, or compost on the upslope side of the log, filling the bottom void area.
6. Stake the filled log every 10 feet maximum through the center of the sock for trenched applications, or every 8 feet for untrenched. The stake shall be a 2" by 2" hardwood. It should extend 12" below grade and protrude at least 3" above the top of the sock. If located on a slope greater than 8:1, the stake shall be angled downslope at a 45 degree angle to prevent the force of the water from dislodging to log.
7. When the length of the compost filter log needed exceeds the available compost filter sock length, the next sock shall be overlapped a minimum of 12" before being filled, and a stake placed through both socks at the overlap.
8. Remove accumulated sediment when it has reached half of the effective height of the log.
9. Inspect weekly and after rain event. If sock is degrading or the sock is failing, vegetate to secure the compost, replace the log, or reinforce with an additional log. If the log has been crushed due to construction equipment, it can be "fluffed" back to its effective height. If the effective height can no longer be restored, the log shall be replaced or reinforced with an additional compost filter log.

Source:

Adapted from
MD Stds & Specs for ESC &
Filtrexx™ International

Symbol:

———— **CFL** ————

Detail No.

DE-ESC-3.1.7

Sheet 2 of 2

Effective July 2023

STANDARD AND SPECIFICATIONS FOR FLOCCULATION

Definition: The process by which small particles of fine soils and sediments are induced to aggregate into larger lumps through the application of a chemical agent.



Purpose: To protect streams from the impact of turbid stormwater discharges, especially when construction continues in wet weather conditions. Traditional soil erosion and sediment control practices may not be adequate to control fine particles suspended in runoff, such as clay and fine silt. Chemical treatment can reduce turbidities to levels comparable to dry weather stream flows.

Conditions Where Practice Applies

Flocculation should only be employed when traditional "first line of defense" practices, such as vegetative stabilization, sediment traps, etc. are ineffective and/or additional treatment of stormwater runoff from a disturbed area is warranted. Turbidity is difficult to control once fine particles are suspended in stormwater runoff from construction sites. Flocculation of runoff after settling larger particulate matter in a sediment pond or other practice is an effective turbidity control if the treatment system is properly designed and implemented. Care must be taken to ensure that chemically treated stormwater discharged from construction sites is nontoxic to aquatic organisms and does not violate applicable State or Federal regulations.

Design Considerations

The design and operation of a flocculation system should take into consideration the factors that determine optimum, cost-effective performance, while ensuring non-toxic discharges.

1. Product Evaluation

- a. Treatment chemicals must be approved by EPA for potable water use.
- b. Petroleum-based polymers are prohibited.
- c. The approval of a treatment chemical shall be conditional, subject to monitoring of treated stormwater at the subject construction site.
- d. Authorization to use a chemical in the field does not relieve the applicant from responsibility for meeting all discharge and receiving water criteria applicable to a site.

2. Planning Considerations

- a. Flocculation systems should be designed as a part of the overall Sediment and Stormwater Management plan whenever problem soils are anticipated. Chemical treatment may be used to correct problem sites in some circumstances with formal written approval.
- b. The right chemical must be used at the right dosage. A dosage that is either too low or too high will not produce the best results. There is an optimum dosage rate that must be determined based on the soil type.
- c. Flocculants are most effective when applied to the soil surface in anticipation of a runoff event. They may also be installed in the form of "floc blocks" in conveyance system upstream from a sediment trapping practice. If applied directly to a pool of sediment-laden runoff, the coagulant must be mixed rapidly into the water to insure proper dispersion.
- d. A flocculation step is important to increase the rate of settling, produce the lowest turbidity, and keep the dosage rate as low as possible.
- e. Too little energy input into the water during the flocculation phase results in flocs that are too small and/or insufficiently dense. Too much energy can rapidly destroy floc as it is formed.
- f. Since the volume of the basin is a determinant in the amount of energy per unit volume, the size of the energy input system could be too small relative to the size of the basin.
- g. Care must be taken in the design of the withdrawal system to minimize outflow velocities and to prevent floc discharge. The discharge should be directed through a physical filter such as a vegetated swale that would catch any unintended floc discharge.

3. Flocculation Materials

- a. A variety of flocculent materials are available. Since trace amounts of flocculent will undoubtedly be discharged, the product used should be non-toxic and safe for both human and aquatic life and should not create Biochemical Oxygen Demand (BOD) problems in the downstream discharge waters.
- b. One flocculent that has been commonly used for stormwater applications is Polyacrylamide (PAM). Two versions of PAM are available, cationic and anionic. Only anionic PAM should be used, as cationic PAM is considered highly toxic. Anionic PAM has been used for many years in the water and wastewater industry and is considered safe for humans and aquatic life when used at the recommended rates.
- c. Chitosan is another flocculent that is derived from the exoskeletons of crustaceans. It is generally considered safe for use in stormwater and water bodies.
- d. Selection of an appropriate flocculent is highly dependent on the soil particle type and concentration. Analysis of a sample of the contaminated water is usually required to select the proper product and application rate. Manufacturers of these products will normally assist in this process.

4. Flocculation System Design

- a. Flocculation procedures shall be designed in accordance with the manufacturer's recommendations. Ponds or portable tanks are typically used for treatment. Flow-through systems with no means to trap or filter the flocculant are not permitted.
- b. A typical flocculation system may contain various components, including but not limited to a stormwater conveyance system, a storage pond, filter, pumps, a chemical feed system, treatment cells, and interconnecting piping.
- c. It is recommended that storage ponds or other holding areas have a capacity of 1.5 times the volume to be treated. Bypass should be provided around the system to accommodate extreme storm events.
- d. Primary settling should be encouraged in the storage pond. A forebay is helpful.
- e. Treatment cell sizing should consider the discharge flow rate and the desired drawdown time.
- f. Discharge rates off site must meet all applicable requirements.

5. Monitoring

- a. Operational monitoring should include pH, conductivity (as a surrogate for alkalinity), turbidity and temperature of untreated stormwater. Other important quantities include total volume treated, amount of polymer used for treatment and settling time.
- b. Discharge monitoring should include pH, turbidity and toxicity of treated stormwater, as well as discharge rates.
- c. Any other monitoring necessary to meet federal, state and local water quality standards.

6. Education

- a. Each contractor who intends to use chemical treatment should be extensively trained by experienced personnel.
- b. If a different contractor is used for chemical stormwater treatment than the general construction site contractor, regular coordination meetings should be held between all responsible parties.

7. Maintenance:

Pretreatment and treatment ponds and cells should be cleaned out periodically, and sediment or floc properly disposed of. Pumps and feed systems must be maintained in good working order. Conveyance systems need to be inspected and maintained in order to function as designed. Check discharge points to ensure that no erosion is occurring from the release of treated runoff.

8. Limitations:

If approval of the chemical treatment system is not received during the application phase of the project, an addendum will be necessary and may result in project delays. Extensive monitoring may be necessary to ensure not only that turbidity reduction goals are being met, but that toxicity of the treated discharge is not an issue. The space necessary for pumps, treatment cells and chemical feed systems can be a problem on smaller sites.

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Standard Detail & Specifications

Flocculation

Design Considerations

The design and operation of a flocculation system should take into consideration the factors that determine optimum, cost-effective performance, while ensuring non-toxic discharges.

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Source:

Adapted from
USDOT/FHWA TD-09-001

Symbol:

Detail No.

DE-ESC-3.1.8

Sheet 1 of 3

Effective July 2023

Standard Detail & Specifications

Flocculation

- b. One flocculent that has been commonly used for stormwater applications is Polyacrylamide (PAM). Two versions of PAM are available, cationic and anionic. Only anionic PAM should be used, as cationic PAM is considered highly toxic. Anionic PAM has been used for many years in the water and wastewater industry and is considered safe for humans and aquatic life when used at the recommended rates.
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- b. A typical flocculation system may contain various components, including but not limited to a stormwater conveyance system, a storage pond, filter, pumps, a chemical feed system, treatment cells, and interconnecting piping.
- c. It is recommended that storage ponds or other holding areas have a capacity of 1.5 times the volume to be treated. Bypass should be provided around the system to accommodate extreme storm events.
- d. Primary settling should be encouraged in the storage pond. A forebay is helpful.
- e. Treatment cell sizing should consider the discharge flow rate and the desired drawdown time.
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- a. Operational monitoring should include pH, conductivity (as a surrogate for alkalinity), turbidity and temperature of untreated stormwater. Other important quantities include total volume treated, amount of polymer used for treatment and settling time.
- b. Discharge monitoring should include pH, turbidity and toxicity of treated stormwater, as well as discharge rates.
- c. Any other monitoring necessary to meet federal, state and local water quality standards.

6. Education

- a. Each contractor who intends to use chemical treatment should be extensively trained by experienced personnel.
- b. If a different contractor is used for chemical stormwater treatment than the general construction site contractor, regular coordination meetings should be held between all responsible parties.

Source:

Adapted from
USDOT/FHWA TD-09-001

Symbol:

Detail No.

DE-ESC-3.1.8

Sheet 2 of 3

Effective July 2023

Standard Detail & Specifications

Flocculation

7. Maintenance:

Pretreatment and treatment ponds and cells should be cleaned out periodically, and sediment or floc properly disposed of. Pumps and feed systems must be maintained in good working order. Conveyance systems need to be inspected and maintained in order to function as designed. Check discharge points to ensure that no erosion is occurring from the release of treated runoff.

8. Limitations:

If approval of the chemical treatment system is not received during the application phase of the project, an addendum will be necessary and may result in project delays. Extensive monitoring may be necessary to ensure not only that turbidity reduction goals are being met, but that toxicity of the treated discharge is not an issue. The space necessary for pumps, treatment cells and chemical feed systems can be a problem on smaller sites.

Source:

Adapted from
USDOT/FHWA TD-09-001

Symbol:

Detail No.

DE-ESC-3.1.8

Sheet 3 of 3

Effective July 2023

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STANDARD AND SPECIFICATIONS FOR PORTABLE DEWATERING PRACTICES

Definition: A portable device through which sediment-laden water is pumped to trap and retain the sediment.



Purpose: To trap and retain sediment prior to pumping the water to drainageways, adjoining properties, and rights-of-way below a project site.

Conditions Where Practice Applies

A portable dewatering practice may be used on sites where space is limited, such as urban construction, where direct discharge of sediment-laden water to stream and storm drainage systems is to be avoided and where larger dewatering practices are impractical.

Design Criteria

Location

The portable dewatering practice shall be located for ease of clean-out and disposal of the trapped sediment, and to minimize the interference with construction activities and pedestrian traffic.

Size

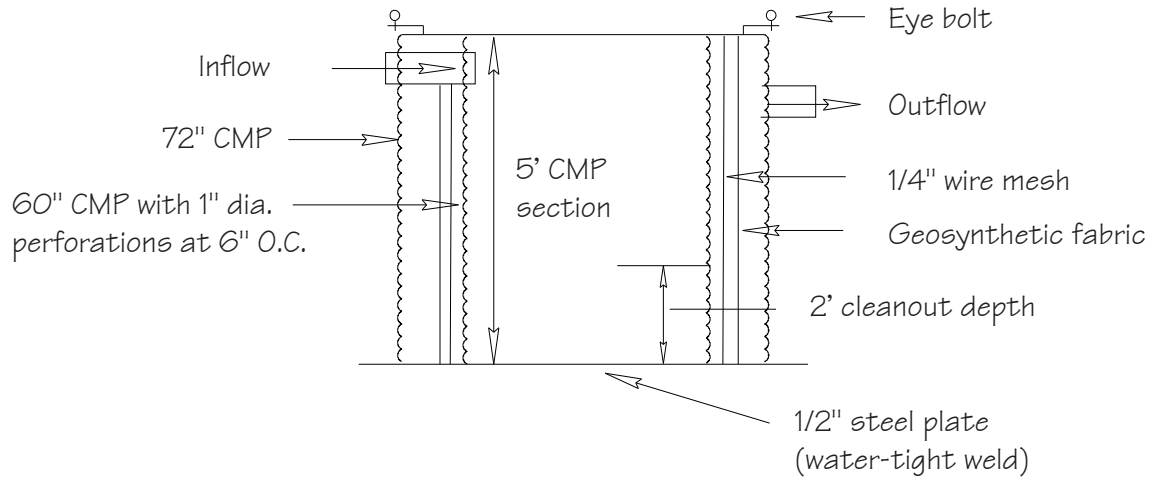
In the absence of other sizing criteria, the following formula should be used in determining the storage volume of the portable dewatering practice: $\text{Pump Discharge (G.P.M.)} \times 32 = \text{Cubic Foot Storage}$.

Details for a portable sediment tank and a geotextile dewatering bag are included in the Handbook. Other container designs may be used if the storage volume is adequate and approval is obtained from the local approving agency.

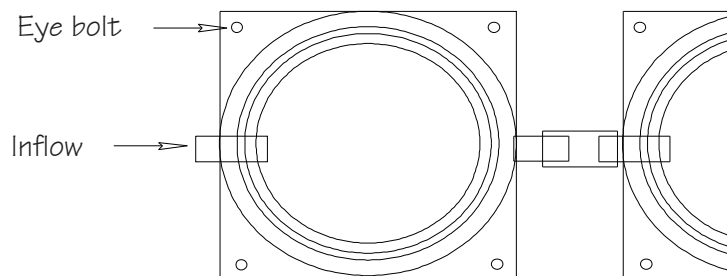
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Standard Detail & Specifications

Portable Sediment Tank



Section



Plan

Construction Notes:

1. Required storage volume = 1 c.f. storage/1 gpm pump discharge.
2. Tanks may be connected in series to provide required storage.

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:



Detail No.

DE-ESC-3.2.1.1

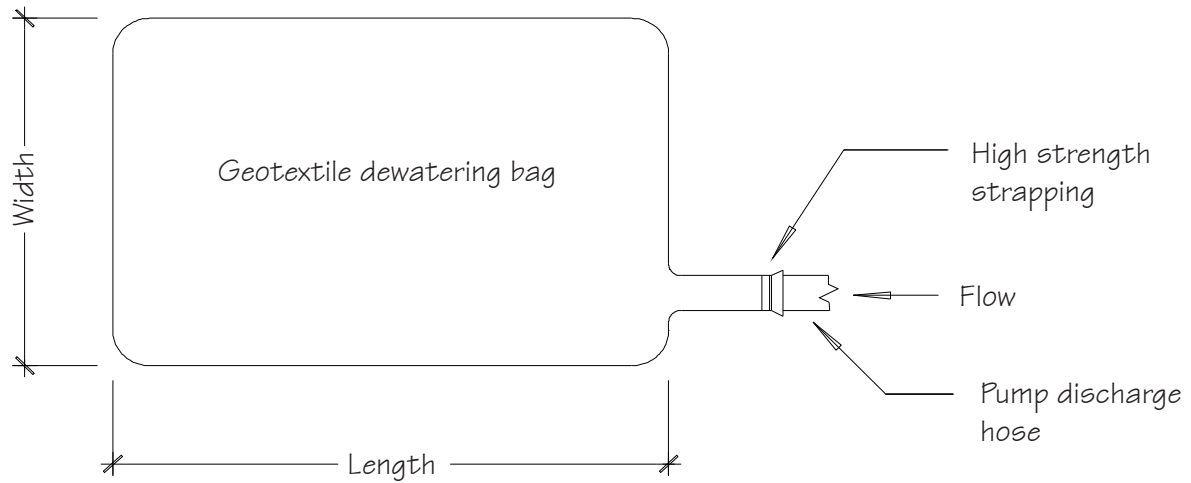
Sheet 1 of 1

Effective July 2023

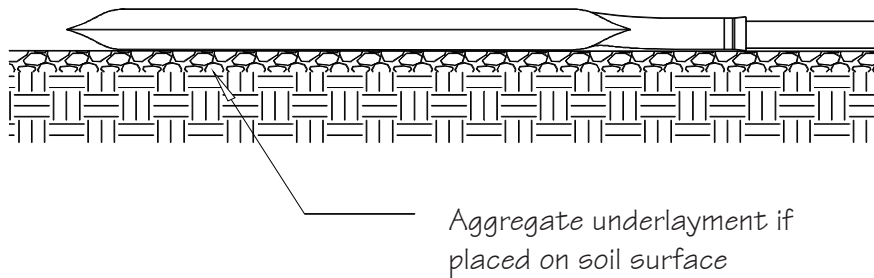
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Standard Detail & Specifications

Geotextile Dewatering Bag



Plan



Profile

NOTE: Pre-manufactured products installed in accordance with manufacturer's recommendations may be used as an equivalent substitute with Departmental approval.

Source:

Adapted from
ACF Products, Inc.

Symbol:



Detail No.

DE-ESC-3.2.1.2

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Geotextile Dewatering Bag

Construction Notes:

1. The dewatering bag should be placed so the incoming water flows into and through the bag, and then flow off the site without creating more erosion. The neck should be tied off tightly to stop the water from flowing out of the bag without going through the walls. The dewatering bag should be placed on a gravel bed to allow water to flow in all directions.
2. The dewatering bag is considered full and should be disposed when it is impractical for the bag to filter the sediment out at a reasonable flow rate. At this point, it should be replaced with a new bag.
3. Disposal may be accomplished as directed by the construction reviewer. If the site allows, the bag may be buried on site and seeded, visible fabric removed and seeded or removed from site to a proper disposal area.

Materials:

1. The geotextile fabric shall be a Type GD-IV.
2. The dewatering bag shall be sewn with a double needle machine using high strength thread. All structural seams will be sewn with high strength, double stitched "J" type. Seam strength test will have the following minimum average roll values:

<u>Type</u>	<u>TEST METHOD</u>	<u>TEST RESULT</u>
Heavy duty	ASTM D-4884	100 lb / in

3. The dewatering bag shall have an opening large enough to accommodate a four (4) inch discharge hose with attached strap to tie off the hose to prevent the pumped water from escaping from the bag without being filtered.

Source:

Adapted from
ACF Products, Inc.

Symbol:



Detail No.

DE-ESC-3.2.1.2

Sheet 2 of 2

Effective July 2023

STANDARD AND SPECIFICATIONS FOR PUMPING PIT

Definition: A temporary pit which is constructed to trap and filter water for pumping to a suitable discharge area.

Purpose: To remove excess water from excavations and/or traps.

Conditions Where Practice Applies

Pumping pits are primarily used to de-water other erosion and sediment control practices such as sediment traps and basins. They may also be used to collect and filter water during the excavation phase of construction, such as during excavation for structural foundations.

Design Criteria

The type of pumping pits and their locations should be shown on the plan. A design is not required but construction should conform to the general criteria outlined on Standard Drawing.

A perforated vertical standpipe is placed in the center of the pit to collect filtered water. Water is then pumped from the center of the pipe to a suitable discharge area.

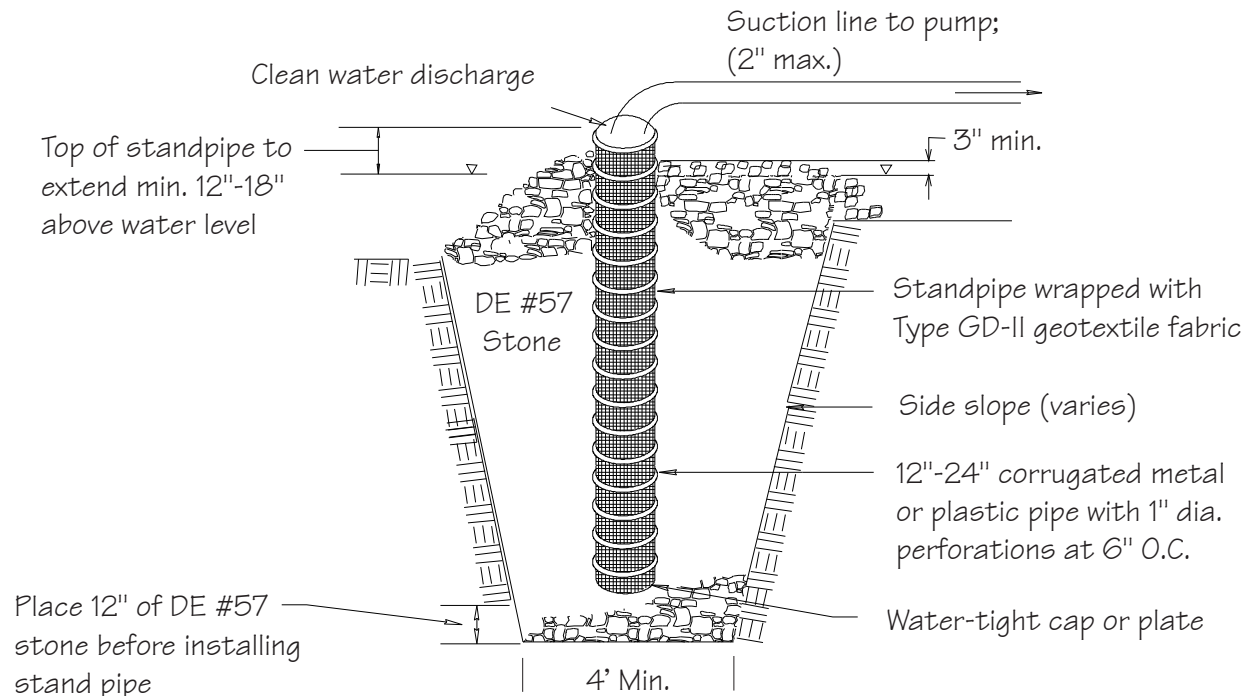
Discharge of water pumped from the standpipe should be to a stabilized area. If water from the pit will be pumped directly to a storm drainage system or free flowing stream, a Type GD-II (see **Appendix A-3**) geotextile should be wrapped around the standpipe to ensure clean water discharge. It is recommended that 1/4-1/2 inch hardware cloth wire be wrapped around and secured to the standpipe prior to attaching the filter cloth. This will increase the rate of water seepage into the standpipe.



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Standard Detail & Specifications

Pumping Pit - Type 1



Section

Construction Notes:

1. Pit dimensions are variable.
2. The standpipe should be constructed by perforating a 12" to 24" diameter corrugated or PVC pipe. The perforations shall be 1/2" X 6" slits or 1" diameter holes 6" on center.
3. A base of DE #57 aggregate should be placed in the pit to a depth of 12". After installing the standpipe, the pit surrounding the standpipe should then be backfilled with DE #57 aggregate.
4. The standpipe should extend 12" to 18" above the lip of the pit or riser crest elevation (basin dewatering).

NOTE: If discharge will be pumped directly to a storm drainage system, the standpipe must be wrapped with Type GD-II geotextile fabric before installation. If desired, 1/2" hardware cloth may be placed around the standpipe, prior to attaching the geotextile fabric. This will increase the rate of water seepage into the pipe.

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:



Detail No.

DE-ESC-3.2.2.1

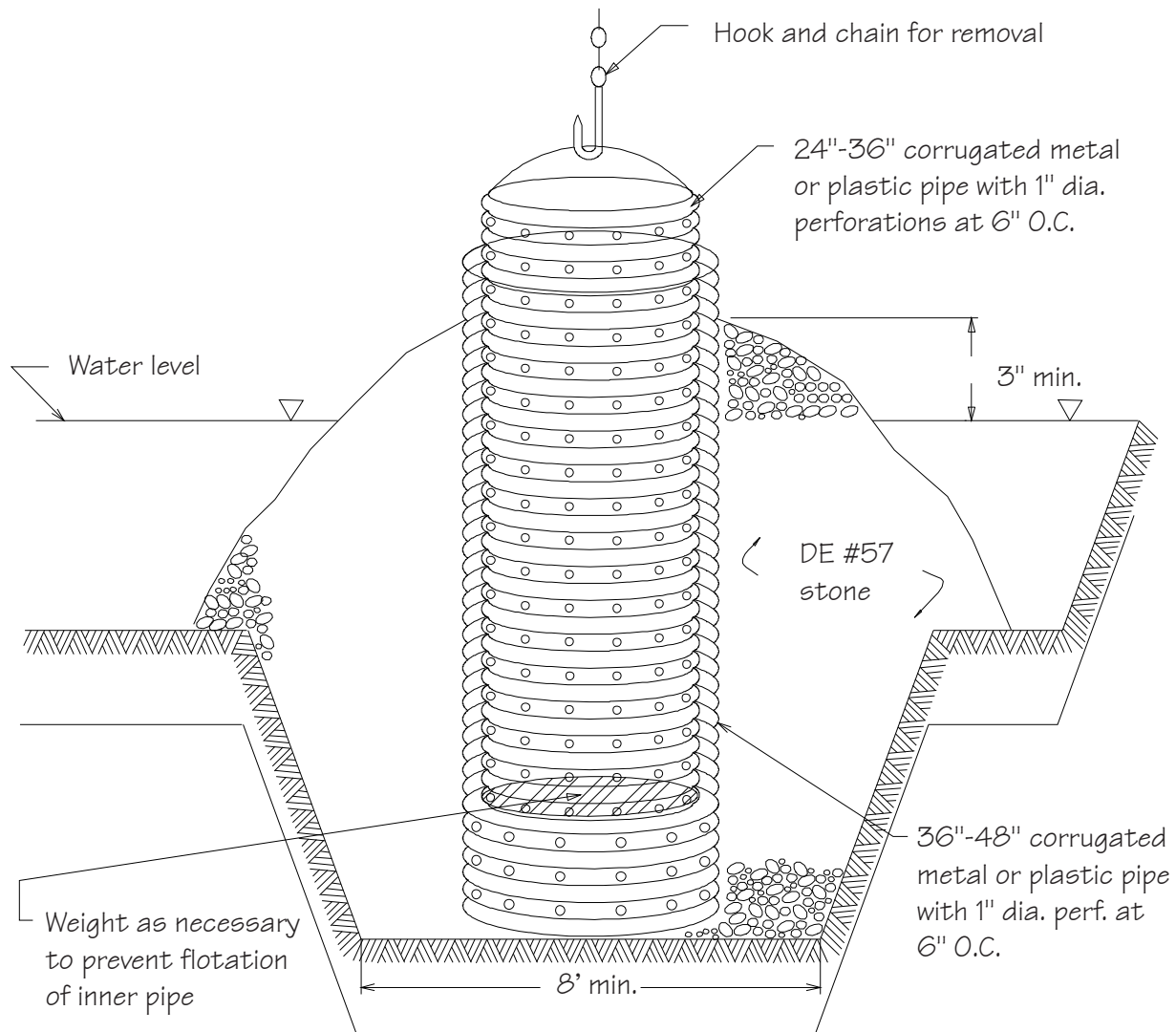
Sheet 1 of 1

Effective July 2023

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Standard Detail & Specifications

Pumping Pit - Type 2



Section

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:



Detail No.

DE-ESC-3.2.2.2

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Pumping Pit - Type 2

Construction Notes:

1. Pit shall have a minimum bottom width of 8'.
2. The inside standpipe should be constructed by perforating a 24" to 36" diameter corrugated or PVC pipe. The perforations shall be 1/2" X 6" slits or 1" diameter holes 6" on center.
3. The outside pipe shall be at least 12" larger in diameter than the inside pipe.
4. After installing the standpipes, the pit surrounding the standpipes should then be backfilled with DE #57 aggregate. The height of the stone shall be a min. 3" above the design high water elevation in the trap or basin.
5. The standpipes should extend 12" to 18" above the design high water elevation in the trap or basin.

NOTE: If discharge will be pumped directly to a storm drainage system, the standpipe must be wrapped with Type GD-II geotextile fabric before installation. If desired, 1/2" hardware cloth may be placed around the standpipe, prior to attaching the geotextile fabric. This will increase the rate of water seepage into the pipe.

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:



Detail No.

DE-ESC-3.2.2.2

Sheet 2 of 2

Effective July 2023

STANDARD AND SPECIFICATIONS FOR DEWATERING DEVICE

Definition: An appurtenance to a sediment trapping structure typically consisting of perforated pipe with a filtering media.



Purpose: To allow sediment-laden runoff to be filtered prior to being discharged to a suitable outlet.

Conditions Where Practice Applies:

Dewatering devices are appropriate where the discharge from a sediment trapping structure can be accomplished via gravity flow. In general, the skimmer dewatering device shall be the preferred option. Under some circumstances, skimmer-type dewatering devices may also be used for pump-out type dewatering activities.

Design Criteria:

The dewatering device shall be designed in such a manner so as to remove the relatively clean water without removing any of the sediment that has settled out and without removing any appreciable quantities of floating debris. Devices utilizing perforated pipe shall provide an adequate number of perforations to maintain its function should partial clogging occur. Some additional criteria for specific types of devices are as follows:

1. Skimmer - Skimmers must be designed so as to float just beneath the water surface in order to remove sediment-laden water most efficiently. If the skimmer floats too high, it may not function at all, leaving the sediment trapping structure without adequate volume for subsequent runoff events. Experience has also shown that if the connection pipe from the skimmer to the outlet structure is entirely constructed with flexible pipe, it is prone to floatation and will inhibit proper functioning. If additional filtration is necessary, the filtering media shall consist of a Type GD-II (see **Appendix A-3**) geotextile fabric wrapped around the perforated portion of the skimmer and attached with plastic snap ties, bands, etc.
2. Proprietary Dewatering Devices - The use of any proprietary or pre-engineered dewatering device must receive prior approval from the Department or one of its delegated agencies.

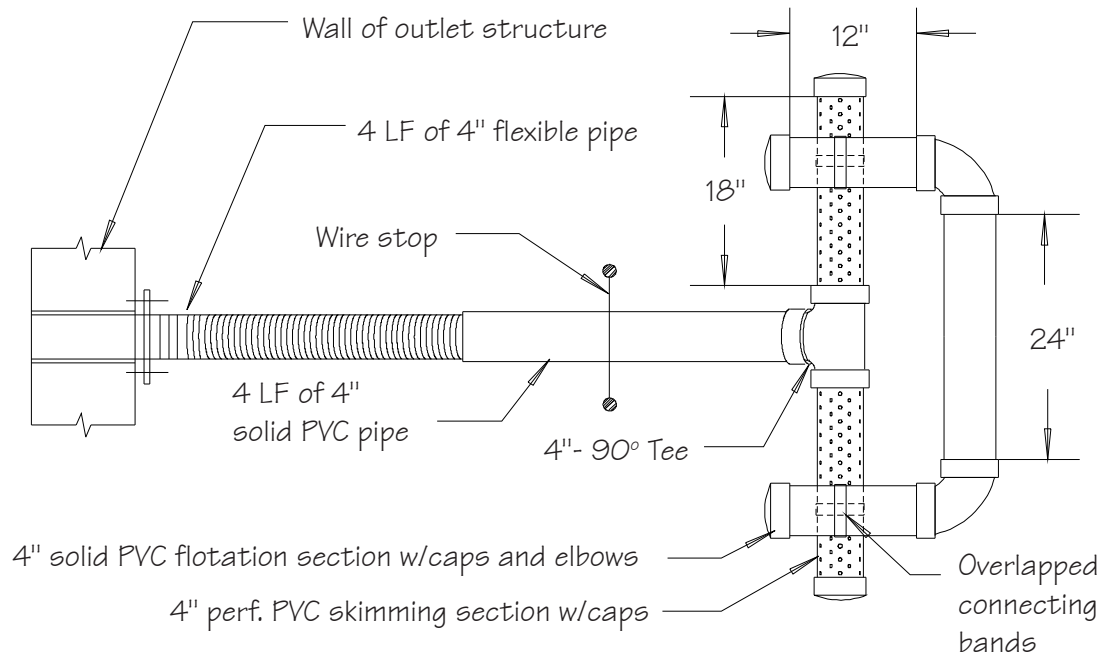
Maintenance:

Dewatering devices should be inspected after each runoff event to ensure they are functioning properly. Filter media should be replaced as needed.

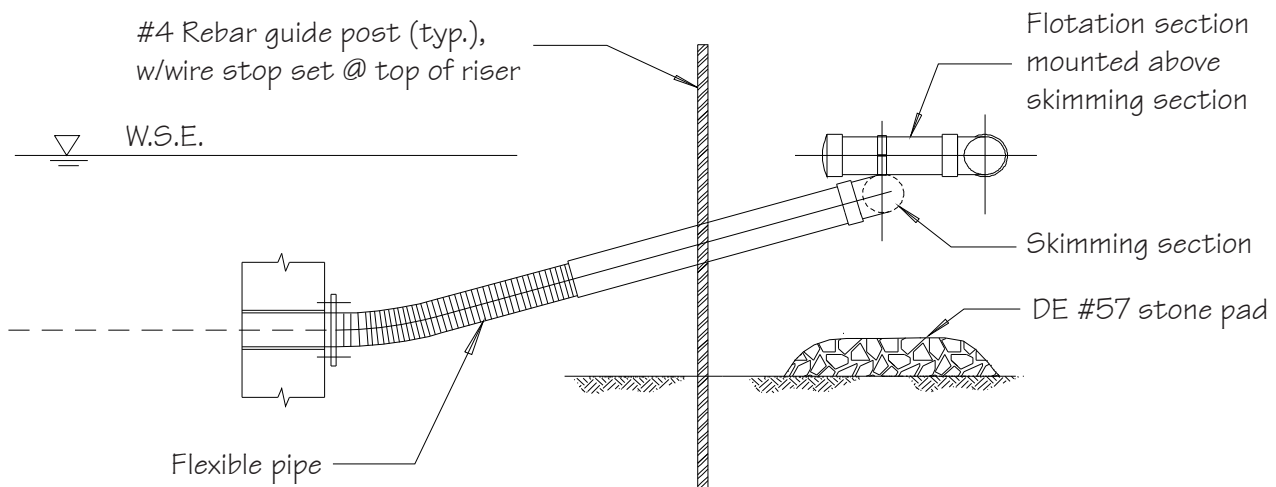
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Standard Detail & Specifications

Skimmer Dewatering Device



Plan



Profile thru $\frac{1}{2}$ of Pipe

Source:

Adapted from drawing by
Vandemark & Lynch, Inc.

Symbol:



Detail No.

DE-ESC-3.2.3.1

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Skimmer Dewatering Device

Construction Notes:

1. Pipe flotation section shall be solvent welded to ensure an airtight assembly. Contractor to conduct a test to check for leaks prior to installation.
2. Skimmer section shall have (12) rows of 1/2" dia. holes, 1-1/4" on center. If additional filtration is necessary, the filtering media shall consist of a Type GD-II geotextile fabric wrapped around the perforated portion of the skimmer and attached with plastic snap ties, bands, etc.
3. Flexible pipe shall be inserted into solid pipe and fastened with (2) #8 wood screws.
4. At a minimum, the structure shall be inspected after each rain and repairs made as needed. If vandalism is a problem, more frequent inspection may be necessary.
5. Construction operations shall be carried out in such a manner that erosion and water pollution are minimized.
6. The structure shall only be removed when the contributing drainage area has been properly stabilized.

Materials:

1. Solid pipe - 4" Sched. 40 PVC
2. Perforated pipe - 4" Sched. 40 PVC
3. 90° Tee (1 ea.) - 4" Sched. 40 PVC
4. 90° Elbow (2 ea.) - 4" Sched. 40 PVC
5. Cap (4 ea.) - 4" Sched. 40 PVC, solid
6. Flexible pipe - 4" corrugated plastic tubing (non-perforated)

Source:

Delaware ESC Handbook

Symbol:



Detail No.

DE-ESC-3.2.3.1

Sheet 2 of 2

Effective July 2023

STANDARD AND SPECIFICATIONS FOR DEWATERING BASIN

Definition: A temporary settling and filtering structure used for dewatering activities.



Purpose: To filter sediment-laden pump discharge water prior to its release to a suitable outlet.

Conditions Where Practice Applies:

Dewatering basins are appropriate whenever sediment-laden water can not be filtered by a gravity-type dewatering device. Furthermore, they are intended to be used at the discharge line from a pump. If sediment-laden water is to be filtered at the intake line, refer to **Section 3.2.2, Standard and Specifications for Pumping Pit**.

Design Criteria

1. The dewatering basin must be sized and operated to allow pumped water to flow through the filtering device without overtopping the structure. The minimum volume provided in the basin shall be based on the following formula:

$$\text{Pump discharge (g.p.m.)} \times 16 = \text{required volume of storage (cu. ft.)}$$

2. Material which is excavated to construct the basin shall be stockpiled nearby so as to be readily available for restoration when the basin is no longer needed. The stockpile shall be protected with perimeter controls and stabilized in accordance with the Standard and Specifications for Vegetative Stabilization.
3. The inside of the basin may be lined with geotextile fabric to help reduce scour within the basin itself.

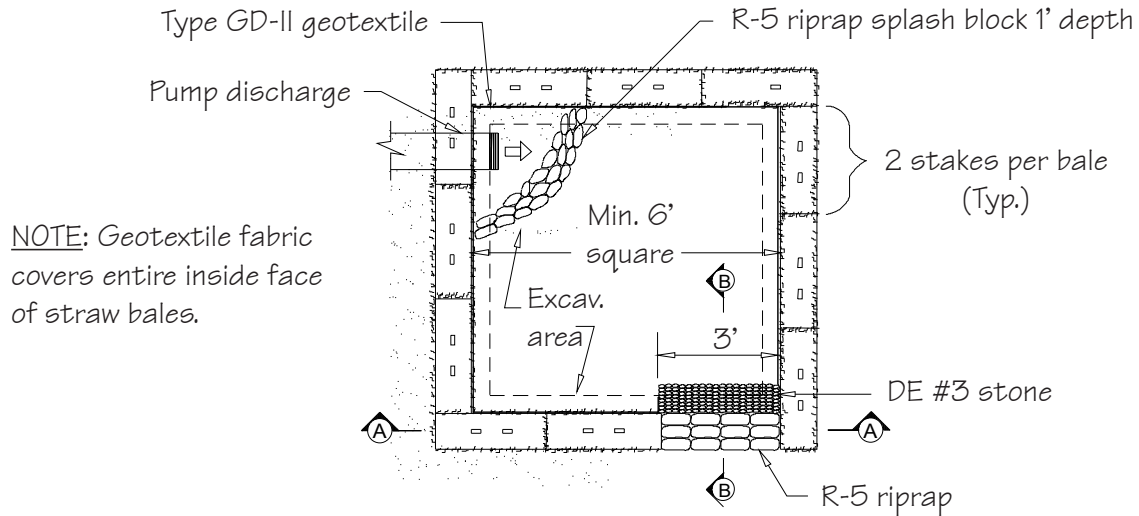
Maintenance

1. The dewatering basin shall be inspected regularly during each day of operation to ensure it is not being overloaded.
2. Once the sediment build-up prevents the structure from functioning as designed, the sediment shall be removed, spread on-site and stabilized or disposed of at an approved disposal site in accordance with the approved plan.

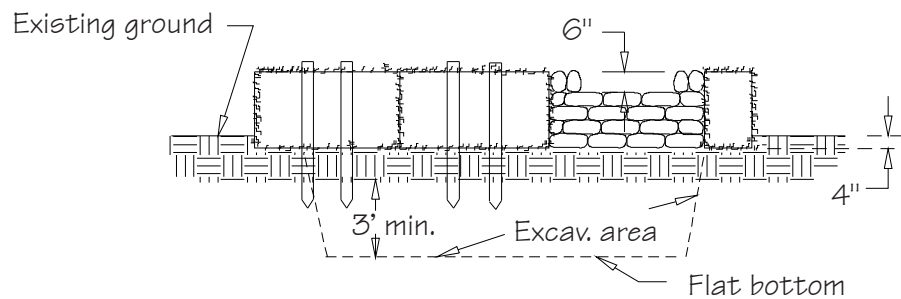
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Standard Detail & Specifications

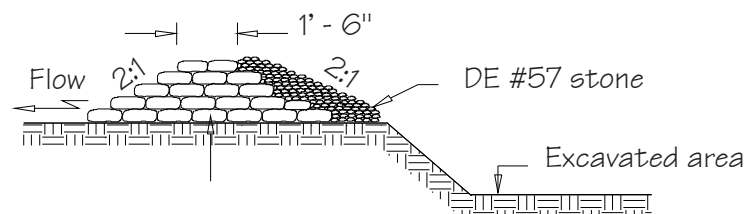
Dewatering Basin - Type 1



Plan



Section A-A



Section B-B

Source:

Adapted from
VA ESC Handbook

Symbol:

DWB-1

Detail No.

DE-ESC-3.2.4.1

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Dewatering Basin - Type 1

Construction Notes:

1. Capacity of the basin shall be based on the following formula:

$$\text{Pump discharge (gpm)} \times 16 = \text{cubic feet of storage required}$$

2. Available volume shall be measured from the floor of the excavation to the crest of the stone weir.
3. The excavated area shall be a min. of 3' below the base of the straw bales.
4. Once the water level reaches the crest of the stone weir, the pump shall be shut off while the structure drains down to the elevation of the wet storage.
5. The wet storage area may be dewatered only after a min. of 6 hours of sediment settling time. This effluent shall be pumped across a well vegetated area or through a silt fence prior to entering a watercourse.
6. Once the wet storage area becomes filled to one-half of the excavated depth, accumulated sediment shall be removed and properly disposed of.
7. The straw bales and/or geotextile fabric shall be inspected on a regular basis and shall be repaired or replaced once sediment prevents the structure from functioning as designed.

Source:

Adapted from
VA ESC Handbook

Symbol:



Detail No.

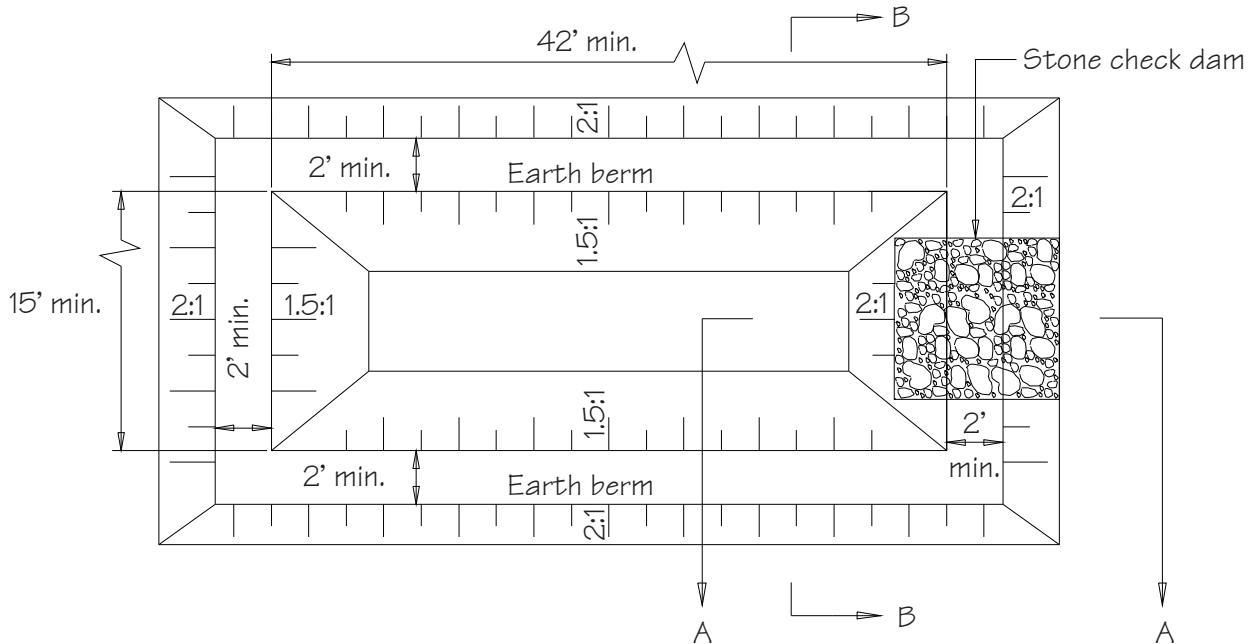
DE-ESC-3.2.4.1

Sheet 2 of 2

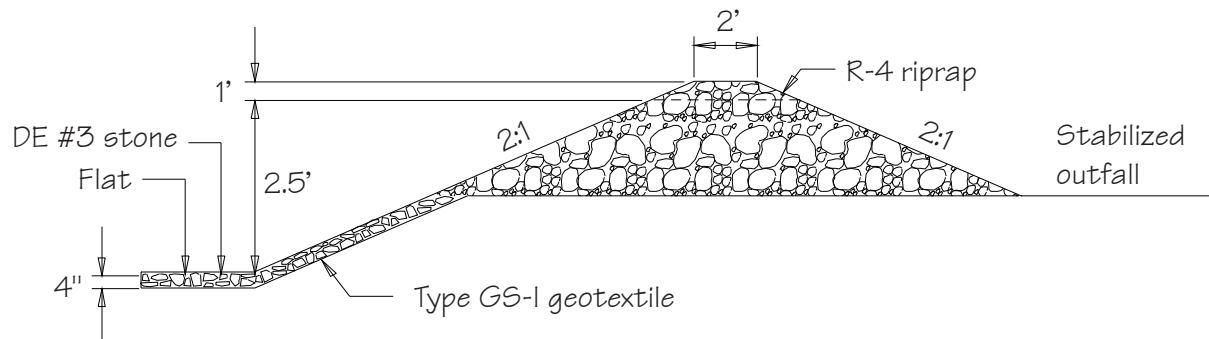
Effective July 2023

Standard Detail & Specifications

Dewatering Basin - Type 2



Plan



Section A-A

Source:

Adapted from
DelDOT Stds. & Specs.

Symbol:

DWB-2

Detail No.

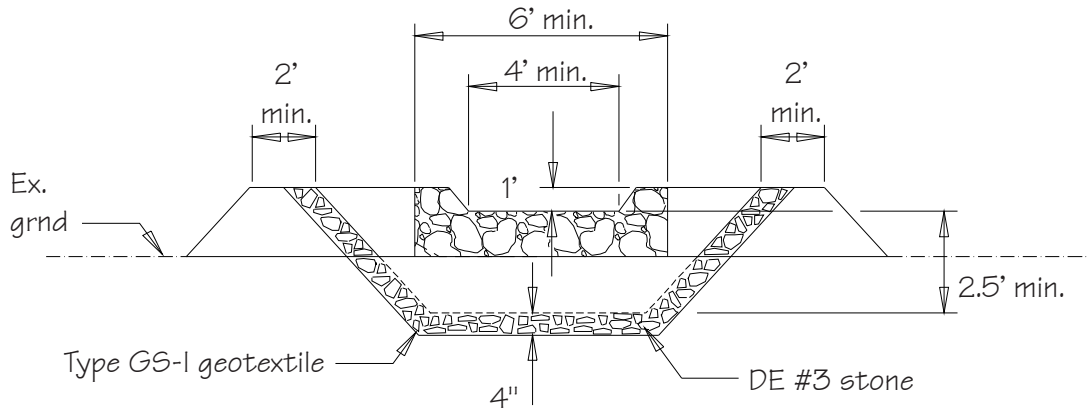
DE-ESC-3.2.4.2

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Dewatering Basin - Type 2



Section B-B

Construction Notes:

1. Length of the basin shall be based on the following formula:

$$\text{Top length (ft)} = 26 + .01 \times \text{pump discharge (gpm)}$$

2. Basin shall have a min. length of 42 feet, a min. width of 15 feet and a min. depth of 3.5 feet as measured from the floor to the top of the berm.
3. Excess excavated material shall be stockpiled in accordance with the approved plan and surface runoff shall be diverted around the basin.
4. The outfall from the basin to the receiving waters shall be stabilized. If used in conjunction with the installation of a coffer dam, dewatering shall begin no sooner than 12 hours after coffer dam is completed in order to allow settling of sediment produced during installation.
5. Pumping into the basin shall cease when the effluent from the basin becomes sediment-laden.
6. Accumulated sediment shall be removed and disposed of in an approved disposal area when the basin is filled to within 18 inches of the crest of the weir.

Source:

Adapted from
DelDOT Stds. & Specs.

Symbol:

DWB-2

Detail No.

DE-ESC-3.2.4.2

Sheet 2 of 2

Effective July 2023

STANDARD AND SPECIFICATIONS FOR TEMPORARY SWALE

Definition: A temporary excavated drainageway.

Purpose: To prevent runoff from entering disturbed areas by intercepting and diverting it to a stabilized outlet or to intercept sediment-laden water and divert it to a sediment trapping device.



Conditions Where Practice Applies: Temporary swales are constructed:

1. To divert flows away from a disturbed area and to a stabilized area.
2. Intermediately across disturbed areas to shorten overland flow distances.
3. To direct sediment-laden water along the base of slopes to a trapping device.
4. To transport off-site flows across disturbed areas such as rights-of-way.

Swales collecting runoff from disturbed areas shall remain in place until the disturbed areas are permanently stabilized.

Design Criteria

Refer to the chart below for proper sizing criteria. For drainage areas larger than 10 acres, refer to the Standard and Specifications for Channels.

	Swale A	Swale B
Drainage Area	5 acres or less	5-10 acres
Bottom of width of flow channel	4'	6'
Depth of flow channel	1'	1'
Side slopes	3:1 or flatter	3:1 or flatter
Grade	0.5% Min 20% Max	0.5% Min 20% Max

Stabilization

Stabilization shall be completed within 14 days of installation in accordance with the Standards and Specifications for Temporary Seeding and Mulching or Mulching only if not in seeding season. The flow channel shall be stabilized as outlined in the standard drawing.

In highly erodible soils, as defined by the local approving agency, use the next higher slope grade for type of stabilization.

Outlet

Temporary swales shall have an outlet that prevents additional erosion and reduces runoff velocity prior to discharge.

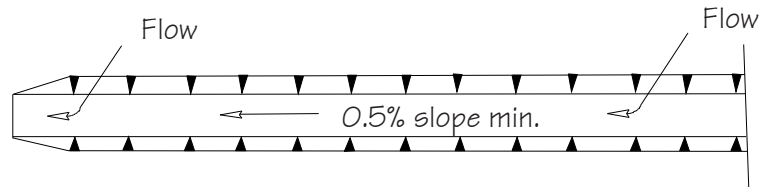
Sediment-laden runoff shall be conveyed to a sediment trapping device such as a sediment trap or sediment basin until the drainage area above the swale is adequately stabilized.

All excavation operations shall be carried out in such a manner that erosion and water pollution shall be minimal. Excavated portions of sediment traps shall have 1:1 or flatter side slopes.

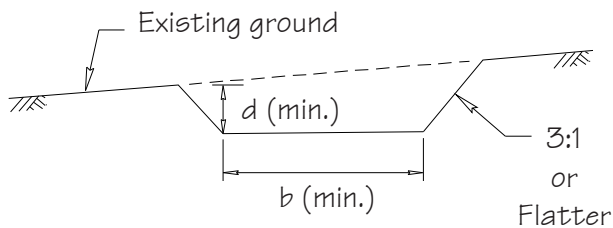
Standard Detail & Specifications

Temporary Swale

Discharge to be directed to sediment trapping device (or stable outlet for clean water).



Plan



Typical Section

	Type A (<u>< 5 ac.</u>)	Type B (<u>5-10 ac.</u>)
b - BOTTOM WIDTH	4'	6'
d - FLOW DEPTH	1'	1'

FLOW CHANNEL STABILIZATION CHART

<u>Stabilization Method</u>	<u>Channel Grade</u>	<u>Type A</u>	<u>Type B</u>
1	0.5-3.0%	Seed with stab. blanket	Seed with stab. blanket
2	3.1-5.0%	Seed with stab. blanket	Seed using stab. blanket; sod; DE #2 stone
3	5.1-8.0%	Seed with stab. blanket; sod; DE #2 stone	Lined R-4 riprap
4	8.1-20%	Lined R-4 riprap	Engineering design

- a. Stone to be DE #2 inch stone in a layer at least 3 inches in thickness and underlain with GS-I geotextile.
- b. Riprap to be R-4 in a layer at least 8 inches thickness and and underlain with GS-I geotextile.

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:

—TS- (A/B)(1-4)—→

Detail No.

DE-ESC-3.3.1

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Temporary Swale

Construction Notes:

1. All temporary swales shall have uninterrupted positive grade to an outlet with a minimum of erosion.
2. Diverted runoff from a disturbed area shall be conveyed to a sediment trapping device.
3. Diverted runoff from an undisturbed area shall outlet directly into an undisturbed stabilized area at a non-erosive velocity.
4. All trees, brush, stumps, obstructions, and other objectionable material shall be removed and disposed of so as not to interfere with the proper functioning of the swale.
5. The swale shall be excavated or shaped to line, grade, and cross section as required to meet the criteria specified herein and be free of bank projections or other irregularities which will impede normal flow.
6. Fills shall be compacted by earth moving equipment.
7. All earth removed and not needed on construction shall be placed so that it will not interfere with the functioning of the swale.
8. Inspection and required maintenance shall be provided after each rain event.

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:

—TS- (A/B)(1-4)—→

Detail No.

DE-ESC-3.3.1

Sheet 2 of 2

Effective July 2023

STANDARD AND SPECIFICATIONS FOR TEMPORARY EARTH BERM

Definition: A temporary earth dike or ridge of compacted soil, located in such a manner as to channel water to a desired location.

Purpose: To direct runoff to a sediment trapping device, thereby reducing the potential for erosion and off-site sedimentation. Earth berms can also be used for diverting clean water away from disturbed areas.

Conditions Where Practice Applies:

Earth berms are often constructed across disturbed areas and around construction sites such as graded parking lots and subdivisions. The berms shall remain in place until the disturbed areas are permanently stabilized.

Design Criteria: See Standard Detail for Type A or Type B temporary earth berms.

Additional Criteria:

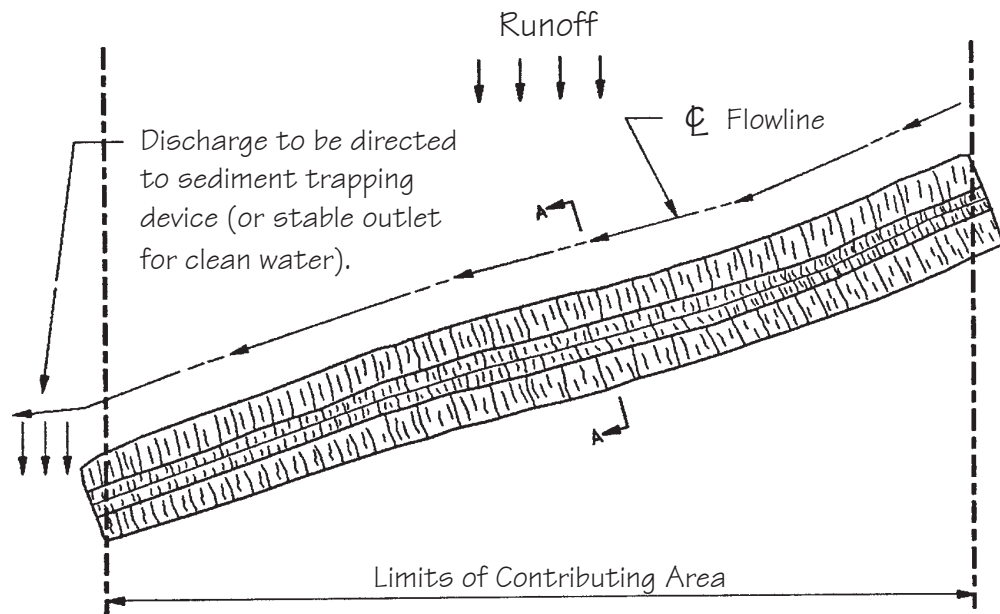
1. For drainage areas > 10 acres refer to the Standard and Specifications for Diversion.
2. Stabilization of the dike shall be completed within 14 days of installation.
3. The local approving agency may require a higher degree of stabilization for highly erodible soils.
4. In situations where an earth dike is used to direct runoff into a sediment trap or basin, adequate protection shall be provided to prevent erosion at the inflow point.



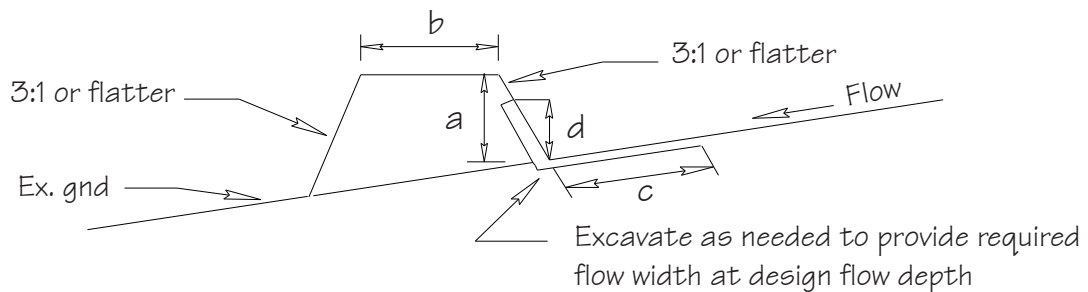
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Standard Detail & Specifications

Temporary Earth Berm



Plan



Section A-A

	Type A (5 ac. or less)	Type B (5-10 ac.)
a - BERM HEIGHT	18"	36"
b - BERM TOP WIDTH	24"	36"
c - FLOW WIDTH	4'	6'
d - FLOW DEPTH	8"	15"

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:

—TB- (A/B)(1-4)—→

Detail No.

DE-ESC-3.3.2

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Temporary Earth Berm

FLOW CHANNEL STABILIZATION CHART

Stabilization Method	Channel Grade	Type A	Type B
1	0.5-3.0%	Seed with stab. blanket	Seed with stab. blanket
2	3.1-5.0%	Seed with stab. blanket	Seed with stab. blanket; sod; DE #2 stone
3	5.1-8.0%	Seed with stab. blanket; sod; DE #2 stone	Lined R-4 riprap
4	8.1-20%	Lined R-4 riprap	Engineering design

- a. Stone to be DE #2 stone in a layer at least 3 inches in thickness and underlain with GS-I geotextile.
- b. Riprap to be R-4 in a layer at least 8 inches thickness and underlain with GS-I geotextile.

Construction Notes:

1. All berms shall be compacted by earth-moving equipment.
2. All berms shall have positive drainage to an outlet.
3. Top width may be wider and side slopes may be flatter if desired to facilitate crossing construction traffic.
4. Field location should be adjusted as needed to utilize a stabilized safe outlet.
5. Earth berms shall have an outlet that functions with a minimum of erosion. Runoff shall be conveyed to a sediment trapping device such as a sediment trap or sediment basin where either the berm channel or the drainage area above the berm are not adequately stabilized.
6. Stabilization shall be: (a) In accordance with standard specifications for seed and straw mulch or straw mulch if not in seeding season, (b) Flow channel as per the chart above.
7. Inspection and required maintenance shall be provided after each rain event.

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:

—TB-(A/B)(1-4)—→

Detail No.

DE-ESC-3.3.2

Sheet 2 of 2

Effective July 2023

STANDARD AND SPECIFICATIONS FOR VEGETATED CHANNEL

Definition: A natural or man-made channel of parabolic or trapezoidal cross-section that is below adjacent ground level and is stabilized by suitable vegetation. The flow channel is normally wide and shallow and conveys the runoff down the slope to a stable outlet.



Purpose: The purpose of a vegetated channel is to convey runoff without causing damage by erosion.

Conditions Where Practice Applies

Vegetated channels are used where added vegetative protection is needed to control erosion resulting from concentrated runoff. They are generally considered to be permanent structures, but may also be used where the design criteria for temporary conveyance structures are exceeded and an engineered design is required. Vegetated channels intended to act as permanent stormwater management practices shall be designed and constructed in accordance with the **Delaware Post-Construction Stormwater BMP Standards & Specifications**.

Design Criteria

1. Capacity

The minimum capacity shall be that required to confine the peak rate of runoff expected from a 10-year frequency, 24-hour NRCS Type II rainfall event or a higher frequency corresponding to the hazard involved.

Peak rates of runoff values used in determining the capacity requirements shall be based on USDA-NRCS methodology as outlined in TR 55 Urban Hydrology and/or TR 20 Project Formulation - Hydrology. Special situations which warrant a different methodology, such as the use of NRCS drainage curves for very flat landscapes, require prior approval from the Department.

2. Stability

All vegetated channels shall be stabilized with a temporary-type matting to accommodate a minimum flow depth of 1 foot. Refer to the Standard and Specifications for Stabilization Matting for additional guidance.

The recommended methodology for stability design of vegetated channels is the tractive force method. **Design Guide 1** outlines the procedures for this type of analysis. This methodology is applicable to a wider range of lining types (including combination linings) and channel slopes than the allowable velocity method. This allows the use of a single design procedure for most of the water conveyance practices contained in this handbook. Vegetated channels may be specified for maximum design shear stresses less than 2 psf. If the maximum design shear stress is equal to or greater than 2 psf, a lined channel shall be specified.

3. Cross Section

The cross section shall be triangular, parabolic, or trapezoidal. The top width of parabolic waterways shall not exceed 30 feet and the bottom width of trapezoidal waterways shall not exceed 15 feet unless multiple or divided waterways, stone center, or other means are provided to control meandering of low flows.

The design water surface elevation of a vegetated channel receiving water from diversions or other tributary channels shall be equal to or less than the design water surface elevation in the diversion or other tributary channels.

When there is a base flow, it shall be handled by a stone center, subsurface drain, or other suitable means since sustained wetness usually prevents adequate vegetative cover. The cross-sectional area of the stone center or subsurface drain size to be provided shall be determined by using a flow rate of 0.1 cfs/acre or by actual measurement of the maximum base flow.

4. Structural Measures

In cases where grade or erosion problems exist, special control measures may be needed such as linings, drop structures, or grade stabilization measures. Where needed, these measures must be supported by adequate design computations. Refer to **Section 3.3.4, Standard and Specifications for Lined Channel** and **Section 3.3.9, Standard and Specification for Chute** for additional guidance.

5. Outlets

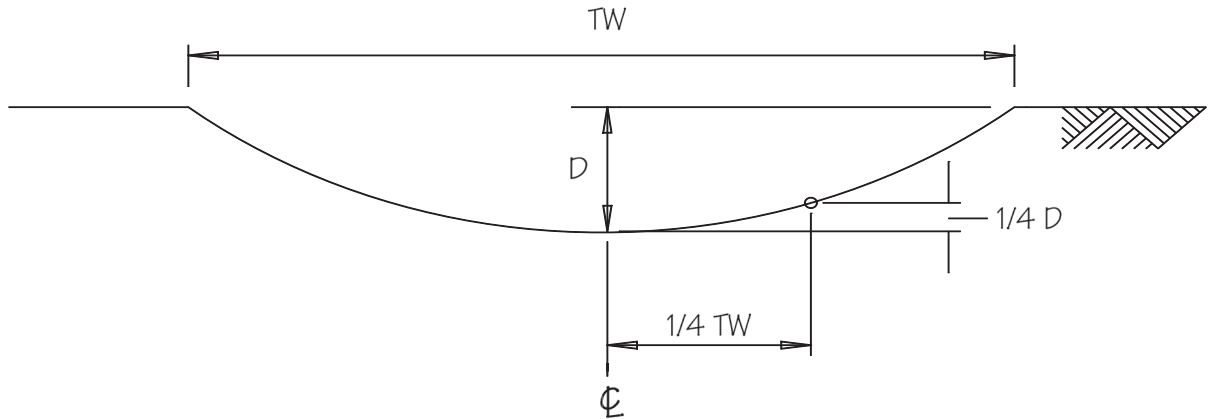
Each channel shall have a stable outlet. The outlet may be another stabilized open channel, grade stabilization structure, etc. In all cases, the outlet must discharge in such a manner as not to cause erosion. Outlets shall be constructed and stabilized prior to the operation of the waterway.

6. Stabilization

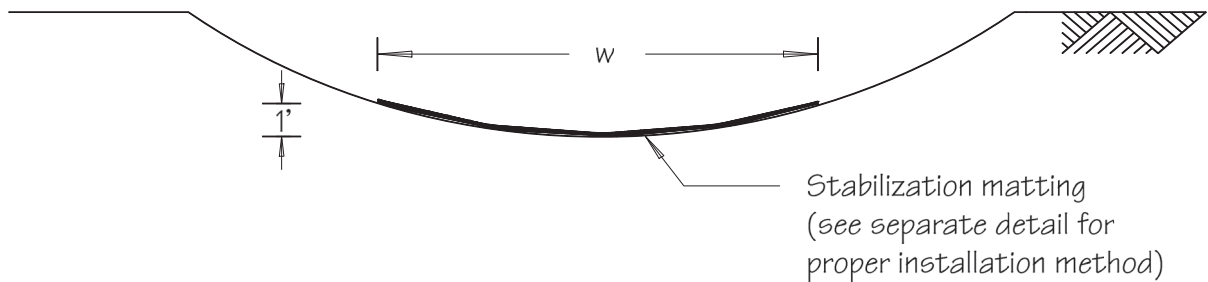
Vegetated channels shall be stabilized in accordance with **Section 3.4.3, Standard and Specifications for Vegetative Stabilization** and **Section 3.4.6, Stabilization Matting**.

Standard Detail & Specifications

Vegetated Channel - Parabolic



Typical Section (Design)



Typical Section (Stabilization)

DATA

Design discharge (Q_d)
 Design topwidth (TW)
 Design depth (D)
 Design channel slope (s)
 Width of stabilization mat (w)
 Type of stabilization matting

Source:

Delaware ESC Handbook

Symbol:

VC-P

Detail No.

DE-ESC-3.3.3.1

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Vegetated Channel - Parabolic

Construction Notes:

1. All trees, brush, stumps, obstructions, and other objectionable material shall be removed and disposed of so as not to interfere with the proper functioning of the waterway.
2. The channel shall be excavated or shaped to line, grade, and cross section as required to meet the criteria specified herein, and be free of bank projections or other irregularities which will impede normal flow.
3. Fills shall be compacted as needed to prevent unequal settlement that would cause damage in the waterway.
4. All earth removed and not needed in construction shall be spread or disposed of so that it will not interfere with the functioning of the waterway.
5. Stabilization shall be done in accordance with the appropriate Standard and Specifications for Vegetative Stabilization and Stabilization Matting.
 - a. It is recommended that, when conditions permit, temporary diversions or other means should be used to prevent water from entering the waterway during the establishment of the vegetation.
 - b. Should groundwater or base flow conditions preclude the establishment of adequate vegetative stabilization throughout the entire design section, provisions shall be made through use of a lining material, stone center drain and/or subsurface drain. Such practices shall be designed and constructed in accordance with the appropriate Standard(s) and Specifications and Standard Detail(s).

Source:

Delaware ESC Handbook

Symbol:

 **VC-P** →

Detail No.

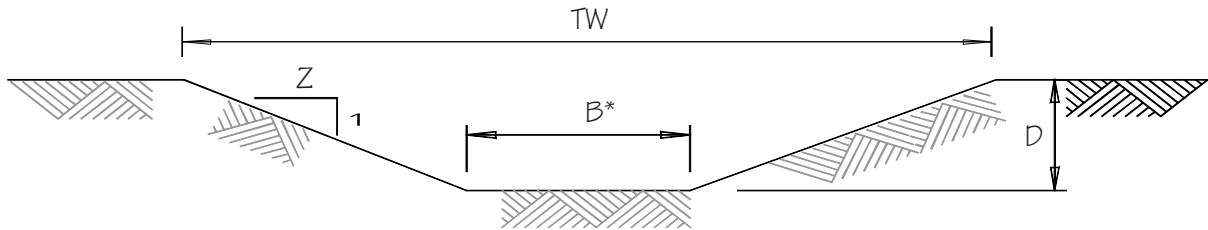
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Sheet 2 of 2

Effective July 2023

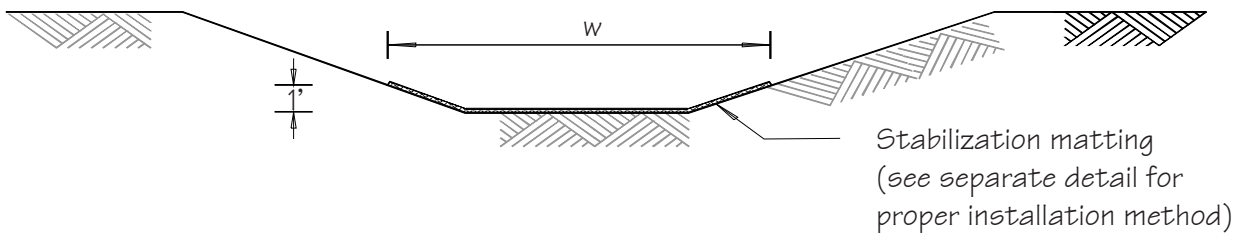
Standard Detail & Specifications

Veg. Channel - Triang./Trap.



* $B = 0$ for triangular section

Typical Section (Design)



Typical Section (Stabilization)

DATA

Design discharge (Q_d)
Design topwidth (TW)
Design depth (D)
Design bottom width (B)
Design sideslope (Z)
Design channel slope (s)
Width of stabilization mat (w)
Type of stabilization matting

Source:

Delaware ESC Handbook

Symbol:

VC-T →

Detail No.

DE-ESC-3.3.3.2

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Veg. Channel - Triang./Trap.

Construction Notes:

1. All trees, brush, stumps, obstructions, and other objectionable material shall be removed and disposed of so as not to interfere with the proper functioning of the waterway.
2. The channel shall be excavated or shaped to line, grade, and cross section as required to meet the criteria specified herein, and be free of bank projections or other irregularities which will impede normal flow.
3. Fills shall be compacted as needed to prevent unequal settlement that would cause damage in the waterway.
4. All earth removed and not needed in construction shall be spread or disposed of so that it will not interfere with the functioning of the waterway.
5. Stabilization shall be done in accordance with the appropriate Standard and Specifications for Vegetative Stabilization and Stabilization Mat.
 - a. It is recommended that, when conditions permit, temporary diversions or other means should be used to prevent water from entering the waterway during the establishment of the vegetation.
 - b. Should groundwater or base flow conditions preclude the establishment of adequate vegetative stabilization throughout the entire design section, provisions shall be made through use of a lining material, stone center drain and/or subsurface drain. Such practices shall be designed and constructed in accordance with the appropriate Standard(s) and Specifications and Standard Detail(s).

Source:

Delaware ESC Handbook

Symbol:



Detail No.

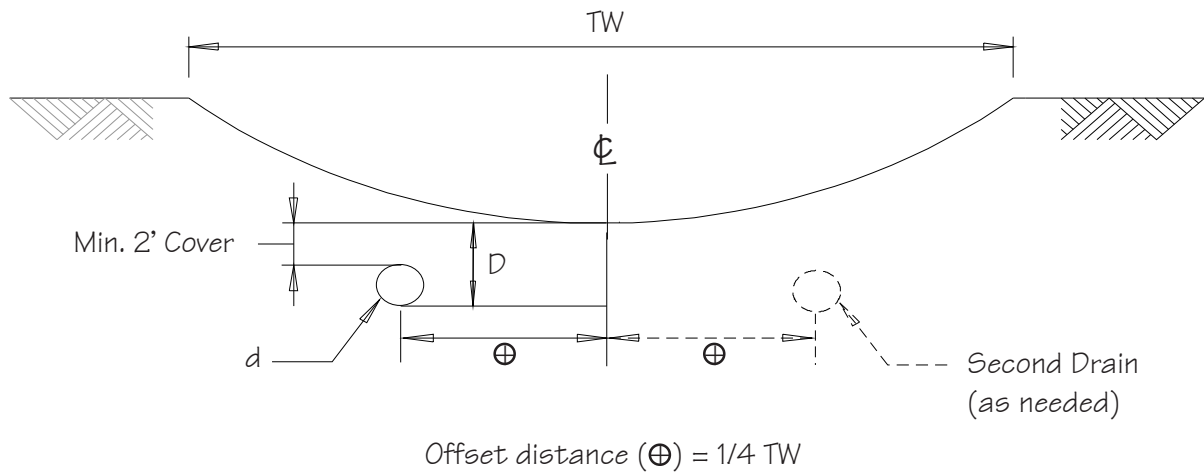
DE-ESC-3.3.3.2

Sheet 2 of 2

Effective July 2023

Standard Detail & Specifications

Channel Pipe Drain



Typical Section

DATA

Offset distance (\oplus)
Drain installation depth (D)
Drain diameter (d)
Drain pipe material

Source:

Adapted from
IL Urban Manual

Symbol:

—(VC/LC)(P/T) + PD→

Detail No.

DE-ESC-3.3.3.3

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Channel Pipe Drain

Construction Notes:

1. Deformed, warped, or damaged pipe shall not be used.
2. All subsurface drains shall be laid to a uniform line and covered with envelope material. The pipe or tubing shall be laid with the perforations down and oriented symmetrically about the vertical center line. Connections will be made with manufactured junctions comparable in strength with the specified pipe or tubing unless otherwise specified. The method of placement and bedding shall be as specified on the drawing.
3. Envelope material shall consist of either filter cloth or DE #8 aggregate.
4. The upper end of each subsurface drain line shall be capped with a tight fitting cap of the same material as the conduit or other durable material unless connected to a structure.
5. A continuous 10-foot section of corrugated metal, cast iron, PVC, or steel pipe without perforations shall be used at the outlet end of the line. No envelope material shall be used around the 10-foot section of pipe. An animal guard shall be installed on the outlet end of the pipe.
6. Where surface water is entering the system, the pipe outlet section of the system shall contain a swing type trash and animal guard.
7. Backfilling shall be done immediately after placement of the pipe. The backfill material shall not contain rocks or other sharp objects. Place backfill in a manner that will not damage or displace the pipe.

Source:

Adapted from
IL Urban Manual

Symbol:

—(VC/LC)(P/T) + PD→

Detail No.

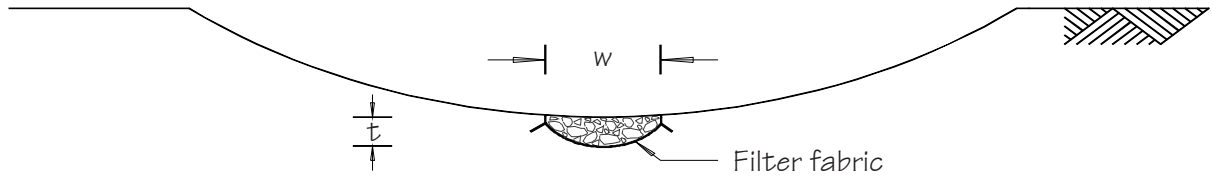
DE-ESC-3.3.3.3

Sheet 2 of 2

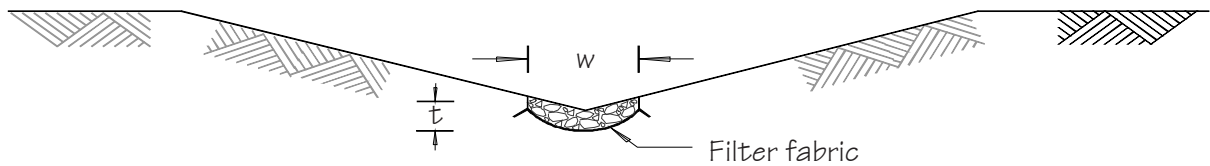
Effective July 2023

Standard Detail & Specifications

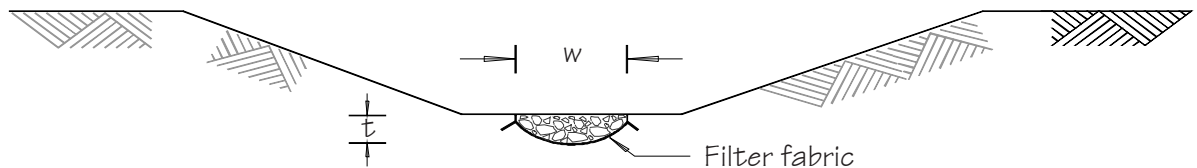
Channel Stone Drain



Typical Section (Parabolic)



Typical Section (Triangular)



Typical Section (Trapazoidal)

Data

Width of stone section (w)

Thickness of stone (t)

Median stone size (d_{50})

Source:

Adapted from
VA E&S Manual

Symbol:

— VC/(P/T) + SD —>

Detail No.

DE-ESC-3.3.3.4

Sheet 1 of 1

Effective July 2023

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STANDARD AND SPECIFICATIONS FOR LINED CHANNEL

Definition: A channel with a lining of stone, or other permanent material. The lined section extends up the side slopes to the designed depth. The earth above the permanent lining may be vegetated or otherwise protected.



Purpose: To provide for the conveyance of concentrated runoff without damage from erosion or flooding where a vegetated channel alone would not be stable.

Scope:

This standard applies to channels with linings of rock riprap, gabions or similar armor. In addition, this standard shall also apply to turf reinforcement mats and other synthetic linings which are considered permanent in nature. It does not apply to irrigation ditches, canal linings, vegetated channels with stone centers (small lined sections to carry prolonged low flows), or to reinforced concrete channels. Neither does it apply to relatively short lined channels on very steep slopes which fall under the scope of the Standard and Specification for Chute.

Conditions Where Practice Applies

This practice applies where the following or similar conditions exist:

1. Concentrated runoff is such that a lining is required to control erosion.
2. Steep grades, wetness, prolonged base flow, seepage, or piping would cause erosion.
3. The location is such that damage from use by people or animals precludes the use of vegetated waterways or outlets.
4. Soils are highly erosive or other soil and climate conditions preclude using vegetation.
5. Space limitations dictate a smaller channel cross section resulting in high velocities.

Design Criteria

1. Capacity

The minimum capacity shall be that required to confine the peak rate of runoff expected from a 10-year frequency, 24-hour NRCS Type II rainfall event or a higher frequency corresponding to the hazard involved.

Peak rates of runoff values used in determining the capacity requirements shall be based on USDA-NRCS methodology as outlined in TR 55 Urban Hydrology and/or TR 20 Project Formulation - Hydrology. Special situations which warrant a different methodology require approval from the Department.

2. Stability

The recommended methodology for stability design of conveyance channels is the tractive force method. **Design Guide 1** outlines the procedures for this type of analysis. This methodology is applicable to a wider range of lining types (including combination linings) and channel slopes than the allowable velocity method. This allows the use of a single design procedure for most of the water conveyance practices contained in this handbook. Vegetated channels may be specified for maximum design shear stresses less than 2 psf. If the maximum design shear stress is equal to or greater than 2 psf, a lined channel shall be specified.

3. Cross Section

The cross section shall be triangular, parabolic, or trapezoidal.

4. Freeboard

The minimum freeboard for lined channels shall be 0.25 feet above the design high water in areas where erosion-resistant vegetation cannot be grown adjacent to the lining on the side slopes. No freeboard is required where good vegetation can be grown and is maintained.

5. Side Slope

The steepest permissible side slopes, horizontal to vertical will be as follows:

Rock riprap.....2 to 1
Gabions.....Vertical

6. Lining Thickness - The minimum lining thickness shall be as follows:

Rock riprap.....1.5 x maximum stone size
Gabion.....9 in. mattress

7. Related Structures

Side inlets, drop structures, and energy dissipators shall meet the hydraulic and structural requirements of the site.

8. Geotextile fabric

A **Type GS-I** geotextile fabric shall be placed beneath all riprap and gabions. The fabric shall meet the minimum properties standards as specified in **Appendix A-3**.

9. Rock riprap

Stone used for riprap or gabions shall be dense and hard enough to withstand exposure to air, water, freezing, and thawing.

Riprap shall be composed of a well graded mixture of stone sizes so that 50 percent of the pieces, by weight, are larger than the d50 size determined in the design.

10. Gabion Baskets

Gabions shall be fabricated in such a manner that the sides, ends, and lid can be assembled at the site into a rectangular basket of similar size. Gabions shall be installed according to manufacturers recommendations. Stone size will vary depending on the mesh opening size and thickness of the baskets. A general rule is the minimum stone size should not pass through the mesh opening and the basket should be at least twice the depth of the maximum stone size. Normally a design stone size is determined for a particular application and a gabion basket is selected to meet these criteria.

11. Outlets

Each lined channel shall have a stable outlet. The outlet may be another channel, grade stabilization structure, etc. In all cases, the outlet must discharge in such a manner as not to cause erosion. Outlets shall be constructed and stabilized prior to the operation of the lined channels. Lined channels with velocities exceeding critical shall discharge into an energy dissipator to reduce velocity to less than critical, and to a velocity the downstream soil and vegetative conditions will be stable.

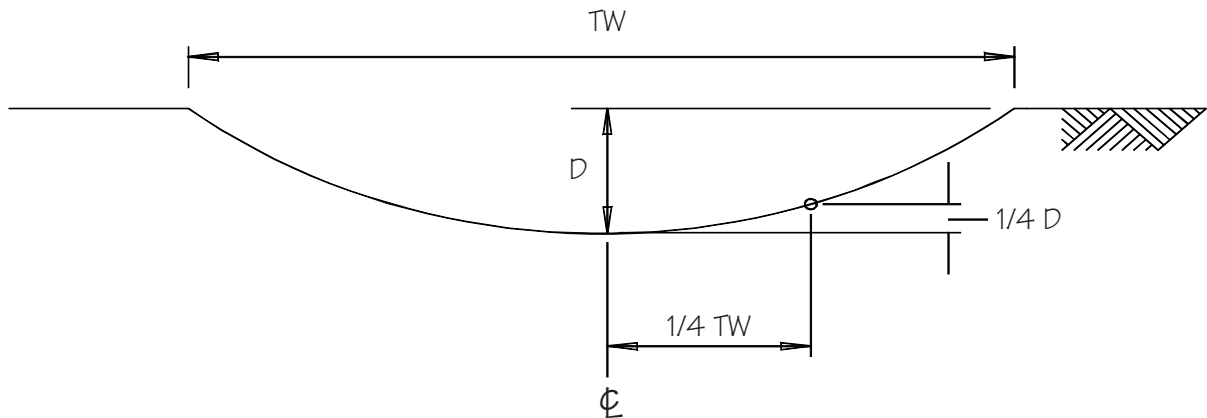
Maintenance

Inspect channels on a regular basis and after any runoff-generating rainfall events. Pay special attention to inlet and outlet sections and other points where concentrated flow enters the channel. Vegetation next to the lining should be maintained in good condition to prevent scouring if out-of-bank flow occurs.

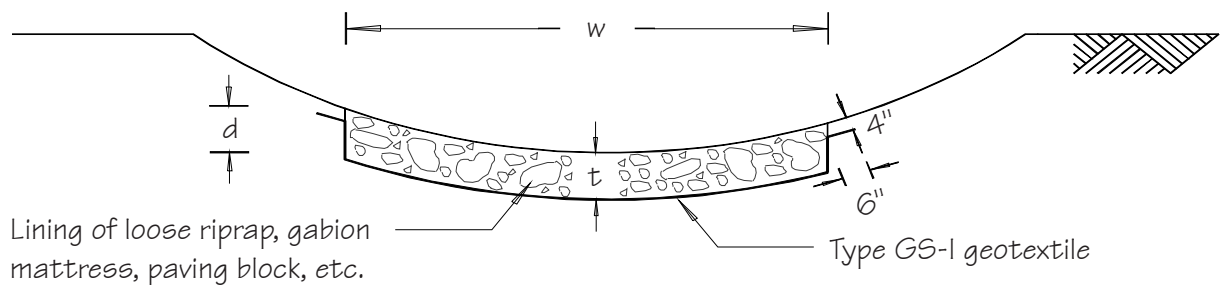
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Standard Detail & Specifications

Lined Channel - Parabolic



Typical Section (Design)



Typical Section (Lining)

DATA

Design discharge (Q_d)

Design topwidth (TW)

Design depth (D)

Width of lining (w)*

Lining flow depth (d)

Thickness of lining (t)*

Median stone size (d_{50})**

*For gabions & reno mattresses,
specify basket dimensions to
be used.

**For paving block, etc., specify size
to be used.

Source:

Adapted from
VA ESC Manual

Symbol:

—— LC/P ——

Detail No.

DE-ESC-3.3.4.1

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Lined Channel - Parabolic

Construction Notes:

1. All trees, brush, stumps, obstructions, and other objectionable material shall be removed and disposed of so as not to interfere with the proper functioning of the waterway.
2. The channel shall be excavated or shaped to line, grade, and cross section as required to meet the criteria specified herein, and be free of bank projections or other irregularities which will impede normal flow.
3. Fills shall be compacted as needed to prevent unequal settlement that would cause damage in the waterway.
4. All earth removed and not needed in construction shall be spread or disposed of so that it will not interfere with the functioning of the waterway.
5. Lining shall be installed to the design dimensions specified on the approved plan. Type GS-I geotextile shall be used on all installations unless specifically approved otherwise. All pre-engineered linings shall be installed in accordance with the manufacturer's recommendations.
6. Lining material shall be as specified on the approved plans with respect to dimension, density, strength, or other criterion so specified.
7. Stabilization shall be done according to the appropriate Standard and Specifications for Vegetative Stabilization.

Source:

Adapted from
VA ESC Manual

Symbol:

—— **LC/P** ——

Detail No.

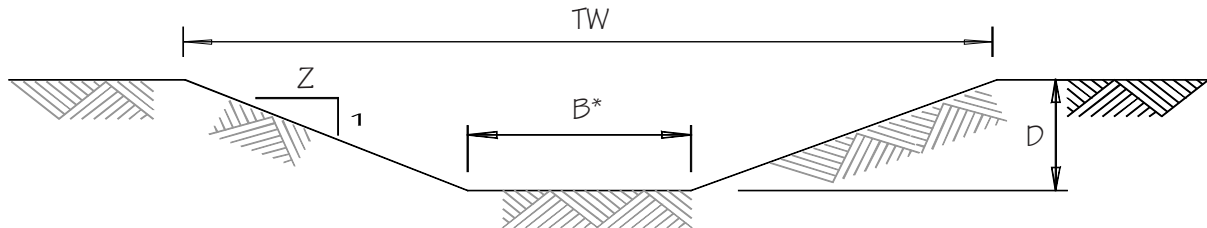
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Sheet 2 of 2

Effective July 2023

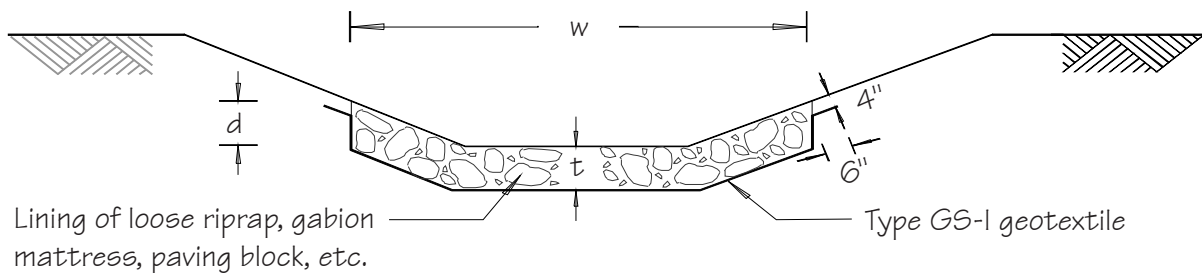
Standard Detail & Specifications

Lined Channel - Triang./Trap.



* $B = 0$ for triangular section

Typical Section (Design)



Typical Section (Lining)

DATA

Design discharge (Q_d)
Design topwidth (TW)
Design depth (D)
Design bottom width (B)
Design sideslope (Z)
Width of lining (w)*
Lining flow depth (d)
Thickness of lining (t)*
Median stone size (d_{50})**

*For gabions & reno mattresses,
specify basket dimensions to
be used.

**For paving block, etc., specify size
to be used.

Source:

Adapted from
VA ESC Manual

Symbol:

———— **LC/T** —————>

Detail No.

DE-ESC-3.3.4.2

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Lined Channel - Triang./Trap.

Construction Notes:

1. All trees, brush, stumps, obstructions, and other objectionable material shall be removed and disposed of so as not to interfere with the proper functioning of the waterway.
2. The channel shall be excavated or shaped to line, grade, and cross section as required to meet the criteria specified herein, and be free of bank projections or other irregularities which will impede normal flow.
3. Fills shall be compacted as needed to prevent unequal settlement that would cause damage in the waterway.
4. All earth removed and not needed in construction shall be spread or disposed of so that it will not interfere with the functioning of the waterway.
5. Lining shall be installed to the design dimensions specified on the approved plan. Type GS-I geotextile shall be used on all installations unless specifically approved otherwise. All pre-engineered linings shall be installed in accordance with the manufacturer's recommendations.
6. Lining material shall be as specified on the approved plans with respect to dimension, density, strength, or other criterion so specified.
7. Stabilization shall be done according to the appropriate Standard and Specifications for Vegetative Stabilization.

Source:

Adapted from
VA ESC Manual

Symbol:

———— **LC/T** —————→

Detail No.

DE-ESC-3.3.4.2

Sheet 2 of 2

Effective July 2023

STANDARD AND SPECIFICATIONS FOR DIVERSION

Definition: A drainage way of parabolic or trapezoidal cross-section with a supporting ridge on the lower side that is constructed across the slope.

Purpose: The purpose of a diversion is to intercept and convey runoff to stable outlets at non-erosive velocities.



Conditions Where Practice Applies

Diversions are generally considered to be permanent structures, but may also be used where the design criteria for temporary earth dikes are exceeded and an engineered design is required. Diversions are used where:

1. Runoff from higher areas is or has potential for damaging properties, causing erosion, or interfering with or preventing the establishment of vegetation on lower areas.
2. Surface and/or shallow subsurface flow is damaging sloping upland.
3. The length of slope needs to be reduced so that soil loss will be reduced to a minimum.

Diversions are to be used only below stabilized or protected areas. Avoid establishment on slopes greater than fifteen percent. Diversions should be used with caution on soils subject to slippage. Designers are cautioned to be aware of local drainage laws and regulations to avoid potential unintended consequences of diverting stormwater runoff to areas that were previously not subject to such flows.

Design Criteria

Diversions are essentially channels which are constructed across a slope. This requires a berm on the downslope side to prevent flow from "kicking out" of the channel. The design for capacity and stability of the channel itself shall be in accordance with the Standard and Specification for Vegetated or Lined Channels. Additional design criteria specific to diversions are as follows:

1. Location

Diversion location shall be determined by considering outlet conditions, topography, land use, soil type, length of slope, seep planes (when seepage is a problem), and the development layout.

Effective July 2023

2. Capacity

A diversion shall have the capacity to carry, as a minimum, the peak discharge from a ten-year frequency rainfall event with freeboard of not less than 0.5 of a foot.

Diversions designed to protect homes, schools, industrial buildings, roads, parking lots, and comparable high risk areas, and those designed to function in connection with other structures, shall have sufficient capacity to carry peak runoff expected from a storm frequency consistent with the hazard involved.

3. Cross Section

The diversion channel shall be parabolic, triangular or trapezoidal in shape. The diversion shall be designed to have stable side slopes. The side slopes shall not be steeper than 3:1 and shall be flat enough to insure ease of maintenance of the diversion and its protective vegetative cover.

The berm shall have a minimum width of four feet at the design water elevation; a minimum of 0.5 foot freeboard and a 10% settlement factor shall be provided.

4. Velocity and Grade

The design velocity for the specified method of stabilization will determine the maximum grade. Maximum permissible velocities of flow for the stated conditions of stabilization shall be as determined in accordance with the Standard and Specifications for Vegetated or Lined Channels.

The use of diversions below high sediment producing areas is not acceptable unless land treatment practices or structural measures designed to prevent damaging accumulations of sediment in the channels are installed with or before the diversions.

5. Outlets

Each diversion must have an adequate outlet. The outlet may be a stable channel, vegetated or paved area, grade stabilization structure, stable watercourse, or pipe outlet. In all cases the outlet must convey runoff to a point where outflow will not cause damage. Vegetated outlets shall be installed before diversion construction, if needed, to insure establishment of vegetative cover in the outlet channel.

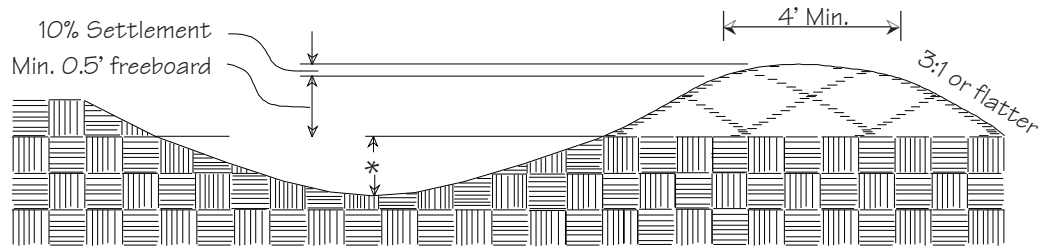
The design elevation of the water surface in the diversion shall not be lower than the design elevation of the water surface in the outlet at their junction when both are operating at design flow.

6. Stabilization

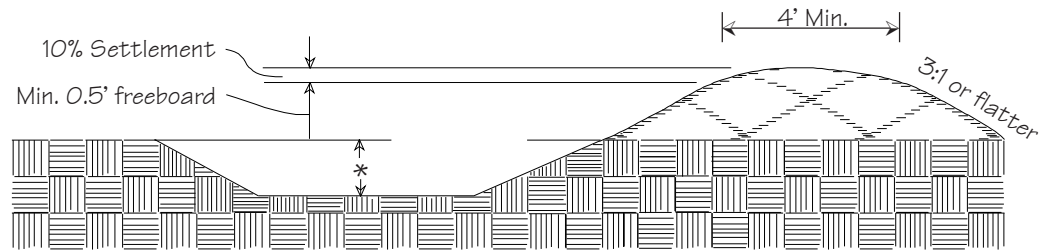
Diversions shall be stabilized in accordance with the appropriate Standard and Specifications for Vegetative Stabilization.

Standard Detail & Specifications

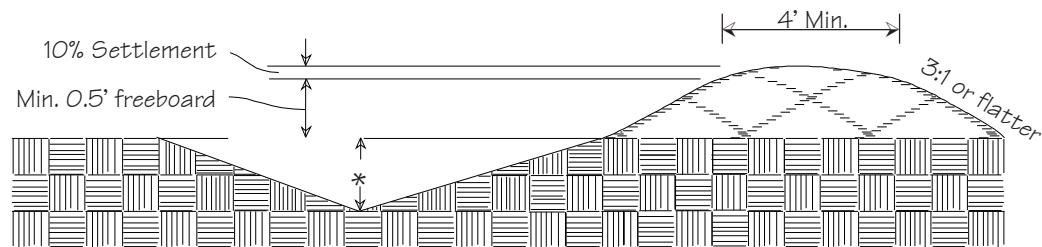
Diversion



Typical Section (Parabolic)



Typical Section (Trapazoidal)



Typical Section (Triangular)

*Flow section to be designed and constructed in accordance with Standard & Specification for Vegetated Channel or Lined Channel. (See separate detail.)

Source:

Adapted from
VA ESC Handbook

Symbol:

—(VC/LC)- (P/T)—
— D —

Detail No.

DE-ESC-3.3.5

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Diversion

Construction Notes

1. All trees, brush, stumps, obstructions, and other objectionable material shall be removed and disposed of so as not to interfere with the proper functioning of the diversion.
2. The diversion shall be excavated or shaped to line, grade, and cross section as required to meet the criteria specified herein, and be free of irregularities which will impede normal flow.
3. Fills shall be compacted as needed to prevent unequal settlement that would cause damage in the completed diversion.
4. All earth removed and not needed in construction shall be spread or disposed of so that it will not interfere with the functioning of the diversion.
5. Flow section shall be installed in accordance with the Standard and Specifications for Vegetated Channel or Lined Channel, as appropriate.
6. Stabilization shall be done according to the appropriate Standard and Specifications for Vegetative Stabilization.

Source:

Adapted from
VA ESC Handbook

Symbol:

—(VC/LC)- (P/T)—→
— D —→

Detail No.

DE-ESC-3.3.5

Sheet 2 of 2

Effective July 2023

STANDARD AND SPECIFICATIONS FOR CHECK DAMS

Definition: Small dams constructed across a swale or channel which act as grade control structures.



Purpose: To reduce the velocity of concentrated flows, thereby reducing erosion of the swale or channel. Although this practice may also trap small amounts of sediment generated in the swale or channel, it is not intended to be a sediment trapping practice and should not be used as such.

Conditions Where Practice Applies

This practice is limited for use in small open channels where it is necessary to slow the velocity of flows in order to prevent erosion. Check dams may be installed as temporary structures during the construction phase or may remain as permanent stormwater management structures. They should not be used in a free flowing stream. Some specific applications include:

1. Temporary swales or channels which, because of their short length of service, cannot receive a non-erodible lining but still need some protection to reduce erosion.
2. Permanent swales or channels which for some reason cannot receive a permanent non-erodible lining for an extended period of time.
3. Either temporary or permanent swales or channels which need protection during the establishment of grass linings.

Planning Considerations

The location of check dams shall provide for maximum velocity reduction. The check dams should be placed in reasonably straight sections of the swale or channel in order to minimize the potential for erosion due to curves in the swale or channel.

If temporary check dams are used in grass-lined swales or channels which will be mowed, care should be taken to remove all the stone when the check dam is removed.

Design Criteria

Check dam spacing is based on the following equation: $X = Y / S$

Where: X = Max. check dam spacing (ft)

Y = Check dam height (ft)

S = Channel slope (ft/ft)

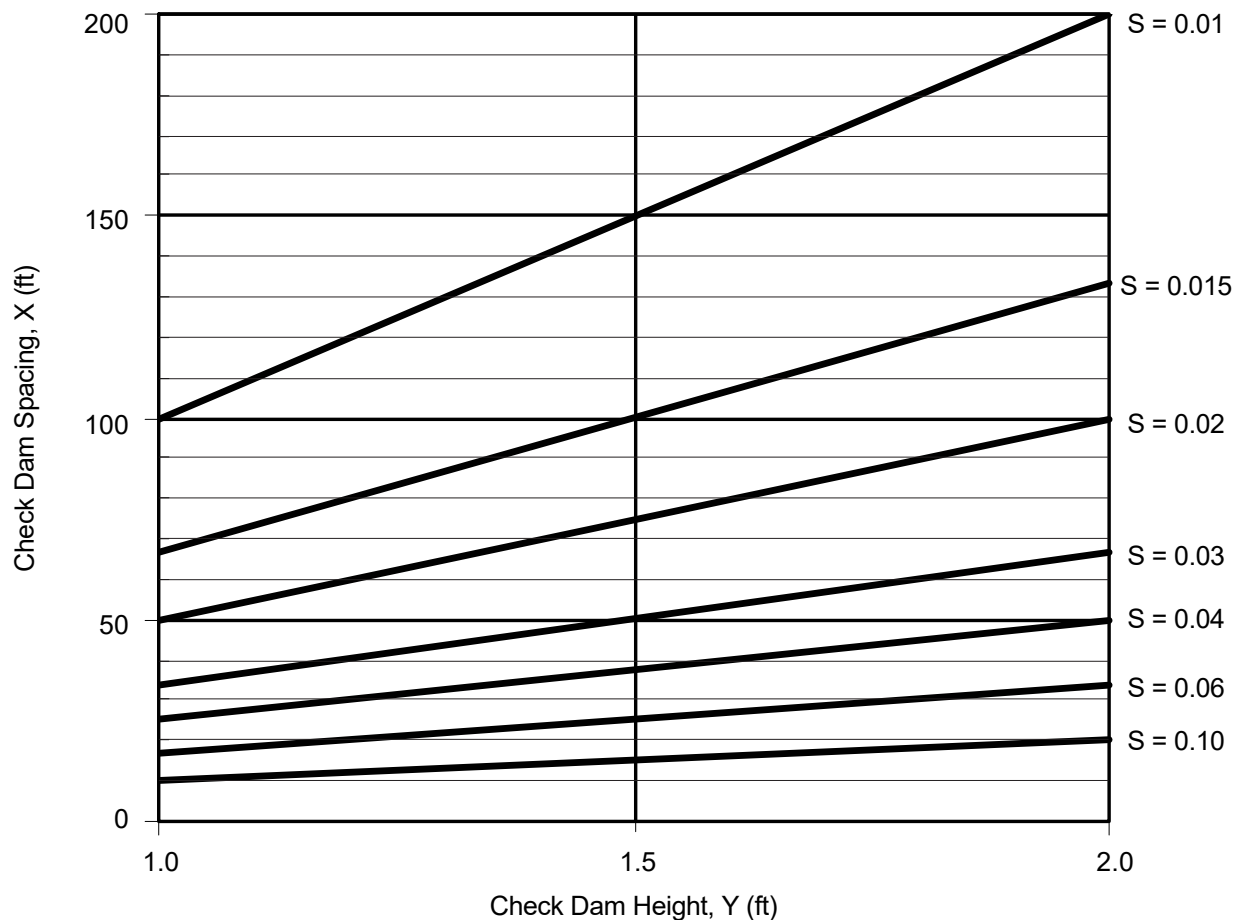


Figure 3.3.6a Check Dam Spacing Chart ($X = Y/S$)

Figure 3.3.6a can be used to solve the check dam spacing equation within the range of typical designs. A maximum spacing of 200 ft. should be used for slopes less than 1.0%. Check dams are not practical on slopes greater than 10%. Alternative designs, such as chutes or lined channels, should be explored for these situations.

Materials

Check dams may be constructed from a variety of materials, including wood, concrete, articulated block, etc. However, most applications in erosion and sediment control will make use of stone or compost logs.

Maintenance

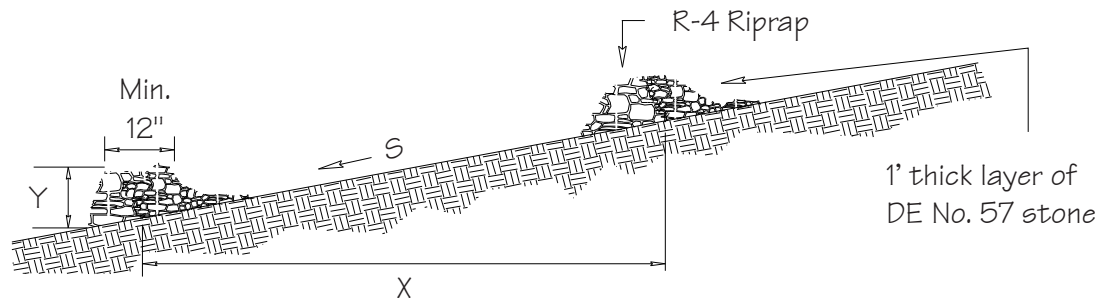
Check dams should be checked for sediment accumulation after each significant rainfall. Sediment should be removed when it reaches one half of the original height or before.

Removal

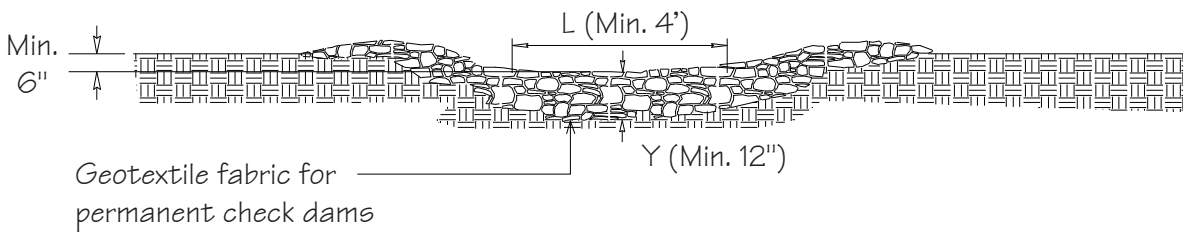
In temporary swales and channels, check dams should be removed and the ditch filled in when it is no longer needed. In permanent structures, temporary check dams may be removed when a permanent lining can be installed. In the case of grass-lined ditches, temporary check dams may be removed when the grass has matured sufficiently to protect the swale or channel. The area beneath the check dams should be seeded and mulched immediately after they are removed.

Standard Detail & Specifications

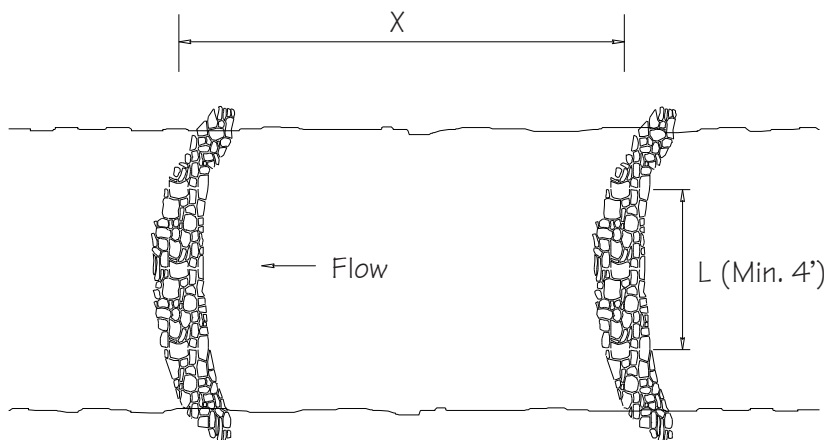
Stone Check Dam



Profile



Section



Plan

DATA

Slope (S)
Spacing (X)
Length of weir (L)
Height of stone (Y)

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:

SCD

Detail No.

DE-ESC-3.3.6.1

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Stone Check Dam

Construction Notes:

1. Swales and channels shall be prepared in accordance with the construction specifications described in the **Standards and Specifications for Temporary Berm, Temporary Swale, Vegetated Channel, or Diversions**.
2. The check dam shall be constructed of 4" to 8" riprap. The riprap shall be placed so that it completely covers the width of the channel.
3. The top of the check dam shall be constructed so that the center is approximately 6" lower than the outer edges, forming a weir that the water can flow across. The minimum length of weir shall be 4'.
4. The maximum height of the check dam at the center of the weir must not exceed two (2) feet.
5. Maximum spacing between dams should be the distance in the channel where the toe of the upstream dam is at the same elevation as the top of the downstream dam. (See **Standard & Specifications for Check Dams** for design chart.)

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:



Detail No.

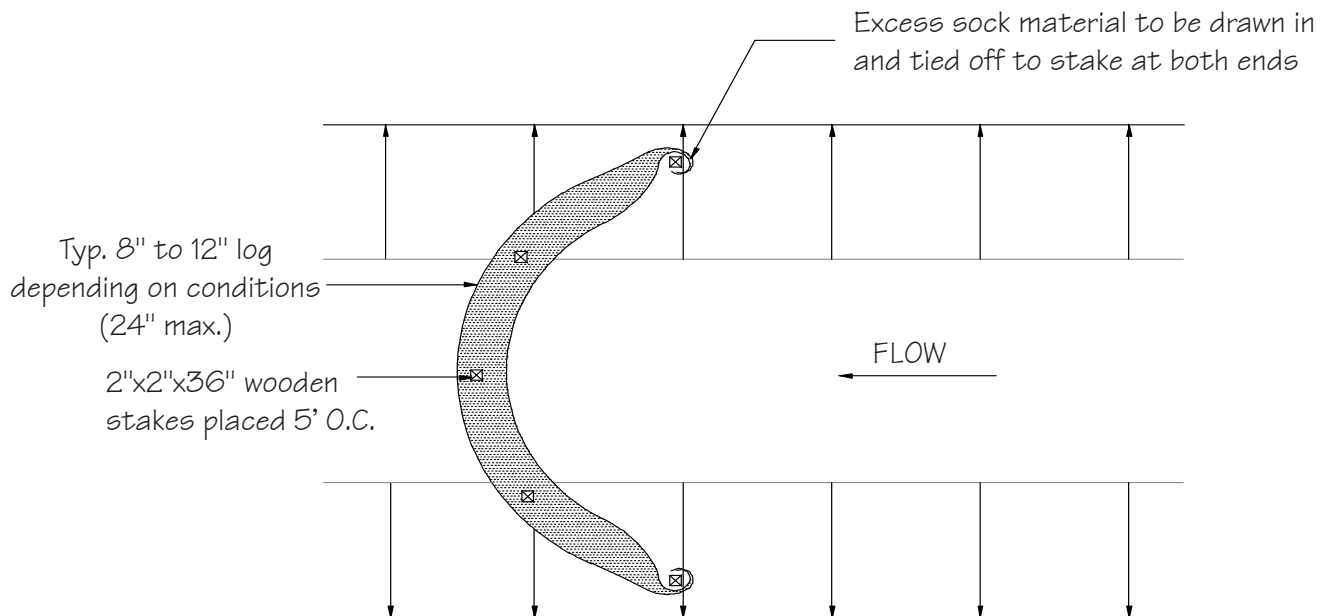
DE-ESC-3.3.6.1

Sheet 2 of 2

Effective July 2023

Standard Detail & Specifications

Compost Log Check Dam



Plan

DATA

Slope (S)
Spacing (X)
Log diameter (D)

Source:

Adapted from
FILTREXX Technologies

Symbol:

CCD

Detail No.

DE-ESC-3.3.6.2

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Compost Log Check Dam

Construction Notes:

1. Swales and channels shall be prepared in accordance with the construction specifications described in the **Standards and Specifications for Temporary Berm, Temporary Swale, Vegetated Channel, or Diversions**.
2. The check dam shall be constructed of compost filter log. The compost filter log shall be placed so that it extends across the full width of the channel.
3. The top of the check dam shall be constructed so that the center is approximately 6" lower than the outer edges, forming a weir that the water can flow across. The ends of the compost filter log shall wrap upslope to prevent end cutting.
4. The maximum height of the check dam at the center of the weir must not exceed two (2) feet.
5. Maximum spacing between dams should be the distance in the channel where the toe of the upstream dam is at the same elevation as the top of the downstream dam. (See **Standard & Specifications for Check Dams** for design chart.)

Source:

Adapted from
FILTREXX Technologies

Symbol:



Detail No.

DE-ESC-3.3.6.2

Sheet 2 of 2

Effective July 2023

STANDARD AND SPECIFICATIONS FOR SUBSURFACE DRAIN

Definition: A perforated conduit or pipe installed below the ground surface which intercepts, collects and conveys excess water to a suitable outlet.



Purpose: A subsurface drain may serve one or more of the following purposes:

1. Improve the environment for vegetative growth by regulating the water table and groundwater flow into channels and other BMP's.
2. Intercept and prevent water movement into a wet area.
3. Relieve artesian pressures.
4. Remove surface runoff.
5. Provide internal drainage of slopes to improve their stability and reduce erosion.
6. Provide internal drainage behind bulkheads, retaining walls, etc.
7. Replace existing subsurface drains that are interrupted or destroyed by construction operations.
8. Provide subsurface drainage for dry stormwater management structures.
9. Improve dewatering of sediment in sediment basins. (See Standard and Specifications for Sediment Basins.)

Conditions Where Practice Applies

Subsurface drains are used in areas having a high water table or where subsurface drainage is required. The soil shall have enough depth and permeability to permit installation of an effective system. This standard does not apply to storm drainage systems or foundation drains.

An outlet for the drainage system shall be available, either by gravity flow or by pumping. The outlet shall be adequate for the quantity of water to be discharged without causing damage above or below the point of discharge and shall comply with all state and local laws.

Design Criteria

The design and installation shall be based on adequate surveys and on-site soils investigations. From a

functional standpoint, subsurface drainage generally falls into two classes: relief and interception drainage. Relief drainage is used to lower a high water table which is generally flat or of very low gradient. As such, relief drains should be located through or near the center of the problem area and should drain in the same general direction as the slope. Interception drainage is used to intercept, reduce the flow, and lower the flowline of the water in the problem area and is particularly applicable for controlling seeps and springs. Interceptor drains should be located on the uphill side of the problem area and should be installed across the slope and drain to the side of the slope.

Typical layouts for subsurface drainage collection systems are shown in Figure 3.3.7a. Such systems shall have a site specific plan showing the appropriate details. The Standard Detail for Channel Drain may be used where subsurface drainage is needed to establish/maintain vegetative cover in a channel under high water table and/or groundwater inflow conditions.

Required Capacity of Drains

The required capacity shall be determined by one or more of the following:

- 1. Where subsurface drainage is to be uniform over an area through a systematic pattern of relief drains, a drainage coefficient of 1 inch to be removed in 24 hours shall be used. (See Drain Charts)
- 2. Where subsurface drainage is to be by random interceptor system or for channel drains, a minimum inflow rate of 0.5 cfs per 1,000 feet of line shall be used to determine the required capacity. If actual field tests and measurements of flow amounts are available, they may be used for determining capacity.

For interceptor subsurface drains on sloping land, increase the inflow rate as follows:

<u>Land Slopes</u>	<u>Increase Inflow Rate By</u>
2-5 percent	10 percent
5-12 percent	20 percent
Over 12 percent	30 percent

- 3. Additional design capacity must be provided if surface water is allowed to enter the system.

Size of Subsurface Drain

The size of subsurface drains shall be determined from the Drain Charts found at the end of this section. Figure 3.3.7d is for corrugated plastic tubing and Figure 3.3.7e is for PVC and other smooth-type pipe. The minimum diameter for a subsurface drain shall be four (4) inches.

Depth and Spacing

The minimum depth of cover of subsurface drains shall be 24 inches where possible. The minimum depth of cover may be reduced to 15 inches where it is not possible to attain the 24 inch depth and where the drain is not subject to equipment loading or frost action. Roots from some types of vegetation can plug drains as the drains get closer to the surface.

For channel drain installations, the drain should be offset from the channel centerline at least one-fourth of the top width distance. In some situations, it may be necessary to install two drains, one on either side of the channel centerline. The spacing of drain laterals in a collection system will be dependent on the permeability of the soil, the depth of installation of the drains and degree of drainage required. Generally, drains installed 36

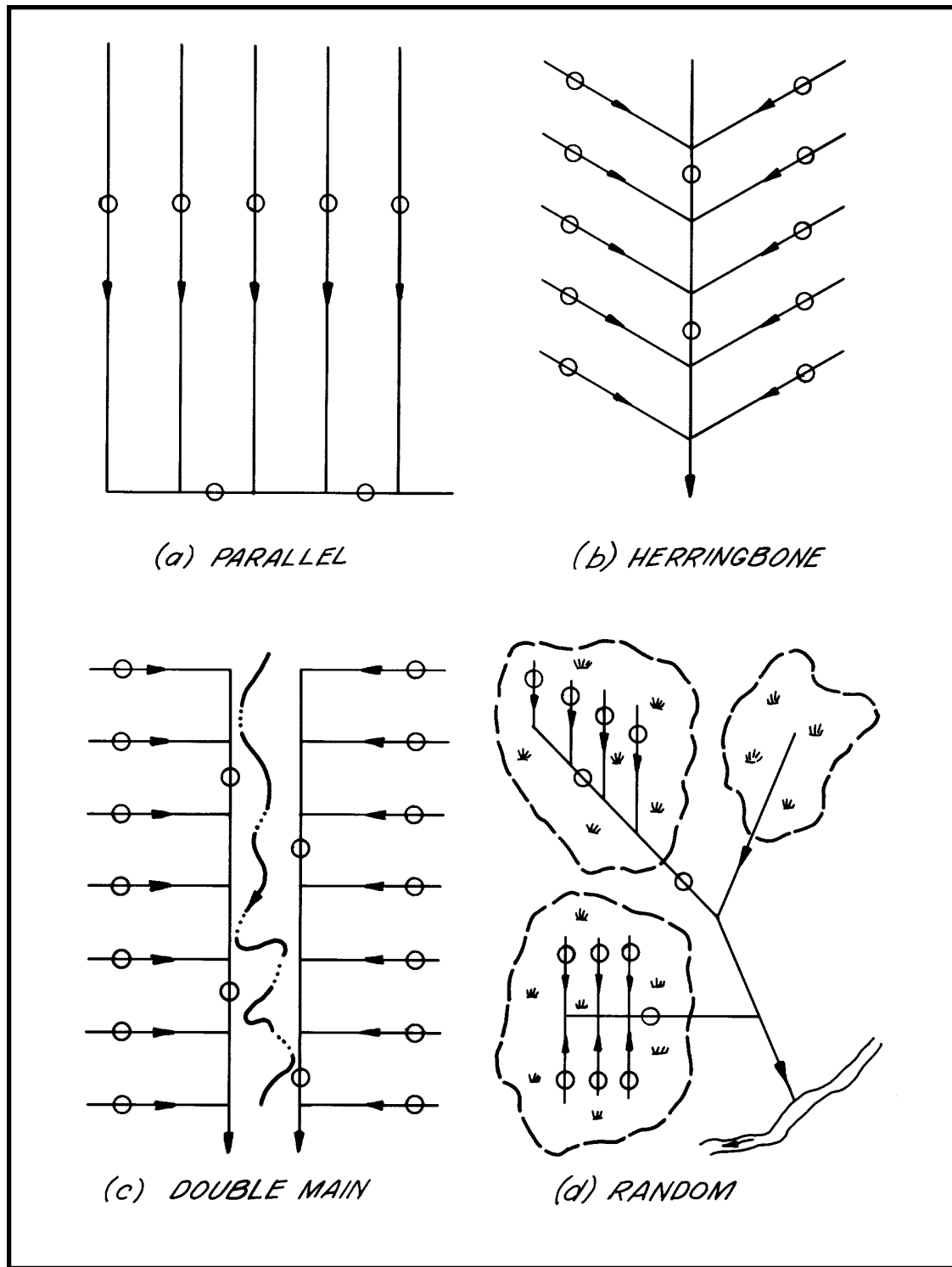


Figure 3.3.7a Typical Subsurface Drain Layout Patterns
 (Source: NRCS, National Engineering Handbook, Sect. 16)

inches deep and spaced 50 feet center-to-center will be adequate. However, this should be verified using the following design methodologies.

1. Relief drains

The ellipse equation is used extensively in the Mid-Atlantic region to determine proper spacing of relief drains. Limitations in its use are contained in Section 16 of NRCS's National Engineering Handbook. The variables used in the equation are shown graphically in Figure 3.3.7b. The equation, itself, is as follows:

$$S = \sqrt{\frac{4k (M^2 + AM)}{q}}$$

Where: S = drain spacing (ft)

k = avg. hydraulic conductivity or permeability (in./hr)

M = vertical distance, after drawdown, of water table above drain at mid-point between lines (ft)

A = depth of barrier below drain (ft)

q = drainage coefficient or rate of water removal (in./hr)

2. Interceptor drains

When it is necessary to install more than one interceptor drain, empirical equations have been developed for the required spacing based on the assumption that the hydraulic gradient of the undisturbed water table is in the range of 0.1 to 0.3 ft/ft or greater. Where the gradient is less than this the drain functions more like a relief drain and spacing may be computed using the ellipse equation. The variables used in the equation for interceptor drain spacing are shown graphically in Figure 3.3.7c. The interceptor drain spacing equation is:

$$L_e = \frac{ki}{q} (d_e - d_w + w_2)$$

Where: L_e = distance downslope from the drain to the point where the water table is at the desired depth after drainage (ft)

k = avg. hydraulic conductivity or permeability (in./hr)

i = hydraulic gradient of the water table prior to drainage (ft/ft)

q = drainage coefficient (in./hr)

d_e = effective depth of the drain (ft)

d_w = desired min. depth to water table after drainage (ft)

w_2 = distance from the ground surface to the water surface table, before drainage, at the distance L_e downslope from the drain (ft)

In the equation above, L_e and w_2 interdependent variables. Therefore, the solution requires an iterative process in which an estimated value of w_2 is used to compute a trial value of L_e . If the actual value of w_2 at distance L_e is outside tolerable limits, another iteration is indicated.

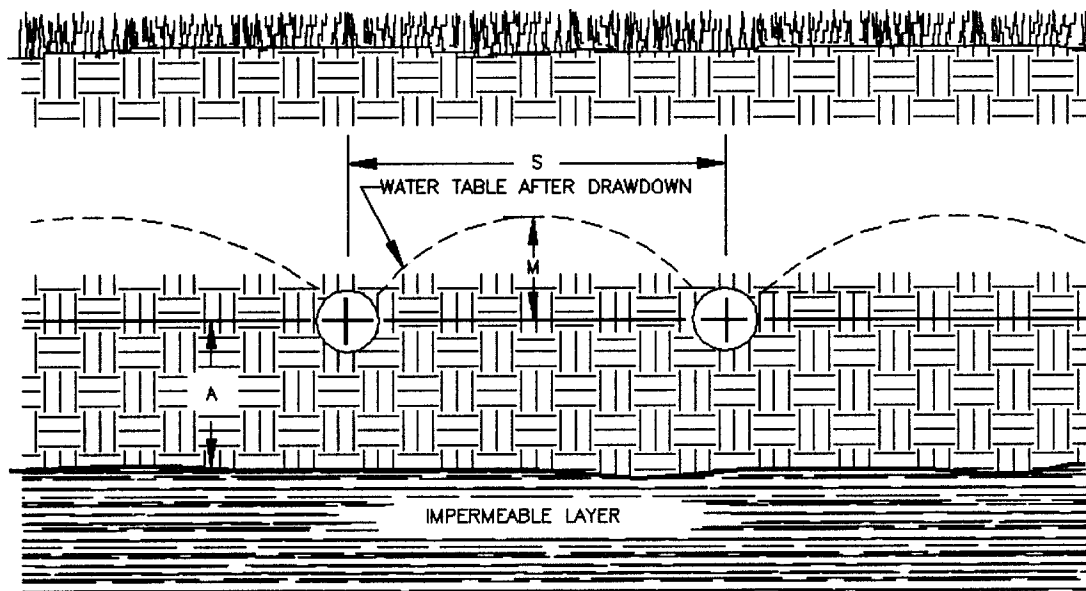


Figure 3.3.7b Terminology used in spacing of relief drains.

Source: VAE&S Handbook

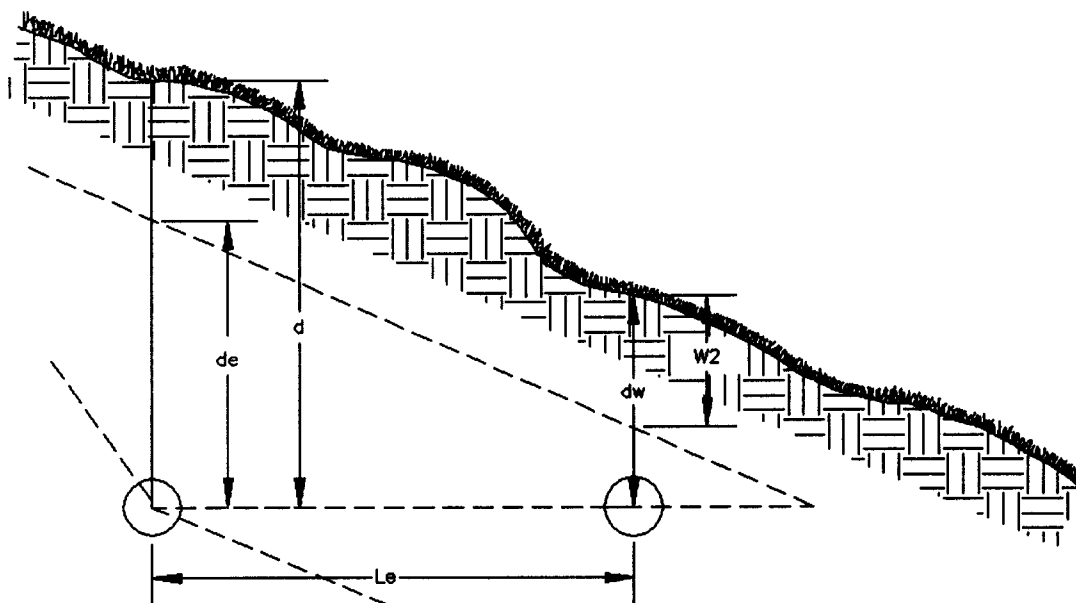


Figure 3.3.7c Terminology used in spacing of interceptor drains.

Source: VAE&S Handbook

Minimum Velocity and Grade

The minimum grade for subsurface drains shall be 0.10 percent. Where surface water enters the system a velocity of not less than 2 feet per second shall be used to establish the minimum grades. Provisions shall be made for preventing debris or sediment from entering the system by means of filters or collection and periodic removal of sediment from installed traps.

Materials for Subsurface Drains

Acceptable subsurface drain materials include perforated, continuous closed joint conduits of corrugated plastic, corrugated concrete, corrugated metal, bituminized fiber and polyvinyl chloride.

The conduit shall meet strength and durability requirements of the site.

Loading

The allowable loads on subsurface drain conduits shall be based on the trench and bedding conditions specified for the job. A factor of safety of not less than 1.5 shall be used in computing the maximum allowable depth of cover for a particular type of conduit.

Envelopes and Envelope Materials

Envelopes shall be used around subsurface drains for proper bedding and to provide better flow into the conduit. Not less than three inches of envelope material shall be used for sand-gravel envelopes. Where necessary to improve the flow of groundwater into the conduit, more envelope material may be required.

Envelope material shall be placed to the height of the uppermost seepage strata. Behind bulkheads and retaining walls, it shall go to within twelve inches of the top of the structure. This standard does not cover the design of filter materials where needed. Envelope materials shall consist of either filter cloth or DE #8 aggregate.

The filter cloth envelope can be either woven or nonwoven monofilament yarns and shall have a sieve opening ranging from 40-80. The envelope shall be placed in such a manner that once the conduit is installed, it shall completely encase the conduit.

The conduit shall be placed and bedded in a sand-gravel envelope. A minimum of three inches depth of envelope materials shall be placed on the bottom of a conventional trench. The conduit shall be placed on this and the trench completely filled with envelope material to minimum depth of 3 inches above the conduit.

Soft or yielding soils under the drain shall be stabilized where required and lines protected from settlement by adding gravel or other suitable material to the trench, by placing the conduit on a plank or other rigid support, or by using long sections of perforated or watertight pipe with adequate strength to insure satisfactory subsurface drain performance.

Use of Heavy Duty Corrugated Plastic Drainage Tubing

Heavy duty corrugated plastic drainage tubing shall be specified where rocky or gravelly soils are expected to

be encountered during installation operations. The quality of tubing will also be specified when cover over this tubing is expected to exceed 24 inches for 4, 5, 6, or 8-inch tubing. Larger size tubing designs will be handled on an case by case basis.

Auxiliary Structure and Subsurface Drain Protection

The outlet shall be protected against erosion, undermining of the conduit, damaging periods of submergence and entry of rodents or other animals into the subsurface drain. An animal guard shall be installed on the outlet end of the pipe.

A continuous 10-foot section of corrugated metal, cast iron, PVC, or steel pipe without perforations shall be used at the outlet end of the line and shall outlet 1.0 foot above the normal elevation of low flow in the outlet ditch or mean high tide in tidal areas. No envelope material shall be used around the 10-foot section of pipe. Two-thirds of the pipe shall be buried.

Conduits under roadways and embankments shall be watertight and designed to withstand the expected loads.

Where surface water enters subsurface drains, inlets shall be designed to exclude debris and prevent sediment from entering the conduit. Lines flowing under pressure shall be designed to withstand the resulting pressures and velocity of flow. Surface waterways shall be used where feasible.

The upper end of each subsurface drain line shall be capped with a tight fitting cap of the same material as the conduit or other durable material unless connected to a structure or cleanout.

DRAINAGE CHART (Corrugated Plastic Tubing)

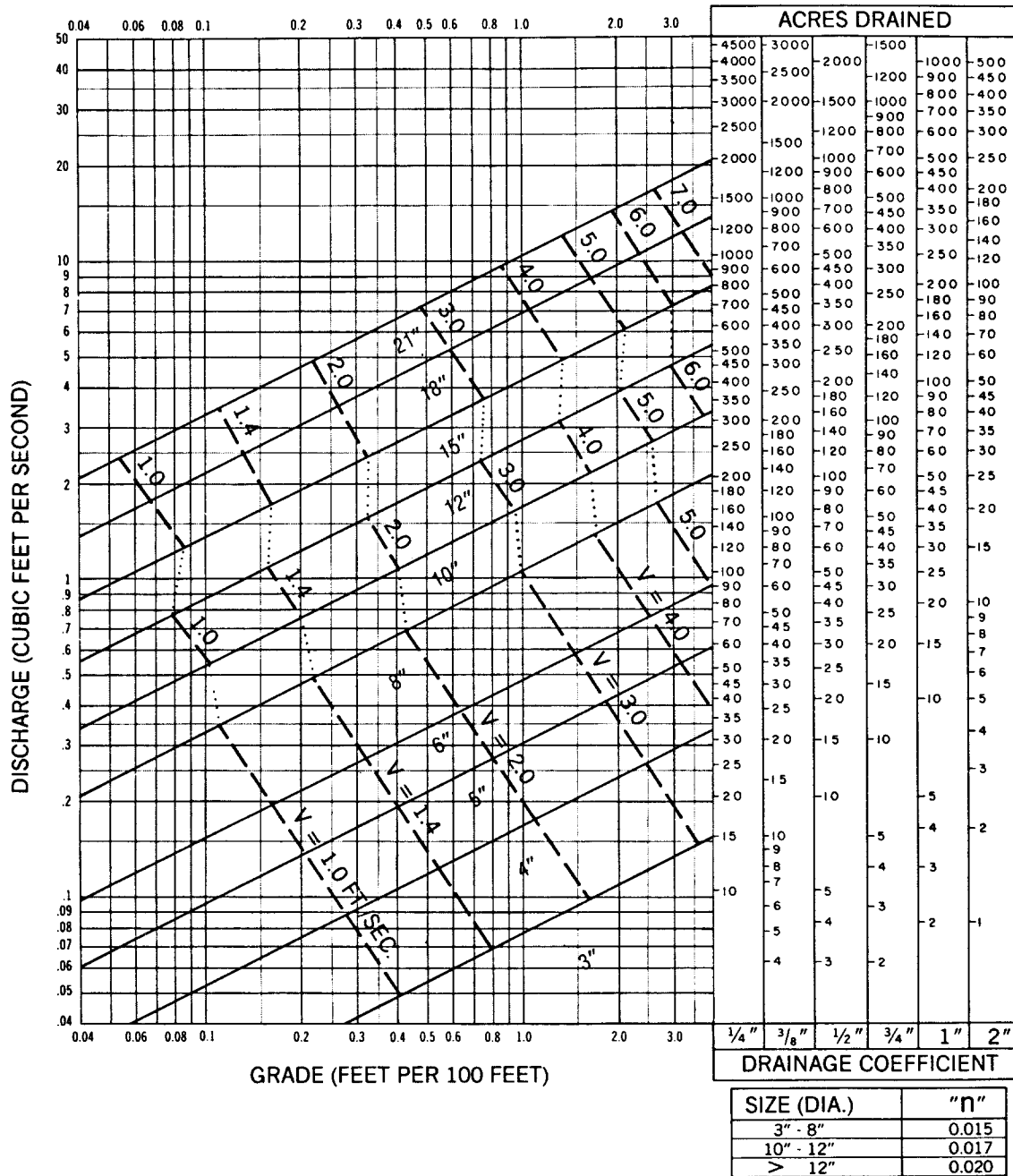


Figure 3.3.7d Drainage chart for corrugated plastic tubing
Source: NRCS, Engineering Field Manual, Chapter 14

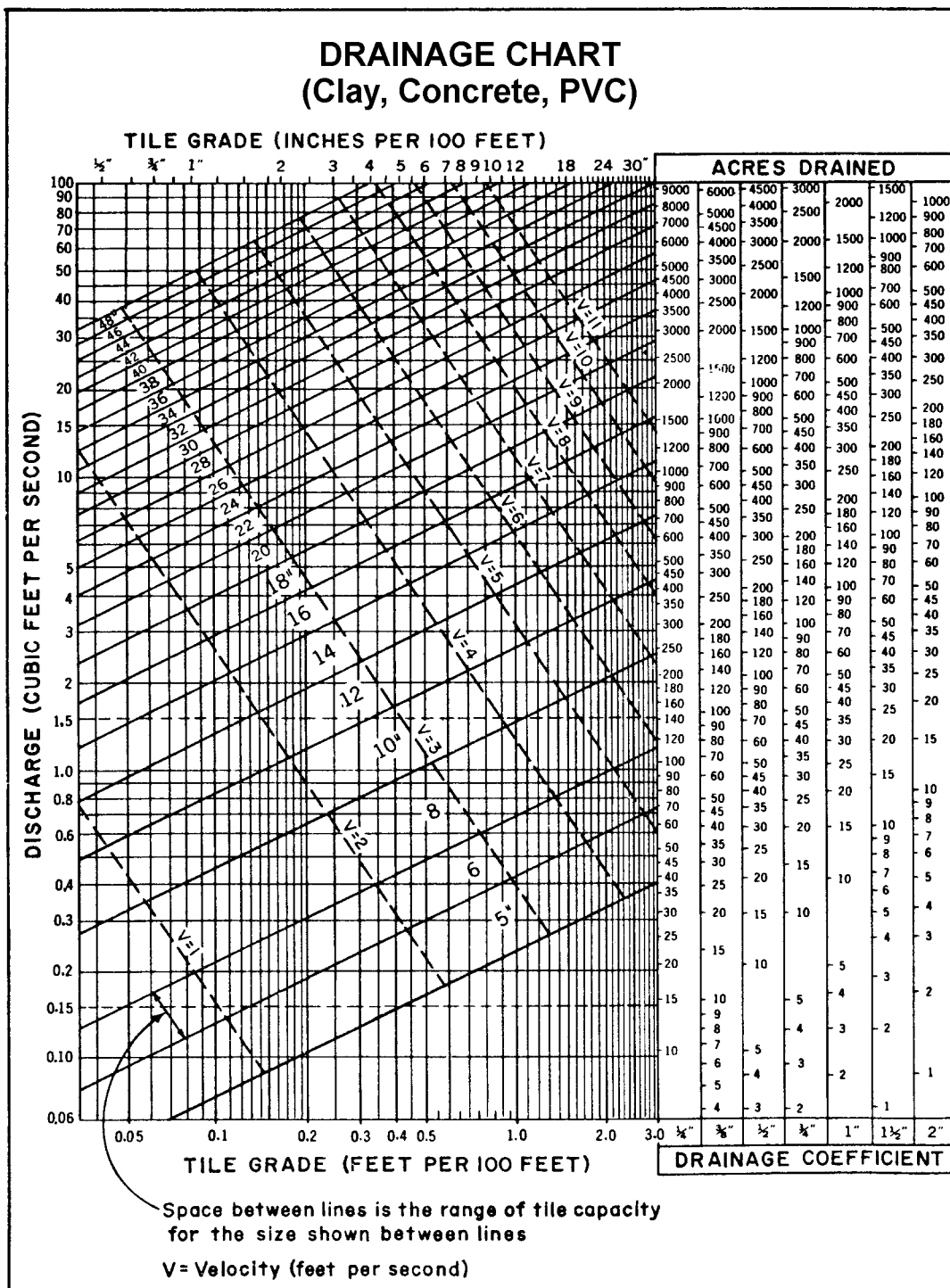


Figure 3.3.7e Drainage chart for clay, concrete and PVC pipe
Source: NRCS, Engineering Field Manual, Chapter 14

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STANDARD AND SPECIFICATIONS FOR PIPE SLOPE DRAIN

Definition: A temporary pipe structure placed from the top of a slope to the bottom of a slope.

Purpose: To convey surface runoff down slopes without causing erosion.



Conditions Where Practice Applies:
Used where concentrated flow of surface runoff must be conveyed down a slope in order to prevent erosion. The maximum allowable drainage area shall be 5 acres.

Design Criteria for Pipe Drop Structure:

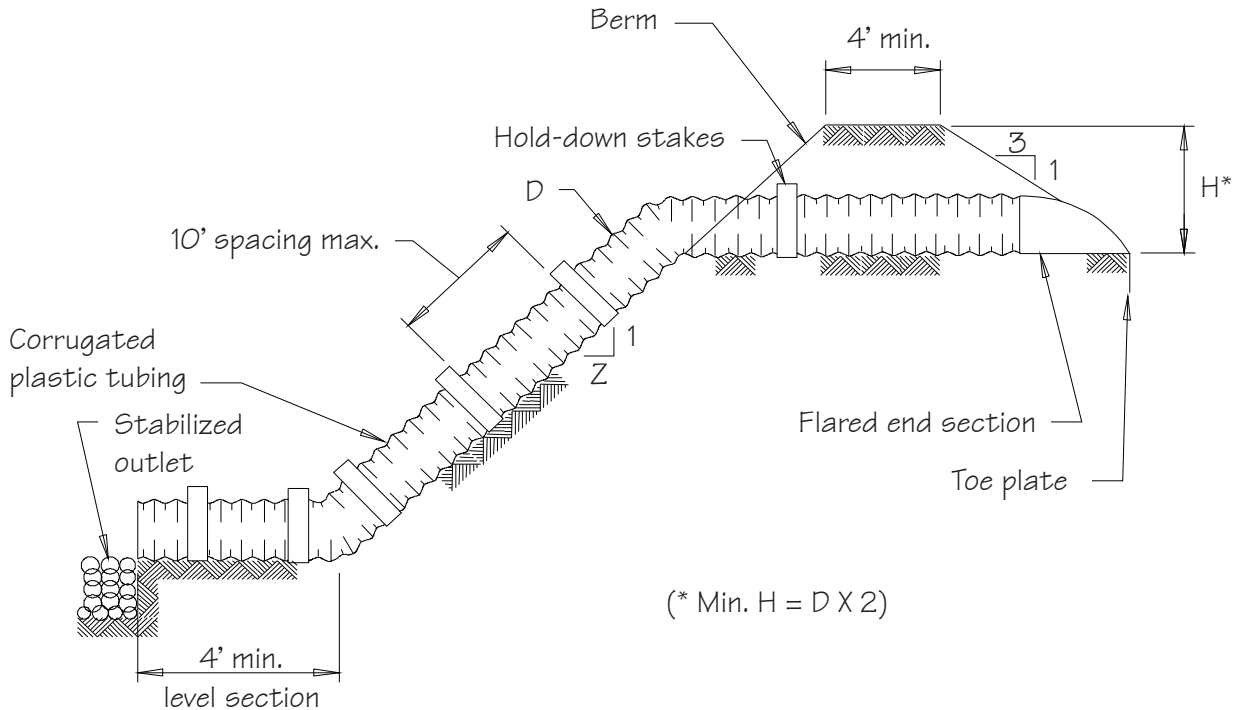
Size	Pipe/Tubing Diameter D (in)	Maximum Drainage Area (Acres)
PSD-12	12	0.5
PSD-18	18	1.5
PSD-21	21	2.5
PSD-24	24	3.5
PSD-30	30	5.0

Outlet
A riprap apron underlain with geotextile shall be installed below the pipe outlet where clean water is being discharged into a stabilized area. The pipe slope drain shall outlet into a sediment trapping device when the drainage area is disturbed. Where a pipe drop structure outlets into a sediment trapping device, it shall discharge at the riser crest or weir elevation.

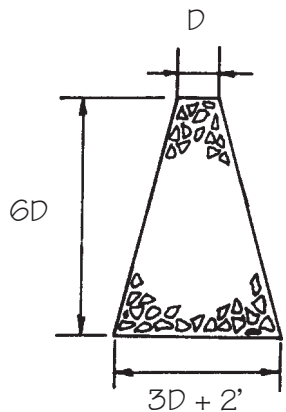
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Standard Detail & Specifications

Pipe Slope Drain



Profile



NOTE: Stabilized outlet to be underlain with GS-1 geotextile

DATA

Contributing D.A.
Height of berm (H)
Pipe diameter (D)

Stabilized Outlet Detail

Source:

Adapted from
IL Urban Manual

Symbol:

— PSD-(Dia.) —→

Detail No.

DE-ESC-3.3.8

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Pipe Slope Drain

Construction Notes:

1. The top of the earth berm over the inlet pipe and those berms carrying water to the pipe shall be at least 2X the pipe diameter at all points. Earth berm side slopes steeper than 3:1 shall have stabilization blanket applied.
2. Flexible tubing is preferred. (Alternate materials must receive prior approval.) All connections shall be made with watertight connecting bands.
3. A flared end section shall be attached to the inlet end of the pipe with a watertight connection.
4. The flexible tubing shall be securely anchored to the slope by hold-down stakes spaced 10' on centers. In no case shall less than two (2) anchors be provided.
5. A riprap apron shall be provided at the outlet. This shall consist of R-4 riprap placed as shown on the Standard Detail and underlain with GS-1 geotextile.
6. The soil around and under the inlet pipe and entrance section shall be hand tamped in 4" increments to the top of the earth dike.
7. Follow-up inspection and any needed maintenance shall be performed after each storm.

MAXIMUM DRAINAGE AREA: 5 ACRES

Source: Adapted from IL Urban Manual	Symbol: 	Detail No. DE-ESC-3.3.8 Sheet 2 of 2 Effective July 2023
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STANDARD AND SPECIFICATIONS FOR CHUTE

Definition: A structure used to control the grade and head cutting in a channel.

Purpose: To stabilize the grade and control erosion in a channel to prevent the formation or advance of gullies.



Conditions Where Practice Applies:

In areas where the concentration and flow velocity require structures to safely convey water from a higher elevation to a lower elevation in a relatively short, steep channel section. Flow coming into a chute is typically contained in a channel. The chute itself may discharge to the same channel at a lower elevation, act as a side-inlet to another channel, or discharge into a body of water such as a sediment trap, pond or stream.

Scope:

This standard shall be limited to chutes which fall under the design criteria stated below. For situations which exceed these criteria, the chute shall have a site-specific design in accordance with the procedures contained in the NRCS National Engineering Handbook, Section 14 or similar guidance.

Design Criteria:

Chutes are essentially channels on very steep slopes. Because of this, the forces of momentum, gravity, and friction play a more important role in their stability as compared to a channel on a mild slope. A chute under this standard and specification having a flexible lining shall be designed in accordance with the tractive force method.

Design Guide 1 outlines the recommended procedure for this methodology.

The hydraulic design of the chute shall be based on the design discharge of the incoming channel. The configuration of the chute itself shall include a transition section for both the incoming and outgoing flow.

Outlet:

The outlet is the most critical component of a chute since it is subjected to the maximum forces associated with the flow. As such, the designer should give serious consideration to providing an energy dissipating structure, such as a stilling basin, at the outlet of the chute. As a minimum, an armored transition section must be provided to protect against impact and scour. The armoring should extend far enough to ensure the flow can transition to the receiving channel or water body in a non-erosive manner.

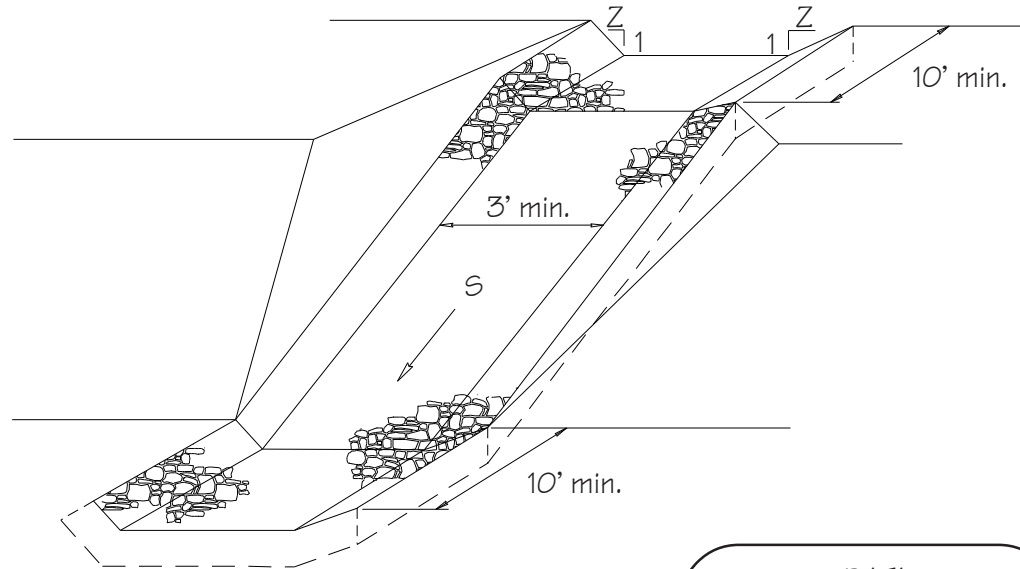
Maintenance:

Periodic visual inspection is crucial for chutes since a failure can lead to severe gully erosion and head-cutting in a very short time. The chute should be checked for signs of failure in the lining as well as evidence of scour between the lining and vegetated areas. If found, repairs should be made immediately.

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Standard Detail & Specifications

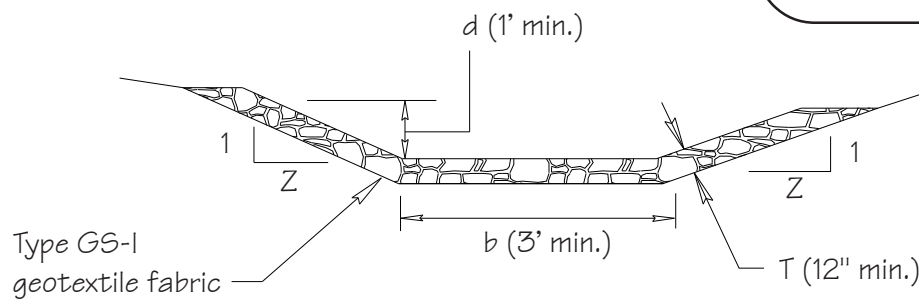
Riprap Chute



Perspective

DATA

Design discharge (Q)
Bottom width (b)
Side slope (Z)
Depth (d)
Riprap size (d_{50})
Riprap thickness (T)
Slope (s)



Typical Section

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:

— RRC —→

Detail No.

DE-ESC-3.3.9.1

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Riprap Chute

Construction Notes:

1. Riprap chutes shall have a trapezoidal cross section with side slopes of 2:1 or flatter. Minimum flow depth shall be 1' with a minimum bottom width of 3'.
2. Entrance and exit aprons shall be provided as transition areas. Aprons shall be a minimum of 10' in length.
3. The riprap layer thickness shall be $1.5 \times D_{max}$, with a minimum of 12".
4. All riprap shall be underlain with Type GS-I geotextile fabric.

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:

— **RRC** —→

Detail No.

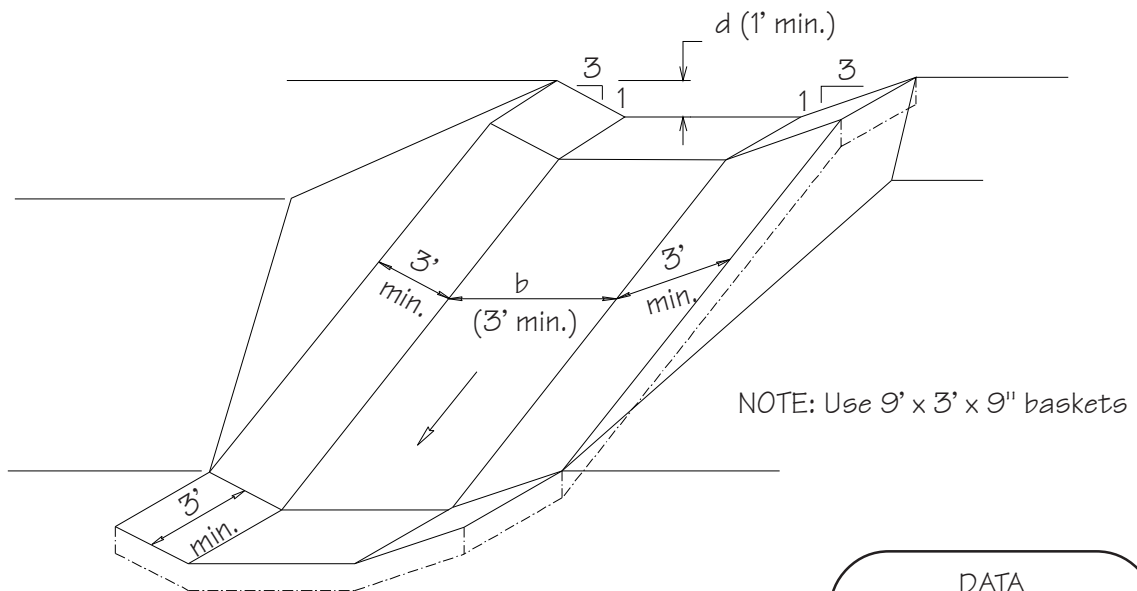
DE-ESC-3.3.9.1

Sheet 2 of 2

Effective July 2023

Standard Detail & Specifications

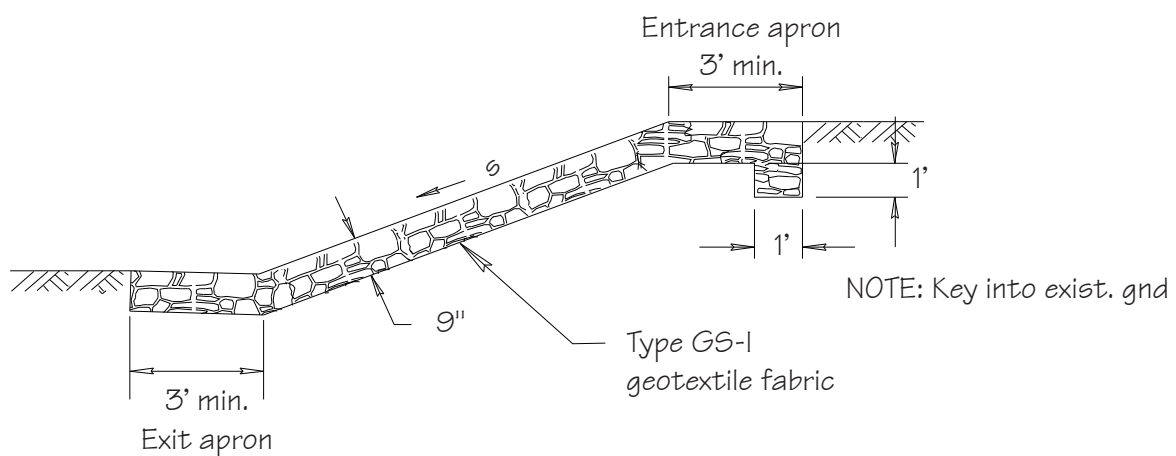
Gabion Mattress Chute



Perspective

DATA

Design discharge (Q)
Bottom width (b)
Depth (d)
Slope (s)



Profile

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:

— GMC —→

Detail No.

DE-ESC-3.3.9.2

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Gabion Mattress Chute

Construction Notes:

1. Gabion mattress chutes shall be constructed of 9' x 3' x 9" gabion baskets forming a trapezoidal cross section. The top mattress shall be keyed into existing ground a minimum of 1' in depth.
2. Entrance and exit aprons shall be provided as transition areas. Aprons shall be a minimum of 3' in length.
3. All baskets shall be underlain with Type GS-I geotextile fabric.

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:

— GMC —→

Detail No.

DE-ESC-3.3.9.2

Sheet 2 of 2

Effective July 2023

STANDARD AND SPECIFICATIONS FOR RIPRAP OUTLET PROTECTION

Definition: A section of rock protection placed at the outlet end of culverts, conduits and channels.



Purpose: To reduce the velocity and energy of water, such that the flow will not erode the receiving downstream reach.

Conditions Where Practice Applies

This practice applies where discharge velocities and energies at the outlets of culverts, conduits and channels are sufficient to erode the next downstream reach. This applies to:

1. Culvert outlets of all types.
2. Pipe conduits from all sediment basins, dry storm water ponds, and permanent ponds.
3. New channels constructed as outlets for culverts and conduits.

Design Criteria

Riprap outlet protection designed under this standard shall have a minimum d50 size of 6". The design of rock outlet protection depends entirely on the location. Pipe outlets at the top of cuts or on slopes steeper than 10 percent cannot be protected by rock aprons or riprap sections due to reconcentration of flows and high velocities encountered after the flow leaves the apron. Such situations require the use of chutes or other grade stabilization structures.

Tailwater depth

The depth of tailwater immediately below the pipe outlet must be determined for the design capacity of the pipe. If the tailwater depth is less than half the diameter of the outlet pipe and the receiving stream is wide enough to accept divergence of the flow, it shall be classified as a Minimum Tailwater Condition. If the tailwater depth is greater than half the pipe diameter and the receiving stream will continue to confine the flow, it shall be classified as a Maximum Tailwater Condition. Pipes which outlet onto flat areas with no defined channel may be assumed to have a Minimum Tailwater Condition.

Apron Size

The apron length and width shall be determined from the curves according to the tailwater condition:

Minimum Tailwater - Use Figure 3.3.10a

Maximum Tailwater - Use Figure 3.3.10b

If the pipe discharges directly into a well-defined channel, the apron shall extend across the channel bottom and up the channel banks to an elevation one foot above the maximum tailwater depth or to the top of the bank, whichever is less.

The upstream end of the apron, adjacent to the pipe shall have a width two (2) times the diameter of the outlet pipe, or conform to pipe end section if used.

Bottom Grade

The outlet protection apron shall be constructed with no slope along its length. There shall be no overfall at the end of the apron. The elevation of the downstream end of the apron shall be equal to the elevation of the receiving channel or adjacent ground.

Alignment

The outlet protection apron shall be straight throughout its entire length.

Materials

The outlet protection may be done using rock riprap or gabions.

Riprap shall be composed of a well graded mixture of stone size so that 50 percent of the pieces, by weight, shall be larger than the d50 size determined by using the charts. A well graded mixture is defined as a mixture composed primarily of larger stone sizes but with a sufficient mixture of other sizes to fill the smaller voids between the stones. The diameter of the largest stone size in such a mixture shall be 1.5 times the d50 size.

Thickness

The minimum thickness of the riprap layer shall be 1.5 times the maximum stone diameter for d50 of 15 inches or less; and 1.2 times the maximum stone size for d50 greater than 15 inches. Refer to **Appendix A-5** for additional information on riprap and stone sizes. The following chart lists some examples:

ROCK RIPRAP SIZES AND THICKNESS			
d50 (inches)	dmax (inches)	NSA No.	Min Blanket Thickness (inches)
6	12	R-4	18
9	18	R-5	22
12	24	R-6	29
24	48	R-8	58

Stone quality

Stone for riprap shall consist of field stone or quarry stone. The stone shall be hard, angular and highly resistant to weathering. The specific gravity of the individual stones shall be at least 2.5.

Recycled concrete may be used provided it has a density of at least 150 pounds per cubic foot, does not have any exposed steel or reinforcing bars, and is the proper size. (NOTE: Use of recycled concrete requires prior approval.)

Filter

A filter is a layer of material placed between the riprap and the underlying soil surface to prevent soil movement into and through the riprap. Riprap shall have a filter placed under it in all cases.

The filter shall be a layer of Type GS-I geotextile material. The fabric shall meet the minimum performance criteria as specified in **Appendix A-3**.

Gabions

Gabions shall be made of hexagonal triple twist mesh with heavily galvanized steel wire. The maximum linear dimension of the mesh opening shall not exceed 4 1/2 inches and the area of the mesh opening shall not exceed 10-square inches.

Gabions shall be fabricated in such a manner that the sides, ends, and lid can be assembled at the construction site into a rectangular basket of the specified size. Gabions shall be of single unit construction and shall be installed according to manufacturers recommendations.

The area on which the gabion is to be installed shall be graded as shown on the drawings. Foundation conditions shall be the same as for placing rock riprap and filter cloth shall be placed under all gabions. Where required, a key may be needed to prevent undermining of the main gabion structure.

Maintenance

Once a riprap outlet has been installed, the maintenance needs are very low. It should be inspected after high flows to see if scour beneath the riprap has occurred, or any stones have been dislodged. Repairs should be made immediately.

Design Procedure

1. Investigate the downstream channel to assure the non-erosive velocities can be maintained.
2. Determine the tailwater condition at the outlet to establish which curve to use.
3. Enter the appropriate chart with the depth of flow and discharge velocity to determine the riprap size and apron length required. It is noted that references to pipe diameters in the charts are based on full flow. For other than full pipe flow, the parameters of depth of flow and velocity must be used.
4. Calculate apron width at the downstream end if a flared section is to be used.

Example :

Pipe Flow (full) with discharge to unconfined section

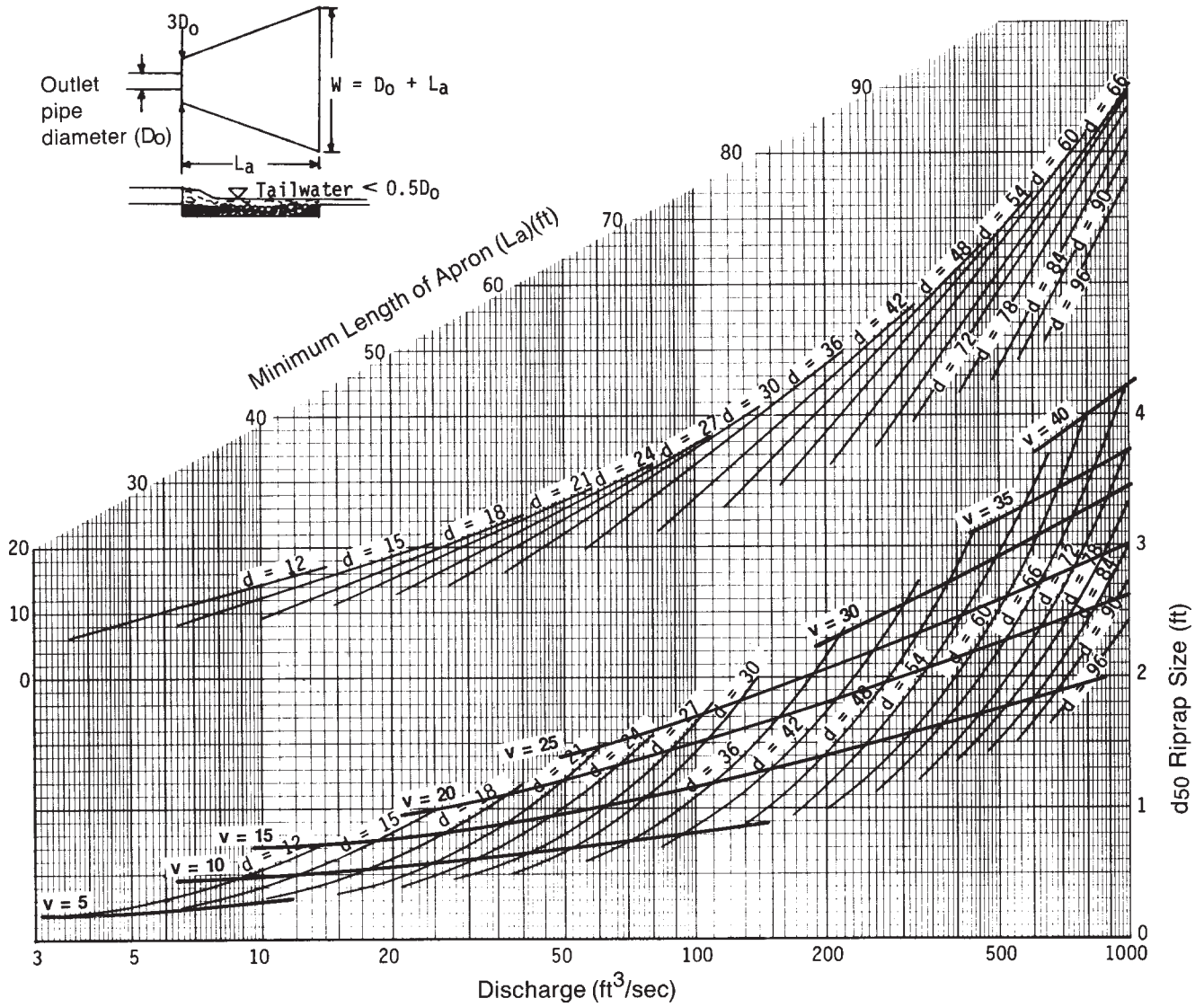
A circular conduit is flowing full:

$Q = 280$ cfs, diam. = 66", tailwater (surface) is 2 ft. above pipe invert, (minimum tailwater condition)

Read $d_{50} = 1.2'$, and apron length 38'

Apron width = diam. + $L_a = 5.5 + 38 = 43.5'$

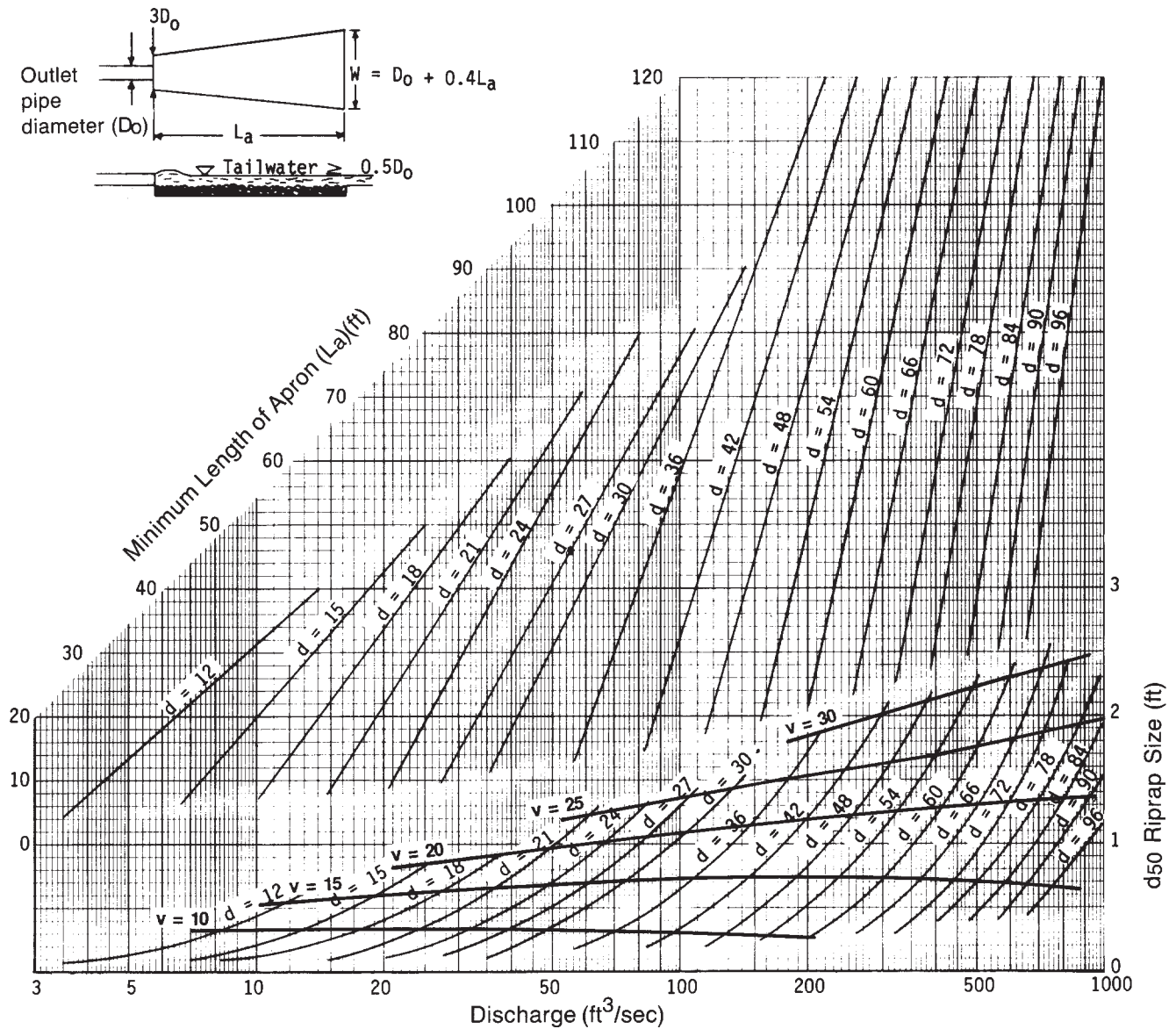
(Tw < 0.5 Dia.)



NOTE: Curves should not be extrapolated; min. d50 = 6"

Figure 3.3.10a Design of outlet protection from a round pipe flowing full, minimum tailwater condition
Source: USDA-NRCS

(Tw ≥ 0.5 Dia.)



NOTE: Curves should not be extrapolated; min. d50 = 6"

Figure 3.3.10b Design of outlet protection from a round pipe flowing full, maximum tailwater condition
Source: USDA-NRCS

Riprap Outlet Protection - 1



Technical drawing of a geotextile fabric (Type GS-I) showing its application in a road construction. The drawing includes a side view of a road cross-section with a slope, a top view of the fabric layout, and a detail view of the fabric's structure. The fabric is labeled "Type GS-I geotextile fabric" and is shown with a length L_a and a width 1 .

DATA

Pipe diameter (D_o)
Apron length (L_a)
Apron width (W)
Riprap size (R No.)
Riprap thickness (T)

Section A-A

$$T_w < 0.5 D_0$$

Symbol:

ROP-1

Effective July 2023

Standard Detail & Specifications

Riprap Outlet Protection - 1

Construction Notes:

1. The subgrade for the riprap shall be prepared to the required lines and grades as shown on the plan. Any fill required in the subgrade shall be compacted to a density of approximately that of the surrounding undisturbed material.
2. The riprap shall conform to the grading limits as shown on the plan.
3. Filter cloth shall be protected from punching, cutting or tearing. Any damage other than an occasional small hole shall be repaired by placing another piece of cloth over the damaged area. All connecting joints should overlap a minimum of 1 ft. If the damage is extensive, replace the entire filter cloth.
4. Stone for the riprap or gabion outlets may be placed by equipment. Riprap shall be placed in a manner to prevent damage to the filter cloth. Hand placement will be required to the extent necessary to prevent damage to the conduits, structures, etc.

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:



Detail No.

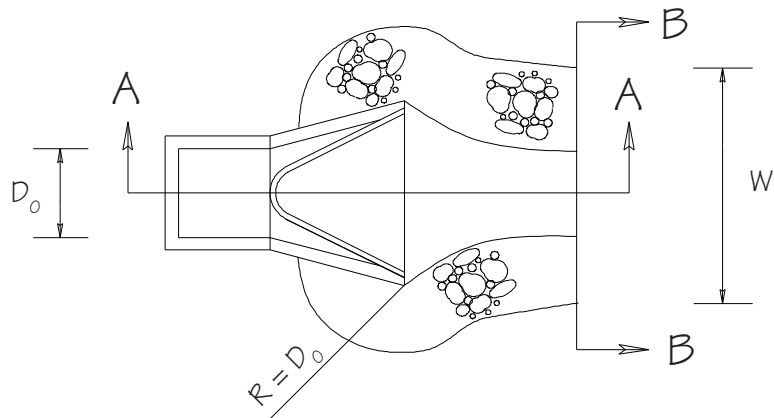
DE-ESC-3.3.10.1

Sheet 2 of 2

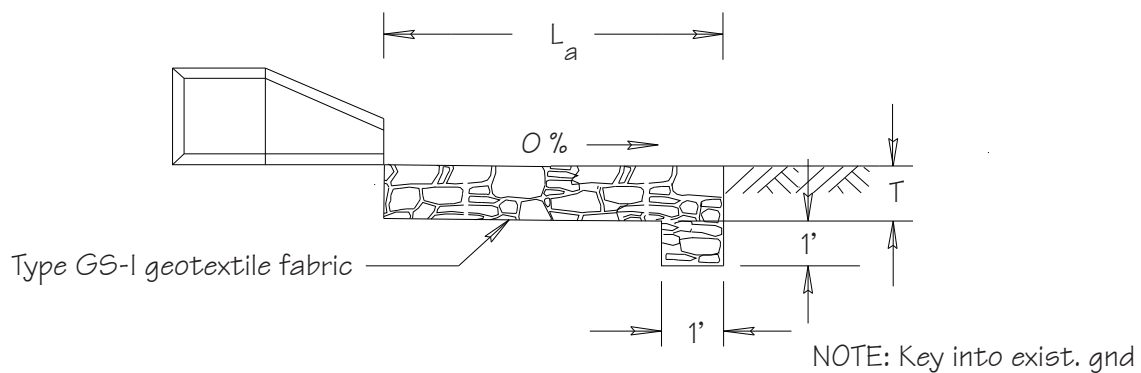
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Standard Detail & Specifications

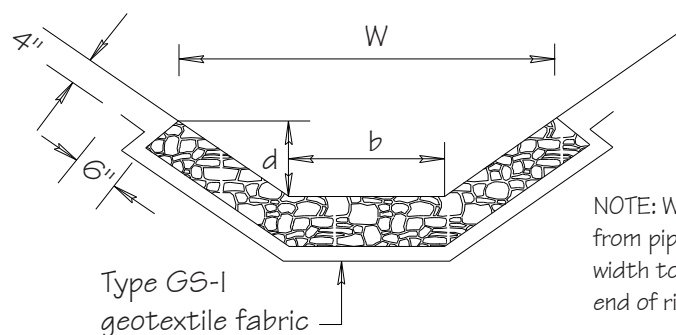
Riprap Outlet Protection - 2



Plan



Section A-A



$$T_w \geq 0.5 D_o$$

Section B-B

Source:

Adapted from
MD E&S Manual

Symbol:



Detail No.

DE-ESC-3.3.10.2

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Riprap Outlet Protection - 2

DATA

Pipe diameter (D_o)

Apron length (L_a)

Apron width (W)

Bottom width (b)

Riprap depth (d)

Riprap size (R No.)

Riprap thickness (T)

Construction Notes:

1. The subgrade for the riprap shall be prepared to the required lines and grades as shown on the plan. Any fill required in the subgrade shall be compacted to a density of approximately that of the surrounding undisturbed material.
2. The riprap shall conform to the grading limits as shown on the plan.
3. Filter cloth shall be protected from punching, cutting or tearing. Any damage other than an occasional small hole shall be repaired by placing another piece of cloth over the damaged area. All connecting joints should overlap a minimum of 1 ft. If the damage is extensive, replace the entire filter cloth.
4. Stone for the riprap or gabion outlets may be placed by equipment. Riprap shall be placed in a manner to prevent damage to the filter cloth. Hand placement will be required to the extent necessary to prevent damage to the conduits, structures, etc.

Source:

Adapted from
MD E&S Manual

Symbol:



Detail No.

DE-ESC-3.3.10.2

Sheet 2 of 2

Effective July 2023

STANDARD AND SPECIFICATIONS FOR RIPRAP STILLING BASIN

Definition: A rock-lined plunge pool placed at the outlet end of culverts and conduits.

Purpose: To reduce the velocity and energy of water, such that the flow will not create a scour hole at the point of discharge. This is accomplished by inducing an hydraulic jump in the stilling basin prior to its discharge to a receiving channel or other stable outlet.



Conditions Where Practice Applies

This practice applies where discharge velocities and energies at the outlets of culverts and conduits are sufficient to erode the downstream reach unless some type of energy dissipation structure is installed. This applies to:

1. Culvert outlets of all types.
2. Pipe conduits from all sediment basins, dry storm water ponds, and permanent ponds.
3. Situations where there is no defined outlet channel for the culvert or conduit.
4. Situations which require a specific design velocity into a receiving channel.

Design Criteria

The design of riprap stilling basins shall be based on the maximum design discharge for the pipe or conduit. Recommended procedures for determining the configuration of the basin and sizing of the riprap are included in **Design Guide 2**. A design worksheet is also included.

Stone quality

Stone for riprap shall consist of field stone or quarry stone. The stone shall be hard, angular and highly resistant to weathering. The specific gravity of the individual stones shall be at least 2.5.

Recycled concrete may be used provided it has a density of at least 150 pounds per cubic foot, does not have any exposed steel or reinforcing bars, and is the proper size. (NOTE: Use of recycled concrete requires prior approval.)

Filter

A filter is a layer of material placed between the riprap and the underlying soil surface to prevent soil movement into and through the riprap. Riprap shall have a filter placed under it in all cases.

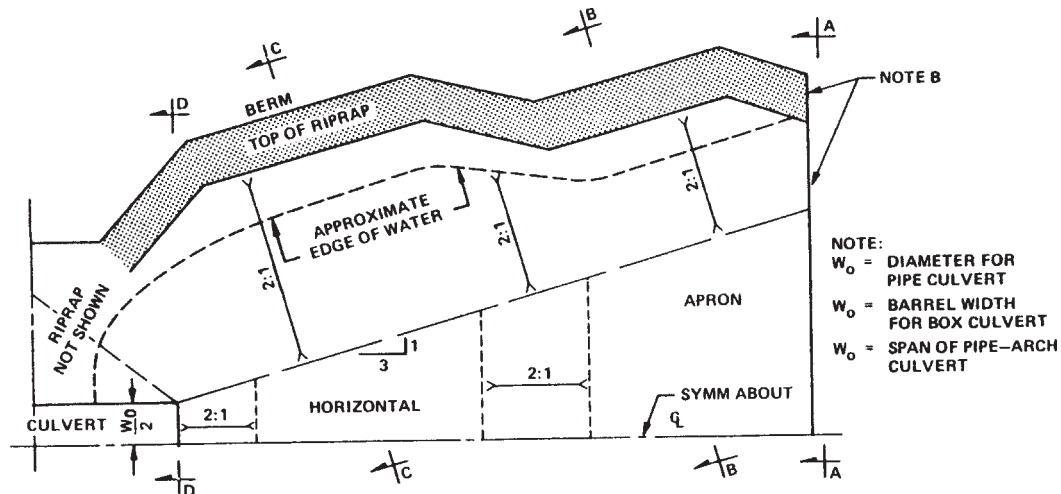
The filter shall be a layer of **Type GS-I** geotextile material. The fabric shall meet the minimum performance criteria as specified in **Appendix A-3**.

Maintenance

Once a riprap stilling basin has been installed, the maintenance needs are very low. It should be inspected after high flows to see if scour beneath the riprap has occurred, or any stones have been dislodged. Repairs should be made immediately.

Standard Detail & Specifications

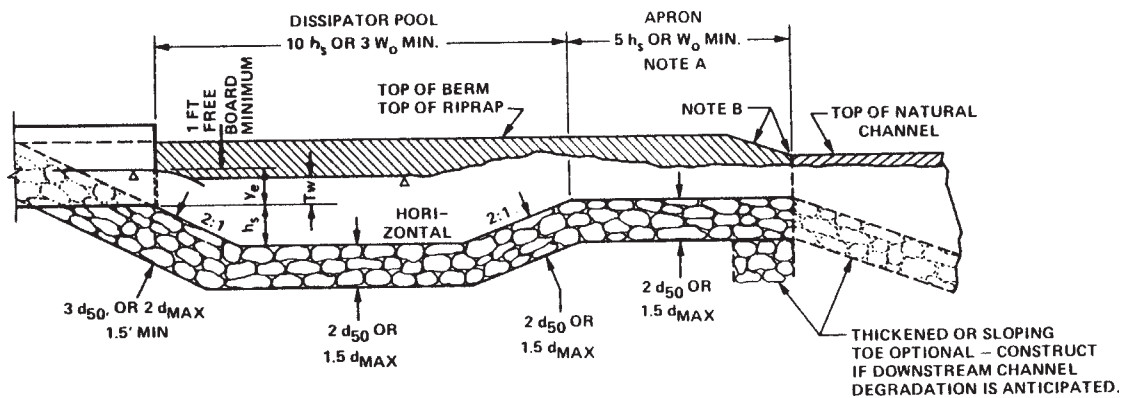
Riprap Stilling Basin



Half - Plan

NOTE A - IF EXIT VELOCITY OF BASIN IS SPECIFIED, EXTEND BASIN AS REQUIRED TO OBTAIN SUFFICIENT CROSS-SECTIONAL AREA AT SECTION A-A SUCH THAT $Q_{des}/(\text{CROSS SECTION AREA AT SEC. A-A}) = \text{SPECIFIED EXIT VELOCITY}$.

NOTE B - WARP BASIN TO CONFORM TO NATURAL STREAM CHANNEL. TOP OF RIPRAP IN FLOOR OF BASIN SHOULD BE AT THE SAME ELEVATION OR LOWER THAN NATURAL CHANNEL BOTTOM AT SEC. A-A.



Profile thru ϕ Basin

Source:

Adapted from
FHWA HEC-14

Symbol:



Detail No.

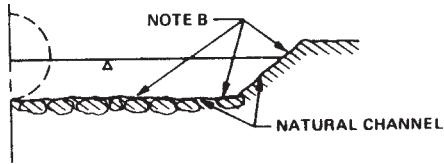
DE-ESC-3.3.11

Sheet 1 of 3

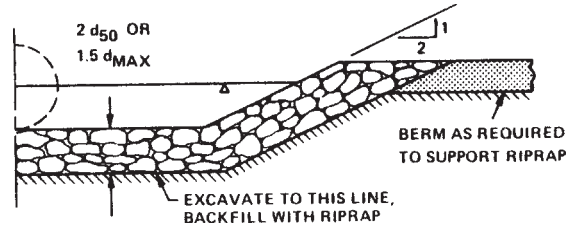
Effective July 2023

Standard Detail & Specifications

Riprap Stilling Basin

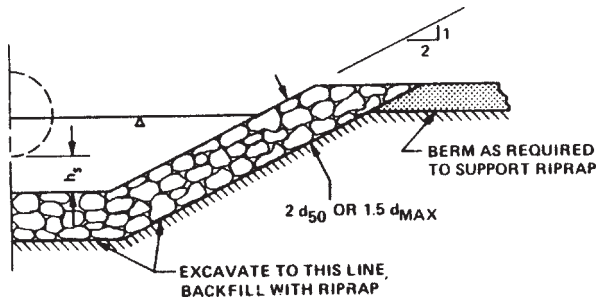


Section A-A

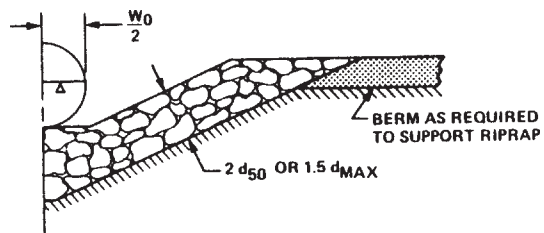


Section B-B

NOTE B - WARP BASIN TO CONFORM TO NATURAL STREAM CHANNEL. TOP OF RIPRAP IN FLOOR OF BASIN SHOULD BE AT THE SAME ELEVATION OR LOWER THAN NATURAL CHANNEL BOTTOM AT SEC. A-A.



Section C-C



Section D-D

DATA

Culvert dimension (w_o)
Depth of basin from culvert invert (h_s)
Riprap size (R No.)

Source:

Adapted from
FHWA HEC-14

Symbol:



Detail No.

DE-ESC-3.3.11

Sheet 2 of 3

Effective July 2023

Standard Detail & Specifications

Riprap Stilling Basin

Construction Notes:

1. The subgrade for the riprap shall be prepared to the required lines and grades as shown on the plan. Any fill required in the subgrade shall be compacted to a density of approximately that of the surrounding undisturbed material.
2. The riprap shall conform to the grading limits as shown on the plan.
3. Geotextile shall be a Type GS-I. Fabric shall be protected from punching, cutting or tearing. Any damage other than an occasional small hole shall be repaired by placing another piece of cloth over the damaged area. All connecting joints should overlap a minimum of 1 ft. If the damage is extensive, replace the entire section.
4. Stone for the riprap or gabion outlets may be placed by equipment. Riprap shall be placed in a manner to prevent damage to the geotextile fabric. Hand placement will be required to the extent necessary to prevent damage to the conduits, structures, etc.

Source:

Adapted from
FHWA HEC-14

Symbol:



Detail No.

DE-ESC-3.3.11

Sheet 3 of 3

Effective July 2023

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STANDARD AND SPECIFICATIONS FOR TOPSOILING

Definition: Placement of topsoil over a prepared subsoil prior to establishment of vegetation.

Purpose: To provide a suitable growth medium for final stabilization with vegetation.



Conditions Where Practice Applies:

This practice is recommended for sites with slopes 2:1 or flatter where:

1. The texture of the exposed subsoil or parent material is not suitable to produce adequate vegetative growth.
2. The soil material is so shallow that the rooting zone is not deep enough to support plants or furnish continuing supplies of moisture and plant nutrients.
3. The original soil to be vegetated contains material toxic to plant growth.
4. The soil is so acid that treatment with limestone is not feasible.
5. High-quality turf and/or landscape plantings are to be established.

Planning Considerations:

Topsoil is the surface layer of the soil profile, generally characterized as being darker than the subsoil due to the presence of organic matter. It is the major zone of root development, carrying much of the nutrients available to plants, and supplying a large share of the water used by plants.

Although topsoil provides an excellent growth medium, there are disadvantages to its use. Stripping, stockpiling, and reapplying topsoil or importing topsoil, may not always be cost-effective. Topsoiling can delay seeding or sodding operations, increasing the exposure time of denuded areas. Most topsoil contains weed seeds, and weeds may compete with desirable species.

Advantages of topsoil include its high organic matter content and friable consistence, water-holding capacity, and nutrient content. Native topsoil that is low in organic matter may be improved through the addition of compost or similar amendments.

In site planning, the option of topsoiling should be compared with that of preparing a seedbed in subsoil. The clay content of subsoils does provide high moisture availability and deter leaching of nutrients and, when properly limed and fertilized, subsoils may provide a good growth medium which is generally free of weed seeds. In many cases topsoiling may not be required for the establishment of less demanding, lower maintenance plant material.

Topsoiling is strongly recommended where ornamental plants or high-maintenance turf will be grown. Topsoiling is a required procedure when establishing vegetation on shallow soils, soils containing potentially toxic materials, and soils of critically low pH (high acid) levels.

The following considerations should be given to any topsoiling operation:

1. Ensure an adequate volume of topsoil exists on the site. Topsoil should be compacted to a preferred depth of 4 inches. This will require additional volume than if it were merely spread loosely.
2. If a soil test indicates the native topsoil does not contain the recommended percentage of organic matter, compost or other similar material may be used as an amendment. Compost shall be provided by a certified supplier. Compost amendments that are intended to meet specific post-construction stormwater management goals shall further meet the requirements of **Appendix 3.06.2 Post Construction Stormwater Management BMP Standards and Specifications, Section 14.0 Soil Amendments**.
3. Stockpiles should be located so as not to interfere with other site work.
4. Project scheduling must account for the time to spread, compact, treat, seed, and mulch the topsoiled area.
5. Care must be taken not to apply topsoil to a subsoil having major textural differences. Clayey topsoil over sandy subsoil is a particularly poor combination, as water may seep along the interface between the soil layers, causing the topsoil to slough. Sandy topsoil over a clay subsoil may also be prone to failure.
6. If topsoil and subsoil are not properly bonded, water will not infiltrate the soil profile evenly, making it difficult to establish vegetation. In order to improve this bonding, the subsoil should be scarified prior to spreading of the topsoil.
7. Topsoiling of steep slopes should generally be avoided unless adequate measures have been taken to prevent slope failure. (See **Section 3.4.2, Standard & Specification for Slope Treatment**.)

Standard Detail & Specifications

Topsoiling

Construction Notes:

1. Site Preparation (Where Topsoil is to be added)

Note: When topsoiling, maintain needed erosion and sediment control practices such as diversions, grade stabilization structures, berms, dikes, waterways and sediment basins.

- a. Grading - Grades on the areas to be topsoiled which have been previously established shall be maintained.
- b. Liming - Where the topsoil is either highly acid or composed of heavy clays, ground limestone shall be spread at the rate of 4-8 tons/acre (200-400 pounds per 1,000 square feet). Lime shall be distributed uniformly over designated areas and worked into the soil in conjunction with tillage operations as described in the following procedures.
- c. Tilling - After the areas to be topsoiled have been brought to grade, and immediately prior to dumping and spreading the topsoil, the subgrade shall be loosened by discing or by scarifying to a depth of at least 3 inches to permit bonding of the topsoil to the subsoil. Pack by passing a bulldozer up and down over the entire surface area of the slope to create horizontal erosion check slots to prevent topsoil from sliding down the slope.

2. Topsoil Material and Application

Note: Topsoil salvaged from the existing site may often be used but it should meet the same standards as set forth in these specifications. The depth of topsoil to be salvaged shall be no more than the depth described as a representative profile for that particular soil type as described in the soil survey published by USDA-SCS in cooperation with Delaware Agricultural Experimental Station.

Source:

USDA - NRCS

Symbol:

Detail No.

DE-ESC-3.4.1

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Topsoiling

Construction Notes (cont.)

- a. Materials - Topsoil shall be a loam, sandy loam, clay loam, silt loam, sandy clay loam, loamy sand or other soil as approved by an agronomist or soil scientist. It shall not have a mixture of contrasting textured subsoil and contain no more than 5 percent by volume of cinders, stones, slag, coarse fragment, gravel, sticks, roots, trash or other extraneous materials larger than 1-1/2 inches in diameter. Topsoil must be free of plants or plant parts of bermudagrass, quackgrass, Johnsongrass, nutsedge, poison ivy, thistles, or others as specified. All topsoil shall be tested by a reputable laboratory for organic matter content, pH and soluble salts. A pH of 6.0 to 7.5 and an organic content of not less than 1.5 percent by weight is required. If pH value is less than 6.0 lime shall be applied and incorporated with the topsoil to adjust the pH to 6.5 or higher. Topsoil containing soluble salts greater than 500 parts per million shall not be used.

Note: No sod or seed shall be placed on soil which has been treated with soil sterilant or chemicals used for weed control until sufficient time has elapsed to permit dissipation of toxic materials.

- b. Grading - The topsoil shall be uniformly distributed and compacted to a minimum of four (4) inches. Spreading shall be performed in such a manner that sodding or seeding can proceed with a minimum of additional soil preparation and tillage. Any irregularities in the surface resulting from topsoiling or other operations shall be corrected in order to prevent the formation of depressions or water pockets. Topsoil shall not be placed while in a frozen or muddy condition, when the subgrade is excessively wet, or in a condition that may otherwise be detrimental to proper grading and seedbed preparation.

Note: Topsoil substitutes or amendments as approved by a qualified agronomist or soil scientist, may be used in lieu of natural topsoil. Compost material used to improve the percentage of organic matter shall be provided by a certified supplier.

Compost amendments that are intended to meet specific post-construction stormwater management goals shall further meet the requirements of **Appendix 3.06.2 Post Construction Stormwater Management BMP Standards and Specifications, Section 14.0 Soil Amendments.**

Source:

USDA - NRCS

Symbol:

Detail No.

DE-ESC-3.4.1

Sheet 2 of 2

Effective July 2023

STANDARD AND SPECIFICATIONS FOR SLOPE TREATMENT

Definition: Grading of sloped areas of a site in a way so as to minimize potential erosive forces.

Purpose: To provide for erosion control and vegetative establishment on those areas which are more prone to erosion due to topography.



Design Criteria

The grading plan should be based on incorporating buildings, streets, utilities, etc. with the existing topography and landscape whenever possible in order to avoid major grade modifications. The information submitted must provide sufficient topographic surveys and soil investigations to determine limitations that must be imposed on the grading operation.

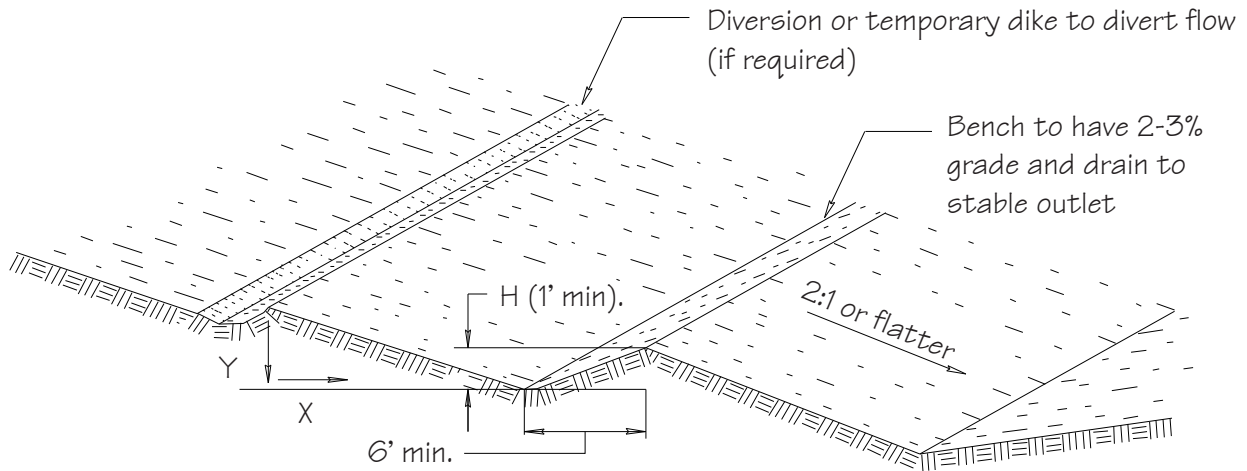
The plan must show existing and proposed contours of the area(s) to be graded. The plan shall also include approved practices for erosion control, slope stabilization, safe disposal of runoff water and drainage. The plan shall also include phasing of these practices. The following shall be incorporated into the plan:

1. Provisions shall be made to safely conduct surface runoff to storm drains, protected outlets, or to stable water courses to insure that surface runoff will not damage slopes or other graded areas.
2. Cut slopes that are to be stabilized with grasses shall not be steeper than 2:1. Fill slopes that are to be stabilized with grasses shall not be steeper than 3:1. (Where the slope is to be mowed the slope should be no steeper than 3:1, 4:1 is preferred because of safety factors related to mowing steep slopes.) Slopes steeper than 2:1 shall require special design and stabilization considerations that shall be adequately shown on the plans.
3. Benches shall be provided whenever the vertical interval (height) exceeds 20 feet for a 2:1 slope, 30 feet for a 3:1 slope, or 40 feet for a 4:1 slope. Benches shall be located to divide the slope face as equally as possible and shall convey the water to a stable outlet. Soils, seeps, rock outcrops, etc., shall also be taken into consideration when designing diversions.
 - a. Benches shall be a minimum of six-feet wide to provide for ease of maintenance.
 - b. Benches shall be designed with a reverse slope of 6:1 or flatter to the toe of the upper slope and with a minimum of one foot in depth. The gradient to the outlet shall be between 2 percent and 3 percent, *unless accompanied by appropriate design and computations.*
 - c. The flow length within a bench shall not exceed 800' *unless accompanied by an appropriate design and computations.* (See **Section 3.3.5, Standard and Specifications for Diversion.**)

-
4. Surface water shall be diverted from the face of all cut-and-fill slopes by the use of diversions, ditches and swales or conveyed downslope by the use of a designed structure, except where:
 - a. The face of the slope is or shall be stabilized and the face of all graded slopes shall be protected from surface runoff until they are stabilized.
 - b. The face of the slope shall not be subject to any concentrated flows of surface water such as from natural drainageways, graded swales, downspouts, etc.
 - c. The face of the slope will be protected by special erosion control materials, sod, gravel, riprap or other stabilization method.
 5. Cut slopes occurring in rippable rock shall be serrated as shown on the appropriate detail. These serrations shall be made with conventional equipment as the excavation is made. Each step or serration shall be constructed on the contour and will have steps cut at nominal two-foot intervals with nominal three-foot horizontal shelves. These steps will vary depending on the slope ratio or the cut slope. The nominal slope line is 1 1/2 : 1. These steps will weather and act to hold moisture, lime, fertilizer and seed thus producing a much quicker and longer lived vegetative cover and better slope stabilization. Overland flow shall be diverted from the top of all serrated cut slopes and carried to a suitable outlet.
 6. Subsurface drainage shall be provided where necessary to intercept seepage that would otherwise adversely affect slope stability or create excessively wet site conditions.
 7. Slopes shall not be created so close to property lines as to endanger adjoining properties without adequately protecting such properties against sedimentation, erosion, slippage, settlement, subsidence or other related damages.
 8. Fill material shall be free of brush, rubbish, rocks, logs, stumps, building debris, and other objectionable material. It should be free of stones over two (2) inches in diameter where compacted by hand or mechanical tampers or over eight (8) inches in diameter where compacted by rollers or other equipment. Frozen material shall not be placed in the fill nor shall the fill material be placed on a frozen foundation.
 9. Stockpiles, borrow areas, and spoil areas shall be shown on the plans and shall be subject to the provision of this Standard and Specifications.
 10. All disturbed areas shall be stabilized in accordance with the Standards and Specifications for Mulching and Vegetative Stabilization.

Standard Detail & Specifications

Slope Treatment - Benching



Slope X:1	Y (max.)
2	20'
3	30'
4	40'

Perspective

DATA

Slope (X:1)
Vertical height (Y)
Bench height (H)

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:



Detail No.

DE-ESC-3.4.2.1

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Slope Treatment - Benching

Construction Notes:

1. All graded or disturbed areas including slopes shall be protected during clearing and construction in accordance with the approved sediment control plan until they are permanently stabilized.
2. Topsoil required for the establishment of vegetation shall be stockpiled in amounts necessary to complete finished grading of all exposed areas.
3. Areas to be filled shall be cleared, grubbed and stripped of topsoil to remove trees, vegetation, roots or other objectionable material.
4. Areas which are to be topsoiled shall be scarified to a minimum depth of three (3) inches prior to placement of topsoil.
5. All fills shall be compacted as required to reduce erosion, slippage, settlement, subsidence or other related problems.
6. All fill is to be placed and compacted in layers not to exceed 8 inches in thickness.
7. Except for approved landfills, fill material shall be free of brush, rubbish, rocks, logs, stumps, building debris and other objectionable materials that would interfere with or prevent construction of satisfactory fills.
8. Frozen materials or soft, mucky or highly compressible materials shall not be incorporated into fills.
9. Fill material shall not be placed on a frozen foundation.
10. All diversions shall be kept free of sediment during all phases of development.
11. Seeps or springs encountered during construction shall be handled in accordance with the Standard and Specifications for Subsurface Drain or other approved methods.
12. All graded areas shall be permanently stabilized immediately following finished grading.
13. Stockpiles, borrow areas and spoil areas shall be shown on the plans and shall be subject to the provisions of this Standard and Specifications.

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:



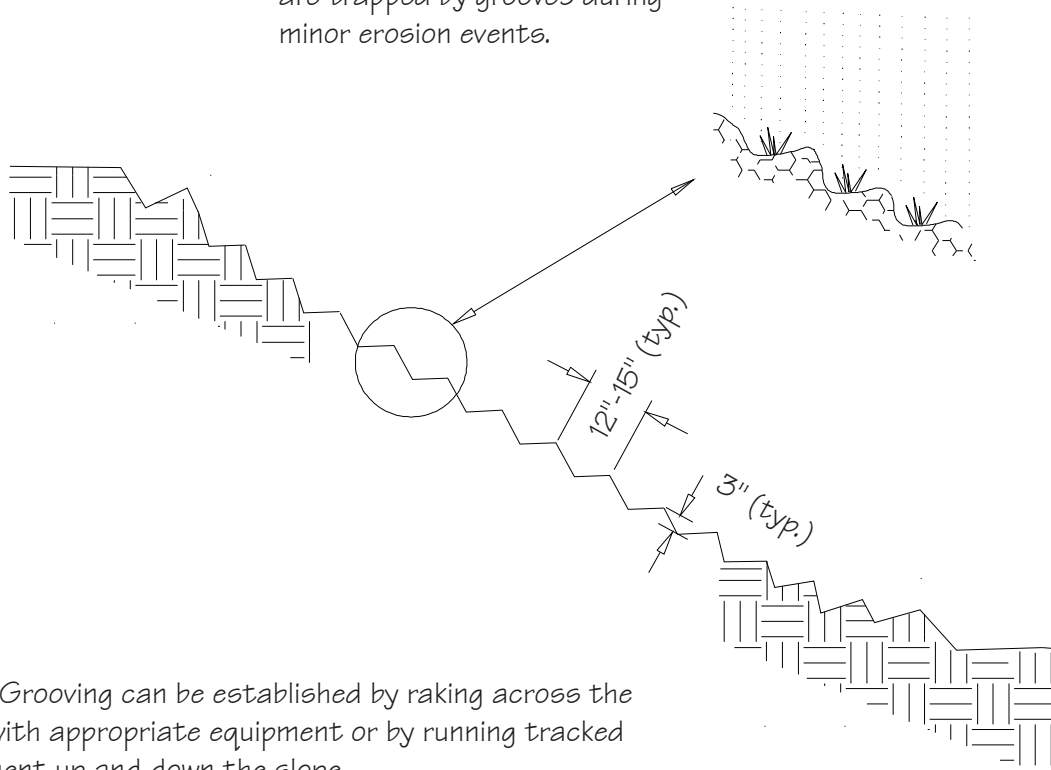
Detail No.

DE-ESC-3.4.2.1
Sheet 2 of 2
Effective July 2023

Standard Detail & Specifications

Slope Treatment - Grooving

Seed, soil and amendments are trapped by grooves during minor erosion events.



NOTE: Grooving can be established by raking across the slope with appropriate equipment or by running tracked equipment up and down the slope.

Section

Source:

Adapted from
VA ESC Handbook

Symbol:



Detail No.

DE-ESC-3.4.2.2

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Slope Treatment - Grooving

Construction Notes:

1. All graded or disturbed areas including slopes shall be protected during clearing and construction in accordance with the approved sediment control plan until they are permanently stabilized.
2. Topsoil required for the establishment of vegetation shall be stockpiled in amounts necessary to complete finished grading of all exposed areas.
3. Areas to be filled shall be cleared, grubbed and stripped of topsoil to remove trees, vegetation, roots or other objectionable material.
4. Areas which are to be topsoiled shall be scarified to a minimum depth of three (3) inches prior to placement of topsoil.
5. All fills shall be compacted as required to reduce erosion, slippage, settlement, subsidence or other related problems.
6. All fill is to be placed and compacted in layers not to exceed 8 inches in thickness.
7. Except for approved landfills, fill material shall be free of brush, rubbish, rocks, logs, stumps, building debris and other objectionable materials that would interfere with or prevent construction of satisfactory fills.
8. Frozen materials or soft, mucky or highly compressible materials shall not be incorporated into fills.
9. Fill material shall not be placed on a frozen foundation.
10. All diversions shall be kept free of sediment during all phases of development.
11. Seeps or springs encountered during construction shall be handled in accordance with the Standard and Specifications for Subsurface Drain or other approved methods.
12. All graded areas shall be permanently stabilized immediately following finished grading.
13. Stockpiles, borrow areas and spoil areas shall be shown on the plans and shall be subject to the provisions of this Standard and Specifications.

Source:

Adapted from
VA ESC Handbook

Symbol:



Detail No.

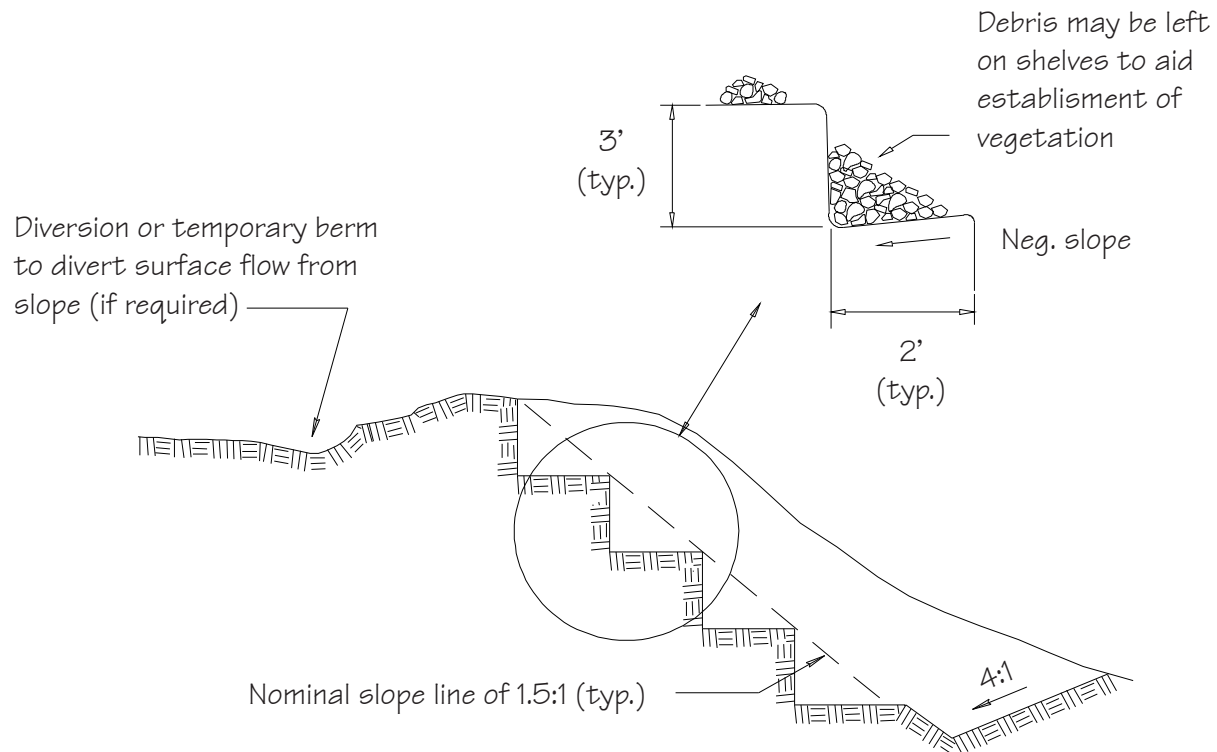
DE-ESC-3.4.2.2

Sheet 2 of 2

Effective July 2023

Standard Detail & Specifications

Slope Treatment - Serrating



Section

NOTE: Serrating is applicable to rippable rock slopes only.

Source:

Adapted from
VA ESC Handbook

Symbol:



Detail No.

DE-ESC-3.4.2.3

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Slope Treatment - Serrating

Construction Notes:

1. All graded or disturbed areas including slopes shall be protected during clearing and construction in accordance with the approved sediment control plan until they are permanently stabilized.
2. Topsoil required for the establishment of vegetation shall be stockpiled in amounts necessary to complete finished grading of all exposed areas.
3. All fills shall be compacted as required to reduce erosion, slippage, settlement, subsidence or other related problems.
4. All fill is to be placed and compacted in layers not to exceed 8 inches in thickness.
5. Except for approved landfills, fill material shall be free of brush, rubbish, rocks, logs, stumps, building debris and other objectionable materials that would interfere with or prevent construction of satisfactory fills.
6. Frozen materials or soft, mucky or highly compressible materials shall not be incorporated into fills.
7. Fill material shall not be placed on a frozen foundation.
8. All diversions shall be kept free of sediment during all phases of development.
9. Seeps or springs encountered during construction shall be handled in accordance with the Standard and Specifications for Subsurface Drain or other approved methods.
10. All graded areas shall be permanently stabilized immediately following finished grading.
11. Stockpiles, borrow areas and spoil areas shall be shown on the plans and shall be subject to the provisions of this Standard and Specifications.

Source:

Adapted from
VA ESC Handbook

Symbol:



Detail No.

DE-ESC-3.4.2.3

Sheet 2 of 2

Effective July 2023

Standard Detail & Specifications

Slope Treatment - EC Log

Construction Notes:

1. All graded or disturbed areas including slopes shall be protected during clearing and construction in accordance with the approved sediment control plan until they are permanently stabilized.
2. The erosion control log shall be placed perpendicular to the slope gradient. The product must have intimate contact with the soil to reduce the occurrence of undermining of the product.
3. Stakes should be driven so that they are perpendicular to the ground surface slope. Refer to the product manufacturer's guidelines for more information on installation and spacing of the stakes.
4. Installing a slope interruption product on frozen ground is not recommended. In the case where the product must be installed on frozen ground, trenching is not required and staking can be accomplished with metal stakes.

Spacing Specifications:

Straw Wattle	12" dia.	Fiber Filt. Tube	9" dia.	Compost Log	12" dia.	18" dia.	24" dia.
Slope Ratio (x:1)	Spacing (L) in ft.	Slope Ratio (x:1)	Spacing (L) in ft.	Slope Ratio (x:1)	Spacing (L) in ft.	Spacing (L) in ft.	Spacing (L) in ft.
1:1	5	1:1	15	1:1 to 2:1	20	30	35
2:1 to 1:1	10	2:1	25	3:1	30	45	60
4:1 to 2:1	20	3:1	35	5:1	50	70	130
5:1 to 4:1	40	4:1	50				
< 6:1	50						

Source:

Adapted from
Filtrexx™ International

Symbol:



Detail No.

DE-ESC-3.4.2.4

Sheet 2 of 2

Effective July 2023

STANDARD AND SPECIFICATIONS FOR VEGETATIVE STABILIZATION

Definition: The preservation and/or establishment of vegetation to prevent the erosion of disturbed areas.



Purpose:

Preserving or establishing a cover of healthy vegetation is the most effective and economical means for preventing soil erosion. The vegetation shields the soil surface from the impact of falling raindrops, slows runoff, holds soil particles in place, improves and maintains the infiltrative capacity of the soil, and removes subsurface water through evapotranspiration. For example, a grass cover placed on bare ground will reduce runoff from a one (1) year frequency storm event (2.8 inches of rainfall) by 50-100 percent, depending on the soil type (Calculation based on Soil Conservation Service Technical Release No. 55).

Because vegetation is so effective in reducing runoff, it can minimize the erosion potential of a construction site and reduce the need for structural practices. It is important, therefore, to preserve as much of the existing vegetation as possible by limiting grading. On large sites, grade and stabilize in stages, so that one area is re-vegetated before another is cleared. If graded areas are to remain idle for extended periods of time, the establishment of a temporary vegetative cover will reduce the runoff and erosion potential. This may significantly reduce the amount of maintenance required for structural controls at the construction site. The cost savings from reduced maintenance may be much greater than the cost of temporary seeding.

The success of vegetative establishment depends on proper application, installation and care. The steps for proper stabilization are:

- ◆ Site preparation;
- ◆ Soil amendments;
- ◆ Seed application and
- ◆ Mulching and mulch anchoring.

Details for each of these steps must be included on all sediment and stormwater plans.

Stands of vegetation also need to be maintained to assure their continuing vigor and function. It is less costly to carry on a maintenance program than it is to make repairs after an extended period of neglect. Maintenance typically includes mowing, fertilizer and lime application, weed management, pest and disease control, tree pruning and removal of invasive or undesirable plants.

Planting vegetation such as trees, shrubs, vines and ground covers on disturbed areas offers an alternative to grasses and provides additional functions such as wildlife food and cover, windbreaks and aesthetic enhancements. These plants are usually reserved for special purpose, high value landscaping. This practice cannot be expected to provide an erosion control cover and prevent soil slippage on a soil that is not stable due to its texture, structure, slope or water movement. For unusual or site-specific applications, it would be best to engage a landscape architect or consulting forester. Additional information may be obtained through the local office of the Delaware Cooperative Extension System, the Delaware Forest Service, the local field office of the Natural Resources Conservation Service, or the local Conservation District.

In summary, preserving the existing vegetation or establishing a new temporary or permanent vegetative cover as soon as possible after grading reduces runoff and erosion. Maintaining vegetation will ensure that these benefits will continue for the long term. This provides better environmental protection and may reduce construction costs by limiting the number of structural practices required and associated maintenance costs.

The following sections contain additional standards and specifications for both temporary and permanent vegetative stabilization, including sodding. There are also several tables and charts to assist the designer in selecting the appropriate plant material for a given set of conditions.

ADDITIONAL STANDARD AND SPECIFICATIONS FOR SOIL TESTING

Definition: Soil is tested to determine the fertility status so that the required amount of lime and fertilizer is applied for optimal plant growth.

Purpose: Soil testing will serve the following purposes:

1. To apply the appropriate amount of lime or fertilizer for optimal plant growth.
2. To provide suitable growth medium for final stabilization with vegetation.

Conditions Where Practice Applies:

Soil testing is recommended for all sites that will be stabilized with vegetation where:

1. Existing soil conditions are not suitable to produce adequate vegetation growth.
2. The soil to be vegetated contains material toxic to plant growth.
3. High-quality turf and/or landscape plantings are to be established.
4. Significant amounts of topsoil have been removed from the site through excavation or grading.
5. Large areas are to be planted with the same type of vegetation (to minimize entire areas with unsuccessful germination or plant survival due to poor soil conditions).

Planning Considerations:

During site construction the top layer of the soil, the topsoil, is altered through grading, compaction, and excavation. The topsoil is an important layer in the soil where plants establish their roots and extract the necessary nutrients for growth and survival. When the topsoil is stripped from the site, establishing vegetation can prove to be unsuccessful, timely, and overall costly. Soil tests provide the following information, pH, buffer pH, lime requirement, P, K, Ca, Mg, Mn, Cu, Zn, and organic matter by LOI. Additional information can be requested. Soil tests provide the fertility of the soil and whether lime or additional fertilizer may be required for successful plant growth. This information is beneficial both economically and environmentally. Determining the fertility of the soil will provide the precise amount of nutrients needed to establish lawns or other plantings.

Obtaining the Soil Sample:

An accurate soil test can only be achieved through obtaining a good soil sample. A soil sample weighing approximately ½ pound is used to represent thousands of pounds of soil on the subject parcel of land. The sample should reflect the site conditions that are to be stabilized with vegetation. Soil testing materials including a sampling tube, auger or spade; soil sample bags; sample information sheets; and sampling instructions available at your County Cooperative Extension office. The soil samples must be placed in the designated cloth bags that are provided at the Extension office. The soil sample along with a small fee is then forwarded to the University of Delaware where the testing occurs.

-
1. The soil sample should consist of 15 to 25 cores taken from the sampling area.
 2. Areas where soil and vegetation conditions appear different should be sampled separately. Locate sample locations on a map or sketch.
 3. The maximum sample area for one soil test is 40 acres.
 4. Each core should be taken to a depth of 6 to 9 inches. Remove any leaf litter or debris before sampling.
 5. Place cores in a **clean** plastic pail and mix them together thoroughly.
 6. Spread the mixture out on **clean** paper to dry.
 7. Fill the sample bag to the level indicated and discard the rest of the material.

Do Not Contaminate the Sample

1. Use clean tools to obtain the sample.
2. Chemicals, fertilizer, or lime on tools or hands can contaminate a soil sample.
3. Steel sampling tools and plastic buckets are recommended for obtaining the sample.

Do not take samples in areas that are significantly different.

1. Stay away from lanes or border areas.
2. Anomalies such as potholes, sandy ridges and eroded areas should be avoided.

Forwarding the Sample

1. Name each sample and keep a complete record of the area represented.
2. Completely fill out the information sheet provided with each sample bag and place in the attached envelope.
3. Do not use sample bags other than those provided by the laboratory.
4. Your recommendations will be no better than the information submitted.

How often should soil be tested?

1. Once adequate fertility levels are established, lawns need only be sampled every 2 to 3 years.
2. Vegetable gardens should be sampled every 1 to 2 years.
3. Where liming is likely, sample well in advance of planting. Because lime reacts slowly, it should be mixed with soil several months before planting.

Additional Information

Contact the local Cooperative Extension Office for methods of applying lime and fertilizers.

New Castle County: 910 South Chapel Street, Newark, DE 19716-1303 (302)-831-2506.

Kent County: 2319 South DuPont Highway, Dover, DE 19901, (302) 697-4000.

Sussex County: University of Delaware, Research and Education Center, R.D. 6, Box 48, Georgetown, DE 19947, (302) 856-7303.

NOTE: Effective January 1, 2004, all persons who control the application of nutrients to 10 acres or greater shall develop and implement a Nutrient Management Plan and become certified by the program. A Nutrient Management Plan is a strategy to manage the amount, placement, timing and application of nutrients. The Plan shall be updated every three years, with annual reports submitted by March 1 of the calendar year.

ADDITIONAL STANDARD AND SPECIFICATIONS FOR TEMPORARY STABILIZATION

Definition: The planting of quick growing vegetation to provide temporary stabilization on disturbed areas.

Purpose: To temporarily stabilize the soil, reduce damage from sediment and runoff to downstream or off-site areas, and to provide protection to disturbed areas until permanent vegetation or other erosion control measures can be established.

Conditions Where Practice Applies

Graded or cleared areas which are subject to erosion for a period of 14 days or more.

Specifications

1. Site Preparation

- a. Prior to seeding, install needed erosion and sediment control practices such as diversions, grade stabilization structures, berms, dikes, grassed waterways, and sediment basins.
- b. Final grading and shaping are not necessary for temporary seedings.

2. Seedbed Preparation

It is important to prepare a good seedbed to ensure the success of establishing vegetation. The seedbed should be well prepared, loose, uniform, and free of large clods, rocks, and other objectionable material. The soil surface should not be compacted or crusted.

3. Soil Amendments - Soil amendments are not typically required for temporary stabilization. However, in some cases soil conditions may be so poor that amendments are needed to establish even a temporary vegetative cover. Under these extreme conditions, the following guidelines should be used:
 - a. Lime - Apply liming materials based on the recommendations of a soil test in accordance with the approved nutrient management plan. If a nutrient management plan is not required, apply dolomitic limestone at the rate of 1 to 2 tons per acre. Apply limestone uniformly and incorporate into the top 4 to 6 inches of soil. For additional information, see **Section 3.4.3.1, Additional Standards and Specifications for Soil Testing**.
 - b. Fertilizer - Apply fertilizer based on the recommendations of a soil test in accordance with the approved nutrient management plan. If a nutrient management plan is not required, apply a formulation of 10-10-10 at the rate of 600 pounds per acre. Apply fertilizer uniformly and incorporate into the top 4 to 6 inches of soils. For additional information, see **Section 3.4.3.1, Additional Standards and Specifications for Soil Testing**.

4. Seeding

- a. **Figure 3.4.3.2a** contains a list of recommended seed species for temporary stabilization and optimum seeding dates. Alternative seed mixes may be used with prior approval from the Department or Delegated Agency.
- b. Apply seed uniformly with a broadcast seeder, drill, cultipacker seeder or hydroseeder. All seed will be applied at the recommended rate and planting depth.
- c. Seed that has been broadcast should be covered by raking or dragging and then lightly tamped into place using a roller or cultipacker. If hydroseeding is used and the seed and fertilizer is mixed, they will be mixed on site and the seeding shall be done immediately and without interruption.

5. Mulching

All mulching shall be done in accordance with **Section 3.4.5, Standard and Specifications for Mulching**.

TEMPORARY SEEDING BY RATES, DEPTHS AND DATES											
Mix #	Species ⁵	Seeding Rate		Optimum Seeding Dates ¹ O = Optimum Planting Period; A = Acceptable Planting Period							Planting Depth ³
	Certified Seed	lb/Ac. ⁴	lb/1000 sq.ft.	Coastal Plain			Piedmont			All	
				2/1-4/30	² 5/1-8/14	8/15-10/31	3/1-4/30	² 5/1-7/31	8/1-10/31	10/31-2/1	
1	Barley	125	4	O	A	O	O	A	O		1-2 inches 2-3" sandy soils
2	Oats	125	4	O	A	A	O	A	A		1-2 inches 2-3" sandy soils
3	Rye	125	4	O	A	O	O	A	O	A	1-2 inches 2-3" sandy soils
4	Perennial Ryegrass	125	4	O	A	O	O	A	O		0.5 inches 1-2" sandy soils
5	Annual Ryegrass	125	4	O	A	O	O	A	O	A	0.5 inches 1-2" sandy soils
6	Winter Wheat	125	4	O	A	O	O	A	O	A	1-2 inches 2-3" sandy soils
7	Foxtail Millet	30 PLS	0.7		O			O			0.5 inches 1-2" sandy soils
8	Pearl Millet	20 PLS	0.5		O			O			0.5 inches 1-2" sandy soils
<p>1. Winter seeding requires 3 tons per acre of straw mulch for proper stabilization.</p> <p>2. May be planted throughout summer if soil moisture is adequate or seeded area can be irrigated.</p> <p>3. Applicable on slopes 3:1 or less.</p> <p>4. Use varieties currently recommended for Delaware. Contact a County Extension Office for information.</p> <p>5. Warm season grasses such as Millet may be used between 5/1 and 9/1 if desired. Seed at 3-5 lbs. per acre. Good on low fertility and acid areas. Seed after frost through summer at a depth of 0.5".</p>											

Figure 3.4.3.2a Temporary seeding guidelines

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ADDITIONAL STANDARD AND SPECIFICATIONS FOR PERMANENT STABILIZATION

Definition: The establishment of perennial vegetation to provide permanent stabilization on disturbed areas.

Purpose: To permanently stabilize soil on disturbed areas and to reduce sediment and runoff to downstream or off-site areas.

Conditions Where Practice Applies

Graded or cleared areas subject to erosion and where a permanent, long-lived vegetative cover is needed. In most cases, vegetation is the preferred method of stabilizing bare soil because of its numerous benefits. However, it cannot be expected to provide an erosion control cover and prevent soil slippage on a soil that is not stable due to its texture, structure, water movement or excessively steep slope.

Minimum Soil Conditions Needed for the Establishment and Maintenance of Permanent Vegetative Cover

1. Enough fine-grained materials to provide the capacity to hold at least a moderate amount of available moisture.
2. Sufficient pore space to permit adequate root penetration.
3. The soil shall be free from any material harmful to plant growth.
4. If these conditions cannot be met, see **Section 3.4.1, Standard and Specifications for Topsoiling**.

Specifications

1. Site Preparation
 - a. Prior to seeding, install needed erosion and sediment control practices such as diversions, grade stabilization structures, berms, dikes, grassed waterways, and sediment basins.
 - b. Grade as needed and feasible to permit the use of conventional equipment for seedbed preparation, seeding, mulch application, anchoring and maintenance. All irregularities in the surface must be corrected in order to prevent the formation of depressions or water pockets.
2. Seedbed Preparation
 - a. It is important to prepare a good seedbed to ensure the success of establishing vegetation. The seedbed shall be well pulverized, loose, uniform, and free of large clods, rocks, and other objectionable material.
 - b. Flat areas and slopes up to 3:1 grade shall be loose and friable to a depth of at least 4 inches. The top layer of soil shall be loosened by raking, disking or other acceptable means before seeding.

-
- c. Slopes steeper than 3:1 shall have the top 1-3 inches of soil loose and friable before seeding.

3. Soil Amendments

- a. Lime - Apply liming materials based on the recommendations of a soil test in accordance with the approved nutrient management plan. If a nutrient management plan is not required, apply dolomitic limestone at the rate of 1 to 2 tons per acre. Apply limestone uniformly and incorporate into the top 4 to 6 inches of soil. For additional information, see **Section 3.4.3.1, Additional Standards and Specifications for Soil Testing**.
- b. Fertilizer - Apply fertilizer based on the recommendations of a soil test in accordance with the approved nutrient management plan. If a nutrient management plan is not required, apply 10-10-10 at the rate of 600 pounds per acre. Apply fertilizer uniformly and incorporate into the top 4 to 6 inches of soils. For additional information, see **Section 3.4.3.1, Additional Standards and Specifications for Soil Testing**.
- c. Incorporation - On sloping land, the final disking and harrowing operation should be on the contour wherever feasible. On slopes steeper than 3:1, the lime and fertilizer shall be worked in the best way possible.

4. Seeding

- a. **Figure 3.4.3.3a** contains a list of recommended seed mixes for various soil conditions and optimum seeding dates. Alternative seed mixes may be used with prior approval from the Department or Delegated Agency.
- b. Every bag of seed is required by law to have an analysis tag attached to it. This tag contains essential information about the content and quality of the turf seed therein. All of the data on the tag relates in some way to the seed in the bag. Following is a list of items and information that they represent:
 - ◆ “Product” is the species or type of seed that was tested.
 - ◆ “Lot” refers to the specific lot of seed tested, providing a tracking of the varieties, production field and components in the bag.
 - ◆ “% Purity” is the number of seeds of a species/variety, expressed as percentages of the whole, found in the mix. “VNS” means “Variety Not Stated” indicating uncertainty about the quality and characteristics of the seed.
 - ◆ “% Germination” refers to the percentage of seed that germinated during testing.
 - ◆ “Other Crop Seeds” is the percentage of crop seeds of the tested sample that have been found during a physical separation of the sample.
 - ◆ “Inert Matter” is the percentage of dust, stems, soil, chaff, etc. of the total weight of the tested sample.
 - ◆ “Weed Seed” refers to the percentage of weed seeds in a sample.
 - ◆ “Noxious Weeds” are the weed seeds considered by local law to be noxious. This number must always be zero.
 - ◆ “Origin”, “Net Weight” and “Date Tested” are self-explanatory.
- c. Apply seed uniformly with a broadcast seeder, drill, cultipacker or hydroseeder. All seed will be applied at the recommended rate and planting depth. Drill seeding is the preferred method, especially when light, fluffy seeds are in the mix. When hydroseeding is the chosen method, the total rate of seed should be

increased by 25% over the rates recommended in **Figure 3.4.3.3a**. Seed mixtures loaded into boxes or containers, such as those found on drill seeders, should be agitated to prevent stratification in the box. Some seeders are also equipped with multiple boxes to separate the seed by species, resulting in even distribution.

- d. Seed that has been broadcast must be covered by raking or dragging and then lightly tamped into place using a roller or cultipacker. If hydroseeding is used and the seed and fertilizer is mixed, they will be mixed on site and the seeding shall be done immediately and without interruption.

5. Mulching

All mulching shall be done in accordance with **Section 3.4.5, Standards and Specifications for Mulching**.

6. Irrigation

- a. Adequate moisture is essential for seed germination and plant growth. Daily irrigation can be critical in establishing permanent vegetation during dry or hot weather or on adverse site conditions.
- b. Irrigation must be carefully controlled to prevent runoff and subsequent erosion. Inadequate or excessive irrigation can do more harm than good.

7. Maintenance

- a. It takes one full year to establish permanent vegetation from the time of planting. Inspect seeded areas for failure and reestablish vegetation as soon as possible. Depending on site conditions, it may be necessary to irrigate, fertilize, overseed, or re-establish plantings in order to provide permanent vegetation for adequate erosion control.
- b. Maintenance fertilization rates should be established by soil test recommendations in accordance with an approved nutrient management plan. Spring seedings may require an application of fertilizer between September 1 and October 15, at least every two years. Fall seedings may require the same between March 15 and May 1 the following year. If slow-release fertilizer is used, follow-up fertilizations may not be necessary for several years. Lime according to soil test recommendations at least once every five years. For additional information, see **Section 3.4.3.1, Additional Standards and Specifications for Soil Testing**.

8. Special Conditions

Under certain site conditions, alternative vegetative stabilization techniques are necessary. Examples include steeply sloped areas, extremely low fertility soils, acidic soils (pH less than 4.0) and dune stabilization. When any of these or other unusual site conditions are encountered, DNREC and/or the appropriate delegated agency may require products, seed species, mixtures and rates other than those listed in the following tables in order to achieve successful stabilization.

PERMANENT SEEDING AND SEEDING DATES													
Seeding Mixtures		Seeding Rate ¹		Optimum Seeding Dates ² O = Optimum Planting Period A = Acceptable Planting Period								Remarks	
Mix No.	Certified Seed ³	lb/Ac	lb/1000 sq. ft.	Coastal Plain				Piedmont				All ⁴	
				2/1-4/30	5/1-8/14	8/15-10/31	3/1-4/30	5/1-7/31	8/1-10/31			10/31-2/1	
1	Tall Fescue Canada Wild Rye	140 10	3.2 0.23	A	O	A	A	O	A			Add 100 lbs./ac Winter Rye	Good erosion control mix Tolerant of low fertility soils Good for droughty sites
2	Deertongue Sheep Fescue White Clover	30 30 10	0.69 0.69 0.35	A	O	A	A	O	A			Add 100 lbs./ac Winter Rye	Good erosion control mix Tolerant of low fertility soils Legume that fixes atmospheric N into soil
3	Tall Fescue (Turf-type) or Strong Creeping Red Fescue or Perennial Ryegrass plus Flatpea ⁵	50 50 50 15	1.15 1.15 1.15 0.34	O	A ⁴	O	O	A ⁴	O			Add 100 lbs./ac. Winter Rye	Good erosion control mix Tall Fescue for droughty conditions. Creeping Red Fescue for heavy shade. Flatpea to suppress woody vegetation.
4	Strong Creeping Red Fescue Kentucky Bluegrass Perennial Ryegrass or Redtop plus White Clover ⁵	100 70 15 5 3	2.3 1.61 0.35 0.11 0.07	O	A ⁴	O	O	A ⁴	O			Add 100 lbs./ac. Winter Rye	Suitable waterway mix. Canada Bluegrass more drought tolerant. Use Redtop for increased drought tolerance.
5	Switchgrass ^{6,7} or Coastal Panicgrass Big Bluestem Little Bluestem Indian Grass	10 10 5 5 5	0.23 0.23 0.11 0.11 0.1		O				O				Native warm-season mixture. Tolerant of low fertility soils. Drought tolerant. Poor shade tolerance. N fertilizer discouraged - weeds
6	Tall Fescue (turf-type) (Blend of 3 cultivars)	150	3.5	O	A ⁴	O	O	A ⁴	O				Managed filter strip for nutrient uptake.
7	Tall Fescue Ky. Bluegrass (Blend) Perennial Ryegrass	150 20 20	3.5 0.46 0.46	O	A ⁴	O	O	A ⁴	O				Three cultivars of Kentucky Bluegrass. Traffic tolerant.
8	Big Bluestem ⁷ Indian Grass ⁷ Little Bluestem ⁷ Creeping Red Fescue plus one of: Partridge Pea Bush Clover Wild Indigo Showy Tick-Trefoil	10 10 8 30 5 3 3 2	0.23 0.23 0.18 0.69 0.11 0.07 0.07 0.05	O	A ⁴		O						All species are native. Indian Grass and Bluestem have fluffy seeds. Plant with a specialized native seed drill. Creeping Red Fescue will provide erosion protection while the warm season grasses get established.

Figure 3.4.3.3a Seed mixes and recommended seeding dates

PERMANENT SEEDING AND SEEDING DATES (cont.)												
Seeding Mixtures		Seeding Rate ¹		Optimum Seeding Dates ² O = Optimum Planting Period A = Acceptable Planting Period								Remarks
Mix No.	Certified Seed ³	lb/Ac	lb/1000 sq.ft.	Coastal Plain				Piedmont			All ⁴	
				2/1-4/30	5/1-8/14	8/15-10/31	3/1-4/30	5/1-7/31	8/1-10/31	10/31-2/1		
9	Redtop Creeping Bentgrass Sheep Fescue Rough Bluegrass	75 35 30 45	1.72 0.8 0.69 1	O	A ⁴	O	O	A ⁴	O	Add 100 lbs./ac. Winter Rye		Quick stabilization of disturbed sites and waterways
10	Switchgrass ⁶	10	0.23	A		O	A		O			Good erosion control, wildlife cover and wetland revegetation.
Residential Lawns												
11	Tall Fescue Perennial Ryegrass Kentucky Bluegrass Blend	100 25 30	2.3 0.57 0.69	O	A ⁴	O	O	A ⁴	O			High value, high maintenance, light traffic, irrigation necessary. Well drained soils, full sun.
12	Tall Fescue Perennial Ryegrass Sheep Fescue	100 25 25	2.3 0.57 0.57	O	A ⁴	O	O	A ⁴	O			Moderate value, low maintenance, traffic tolerant
13	Creeping Red Fescue Chewings Fescue Rough Bluegrass Kentucky Bluegrass	50 50 20 20	1.15 1.15 0.4 0.4	O	A ⁴	O	O	A ⁴	O			Shade tolerant, moderate traffic tolerance, moderate maintenance.
14	Creeping Red Fescue Rough Bluegrass or Chewings Fescue	50 90	1.15 2.1	O	A ⁴	O	O	A ⁴	O			Shade tolerant, moisture tolerant.
15	K-31 Tall Fescue	150	3.5	O	A ⁴	O	O	A ⁴	O			Monoculture, but performs well alone in lawns. Discouraged.

1. When hydroseeding is the chosen method of application, the total rate of seed should be increased by 25%.
2. Winter seeding requires 3 tons per acre of straw mulch. Planting dates listed above are average for Delaware. These dates may require adjustment to reflect local conditions.
3. All seed shall meet the minimum purity and minimum germination percentages recommended by the Delaware Department of Agriculture. The maximum % of weed seeds shall be in accordance with Chapter 15, Title 3 of the Delaware Code.
4. Turf-type species may be planted throughout summer if soil moisture is adequate or seeded area can be irrigated.
5. It is recommended that all leguminous seed be inoculated.
6. Warm season grass mix and Switchgrass cannot be mowed more than 4 times per year.
7. Warm season grasses require a soil temperature of at least 50 degrees in order to germinate and will remain dormant until then.

Figure 3.4.3.3a Seed mixes and recommended seeding dates (cont.)

Permanent Stabilization Mixtures for Various Uses		
	Planting Mixtures by Soil Drainage Class	
Application	Well Drained Soils ¹	Poorly Drained Soils ¹
Residential/commercial lots	11,12,13,15	14,15
Residential open space	8	Contact plant specialist for site specific recommendations.
Pond and channel banks, dikes, berms and dams	2, 4	9,10,14
Drainage ditches, swales, detentions basins	3, 4, 13	9,14
Filter strips	2, 5, 6	6, 13
Grassed waterways, spillways	1,2,4	6, 9
Recreation areas, athletic fields	7,15	14,15
Steep slopes and banks, roadsides, borrow areas	1,2,3,4	4, 6
Sand and gravel pits, sanitary landfills	1,2,3,5	3, 4
Dredged material, spoilbanks, borrow areas	1,2	9,10
Streambanks and shorelines ²	2, 3	2, 3
Utility rights-of-way	1,2,3,4	3,14

1. Refer to **Fig. 3.4.3.3a** for detailed information on seed mixes.

2. Refer to Chapters 16 and 18 of the NRCS Field Engineering Manual for additional measures.

NOTE: Refer to NRCS critical area planting standard for additional seed mixtures.

Figure 3.4.3.3b Seed mix selection chart

SPECIES	RECOMMENDED SEED VARIETIES
Tall Fescue	Alamo E, Apache II, Guardian, Rebel II, Shenandoah, Safari, Crossfire, Titan 2, Duke, Barrington, Comstock, Crossfire, Dominion, Heritage, Plantation, Rebel 2000, Titan 2
Kentucky Blue Grass	<i>Low Maintenance Varieties</i> : Barirus, Caliber, Eagleton, Freedom, Haga, Livingston, Merit, Midnight, Monopoly, Washington <i>Shade Tolerant Varieties</i> : Princeton, America, Brilliant, Champagne, Coventry, Unique, Liberator, Moonlight, Showcase, Nuglade, Compact
Perennial Rye Grass	Palmer III, Blazer II, Pennfine, Seville, Pinnacle, Pick MDR
Creeping Red Fescue	Cindy Lou, Jasper, Dawson, Pennlawn, Flyer, Ruby, Salem
Red Top	Streaker, Barracuda
Chewings Fescue	Longfellow, Jamestown, Discovery, Scaldis, Bighorn

NOTES:

1. The grass species listed in **Fig. 3.4.3.3a** are often available in many varieties. The seed choices listed above are the recommended varieties based on regional performance and availability.

2. The varieties listed above are examples of recommended varieties. Contact University of Delaware, Cooperative Extension Service for additional information.

Figure 3.4.3.3c Recommended seed varieties

ADDITIONAL STANDARD AND SPECIFICATIONS FOR SODDING

Definition: The establishment of grass to provide permanent stabilization on disturbed areas using sod.

Purpose: To provide immediate vegetative cover in order to stabilize soil on disturbed areas.

Conditions Where Practice Applies

Disturbed areas that require immediate and permanent vegetative cover, areas where sodding is the preferred means of grass establishment or areas where prompt use and aesthetics are important.

Special Conditions

1. Turfgrass sod shall be certified for use in the State of Delaware. It should be at least 1 year old, but no more than 3 years old.
2. Sod shall be machine cut at a uniform soil thickness of $\frac{3}{4}$ inch, plus or minus $\frac{1}{4}$ inch, at the time of cutting. Measurement for thickness shall exclude top growth and thatch.
3. Standard size sections of sod shall be strong enough to support their own weight and retain their size and shape when lifted from one end. All sod shall be uniform; broken, torn or uneven sections will not be acceptable.
4. Sod shall not be harvested or transplanted when moisture content (excessively dry or wet) may adversely affect its survival.
5. Sod should be harvested, delivered and installed within a period of 36 hours. Sod not transplanted within this period shall be inspected and approved prior to its installation.
6. The preferred planting period for sod is early fall (September) followed by the period between February 15 and April 30. Sod can be laid between May 1 and August 30 with frequent supplemental watering. When planted after October 1, frost-heaving can be a problem if sufficient rooting has not taken place.

Specifications

1. Surface Preparation
 - a. Before laying sod, the surface shall be uniformly graded and cleared of all roots, brush, trash, and debris. Stones and clods larger than 2 inches shall also be removed.
 - b. Surfaces that have become hard packed shall be scarified prior to laying sod.
2. Soil Amendments
 - a. Lime - Apply liming materials based on the recommendations of a soil test in accordance with the approved nutrient management plan. If a nutrient management plan is not required, apply dolomitic

limestone at the rate of 1 to 2 tons per acre. Apply limestone uniformly and incorporate into the top 4 to 6 inches of soil. For additional information, see **Section 3.4.3.1, Additional Standards and Specifications for Soil Testing**.

- b. Fertilizer - Apply fertilizer based on the recommendations of a soil test in accordance with the approved nutrient management plan. If a nutrient management plan is not required, apply 10-10-10 at the rate of 600 pounds per acre. Apply fertilizer uniformly and incorporate into the top 4 to 6 inches of soils. For additional information, see **Section 3.4.3.1, Additional Standards and Specifications for Soil Testing**.

3. Sod Installation

- a. During periods of excessively high temperature, the soil shall be lightly irrigated immediately prior to laying the sod.
- b. The first row of sod shall be laid in a straight line with subsequent rows placed parallel to and tightly wedged against each other. Lateral joints shall be staggered in a brick-like pattern. Insure that sod is not stretched or overlapped and that all joints are butted tight in order to prevent voids which would cause drying of the roots.
- c. The sod industry generally recommends that on sloping areas where erosion might be a problem, sod should be laid with the long edges parallel to the contour, with staggered joints and secured with pegs or staples. However, on long slope lengths, this could make the installation prone to slump failure. A well pegged vertical installation may be preferable under these conditions with prior approval. If possible, divert runoff away from the slope until root establishment.
- d. As sodding is completed in any one section, the entire area shall be rolled or tamped to insure solid contact of roots with the soil surface. Sod shall be watered immediately after rolling or tamping until the underside of the new sod and soil surface below the sod are thoroughly wet. The operations of laying, tamping and irrigating for any piece of sod shall be completed within eight hours.

4. Sod Maintenance

- a. In the absence of adequate rainfall, watering shall be performed daily or as often as necessary during the first week and in sufficient quantities to maintain moist soil to a depth of 4 inches.
- b. After the first week, sod shall be watered as necessary to maintain adequate moisture and insure establishment. Never allow sod to dry out completely.
- c. The first mowing should not be attempted until sod is firmly rooted. No more than 1/3 of the grass leaf shall be removed by the initial cutting or subsequent cuttings. Grass height shall be maintained between 2 and 3 inches unless otherwise specified.
- d. Maintenance of established sod includes fertilization in spring and fall based on soil test recommendations in accordance with an approved nutrient management plan. Lime according to soil test recommendations at least once every five years. For additional information, see **Section 3.4.3.1, Additional Standards and Specifications for Soil Testing**.

Standard Detail & Specifications

Vegetative Stabilization

TEMPORARY SEEDING BY RATES, DEPTHS AND DATES

Mix #	Species ⁵	Seeding Rate		Optimum Seeding Dates ¹ O = Optimum Planting Period; A = Acceptable Planting Period							Planting Depth ³
	Certified Seed	lb/Ac ⁴	lb/1000 sq.ft.	Coastal Plain			Piedmont			All	
				2/1-4/30	2 5/1-8/14	8/15-10/31	3/1-4/30	2 5/1-7/31	8/1-10/31	10/31-2/1	
1	Barley	125	4	O	A	O	O	A	O		1-2 inches 2-3" sandy soils
2	Oats	125	4	O	A	A	O	A	A		1-2 inches 2-3" sandy soils
3	Rye	125	4	O	A	O	O	A	O	A	1-2 inches 2-3" sandy soils
4	Perennial Ryegrass	125	4	O	A	O	O	A	O		0.5 inches 1-2" sandy soils
5	Annual Ryegrass	125	4	O	A	O	O	A	O	A	0.5 inches 1-2" sandy soils
6	Winter Wheat	125	4	O	A	O	O	A	O	A	1-2 inches 2-3" sandy soils
7	Foxtail Millet	30 PLS	0.7		O			O			0.5 inches 1-2" sandy soils
8	Pearl Millet	20 PLS	0.5		O			O			0.5 inches 1-2" sandy soils

1. Winter seeding requires 3 tons per acre of straw mulch for proper stabilization.
2. May be planted throughout summer if soil moisture is adequate or seeded area can be irrigated.
3. Applicable on slopes 3:1 or less.
4. Use varieties currently recommended for Delaware. Contact a County Extension Office for information.
5. Warm season grasses such as Millet may be used between 5/1 and 9/1 if desired. Seed at 3-5 lbs. per acre. Good on low fertility and acid areas. Seed after frost through summer at a depth of 0.5".

NOTE: Alternative seed mixes may be used with prior approval from the Department or Delegated Agency.

Source:

Delaware ESC Handbook

Symbol:

Detail No.

DE-ESC-3.4.3

Sheet 1 of 4

Effective July 2023

Standard Detail & Specifications

Vegetative Stabilization

PERMANENT SEEDING AND SEEDING DATES											
Seeding Mixtures		Seeding Rate ¹		Optimum Seeding Dates ² O = Optimum Planting Period A = Acceptable Planting Period						Remarks	
Mix No.	Certified Seed ³			Coastal Plain			Piedmont			All ⁴	
	Well Drained Soils	lb/Ac	lb/1000 sq.ft.	2/1-4/30	5/1-8/14	8/15-10/31	3/1-4/30	5/1-7/31	8/1-10/31	10/31-2/1	
1	Tall Fescue Canada Wild Rye	140 10	3.2 0.23	A O	O A	A A	A O	O A	A A	Add 100 lbs./ac. Winter Rye	Good erosion control mix Tolerant of low fertility soils Good for droughty sites
2	Deertongue Sheep Fescue White Clover	30 30 10	0.69 0.69 0.35	A O A	O A A	A A A	A O A	O A A	A A A	Add 100 lbs./ac. Winter Rye	Good erosion control mix Tolerant of low fertility soils Legume that fixes atmospheric N into soil
3	Tall Fescue (Turf-type) or Strong Creeping Red Fescue or Perennial Ryegrass plus Flatpea ⁵	50 50 50 15	1.15 1.15 1.15 0.34	O O O O	A ⁴ A ⁴ A ⁴ A ⁴	O O O O	O O O O	A ⁴ A ⁴ A ⁴ A ⁴	O O O O	Add 100 lbs./ac. Winter Rye	Good erosion control mix Tall Fescue for droughty conditions. Creeping Red Fescue for heavy shade. Flatpea to suppress woody vegetation.
4	Strong Creeping Red Fescue Kentucky Bluegrass Perennial Ryegrass or Redtop plus White Clover ⁵	100 70 15 5 3	2.3 1.61 0.35 0.11 0.07	O O O O O	A ⁴ A ⁴ A ⁴ A ⁴ A ⁴	O O O O O	O O O O O	A ⁴ A ⁴ A ⁴ A ⁴ A ⁴	O O O O O	Add 100 lbs./ac. Winter Rye	Suitable waterway mix. Canada Bluegrass more drought tolerant. Use Redtop for increased drought tolerance.
5	Switchgrass ^{6,7} or Coastal Panicgrass Big Bluestem Little Bluestem Indian Grass	10 10 5 5 5	0.23 0.23 0.11 0.11 0.1	O O O O O	A ⁴ A ⁴ A ⁴ A ⁴ A ⁴	O O O O O	O O O O O	A ⁴ A ⁴ A ⁴ A ⁴ A ⁴	O O O O O		Native warm-season mixture. Tolerant of low fertility soils. Drought tolerant. Poor shade tolerance. N fertilizer discouraged - weeds
6	Tall Fescue (turf-type) (Blend of 3 cultivars)	150	3.5	O	A ⁴	O	O	A ⁴	O		Managed filter strip for nutrient uptake.
7	Tall Fescue Ky. Bluegrass (Blend) Perennial Ryegrass	150 20 20	3.5 0.46 0.46	O O O	A ⁴ A ⁴ A ⁴	O O O	O O O	A ⁴ A ⁴ A ⁴	O O O		Three cultivars of Kentucky Bluegrass. Traffic tolerant.
8	Big Bluestem ⁷ Indian Grass ⁷ Little Bluestem ⁷ Creeping Red Fescue plus one of: Partridge Pea Bush Clover Wild Indigo Showy Tick-Trefoil	10 10 8 30 5 3 3 2	0.23 0.23 0.18 0.69 0.11 0.07 0.07 0.05	O O O O O O O O	A ⁴ A ⁴ A ⁴ A ⁴ A ⁴ A ⁴ A ⁴ A ⁴	O O O O O O O O	O O O O O O O O	A ⁴ A ⁴ A ⁴ A ⁴ A ⁴ A ⁴ A ⁴ A ⁴	O O O O O O O O		All species are native. Indian Grass and Bluestem have fluffy seeds. Plant with a specialized native seed drill. Creeping Red Fescue will provide erosion protection while the warm season grasses get established.

NOTE: Alternative seed mixes may be used with prior approval from the Department or Delegated Agency.

Source:

Delaware ESC Handbook

Symbol:

Detail No.

DE-ESC-3.4.3

Sheet 2 of 4

Effective July 2023

Standard Detail & Specifications

Vegetative Stabilization

PERMANENT SEEDING AND SEEDING DATES (cont.)											
Seeding Mixtures		Seeding Rate ¹		Optimum Seeding Dates ² O = Optimum Planting Period A = Acceptable Planting Period						Remarks	
Mix No.	Certified Seed ³			Coastal Plain			Piedmont			All ⁴	
	Poorly Drained Soils	lb/Ac	lb/1000 sq.ft.	2/1-4/30	5/1-8/14	8/15-10/31	3/1-4/30	5/1-7/31	8/1-10/31	10/31-2/1	
9	Redtop Creeping Bentgrass Sheep Fescue Rough Bluegrass	75 35 30 45	1.72 0.8 0.69 1	O	A ⁴	O	O	A ⁴	O	Add 100 lbs./ac. Winter Rye	Quick stabilization of disturbed sites and waterways
10	Switchgrass ⁶	10	0.23	A		O	A		O		Good erosion control, wildlife cover and wetland revegetation.
Residential Lawns											
11	Tall Fescue Perennial Ryegrass Kentucky Bluegrass Blend	100 25 30	2.3 0.57 0.69	O	A ⁴	O	O	A ⁴	O		High value, high maintenance, light traffic, irrigation necessary. Well drained soils, full sun.
12	Tall Fescue Perennial Ryegrass Sheep Fescue	100 25 25	2.3 0.57 0.57	O	A ⁴	O	O	A ⁴	O		Moderate value, low maintenance, traffic tolerant
13	Creeping Red Fescue Chewings Fescue Rough Bluegrass Kentucky Bluegrass	50 50 20 20	1.15 1.15 0.4 0.4	O	A ⁴	O	O	A ⁴	O		Shade tolerant, moderate traffic tolerance, moderate maintenance.
14	Creeping Red Fescue Rough Bluegrass or Chewings Fescue	50 90	1.15 2.1	O	A ⁴	O	O	A ⁴	O		Shade tolerant, moisture tolerant.
15	K-31 Tall Fescue	150	3.5	O	A ⁴	O	O	A ⁴	O		Monoculture, but performs well alone in lawns. Discouraged.

- When hydroseeding is the chosen method of application, the total rate of seed should be increased by 25%.
- Winter seeding requires 3 tons per acre of straw mulch. Planting dates listed above are average for Delaware. These dates may require adjustment to reflect local conditions.
- All seed shall meet the minimum purity and minimum germination percentages recommended by the Delaware Department of Agriculture. The maximum % of weed seeds shall be in accordance with Chapter 15, Title 3 of the Delaware Code.
- Turf-type species may be planted throughout summer if soil moisture is adequate or seeded area can be irrigated.
- It is recommended that all leguminous seed be inoculated.
- Warm season grass mix and Switchgrass cannot be mowed more than 4 times per year.
- Warm season grasses require a soil temperature of at least 50 degrees in order to germinate and will remain dormant until then.

NOTE: Alternative seed mixes may be used with prior approval from the Department or Delegated Agency.

Source:

Delaware ESC Handbook

Symbol:

Detail No.

DE-ESC-3.4.3

Sheet 3 of 4

Effective July 2023

Standard Detail & Specifications

Vegetative Stabilization

Construction Notes:

1. Site Preparation

- a. Prior to seeding, install needed erosion and sediment control practices such as diversions, grade stabilization structures, berms, dikes, grassed waterways, and sediment basins.
- b. Final grading and shaping is not necessary for temporary seedings.

2. Seedbed Preparation

It is important to prepare a good seedbed to ensure the success of establishing vegetation. The seedbed should be well prepared, loose, uniform, and free of large clods, rocks, and other objectionable material. The soil surface should not be compacted or crusted.

3. Soil Amendments

- a. Lime - Apply liming materials based on the recommendations of a **soil test** in accordance with the approved nutrient management plan. If a nutrient management plan is not required, apply dolomitic limestone at the rate of 1 to 2 tons per acre. Apply limestone uniformly and incorporate into the top 4 to 6 inches of soil.
- b. Fertilizer - Apply fertilizer based on the recommendations of a **soil test** in accordance with the approved nutrient management plan. If a nutrient management plan is not required, apply a formulation of 10-10-10 at the rate of 600 pounds per acre. Apply fertilizer uniformly and incorporate into the top 4 to 6 inches of soils.

4. Seeding

- a. For **temporary stabilization**, select a mixture from **Sheet 1** . For a **permanent stabilization**, select a mixture from **Sheet 2** or **Sheet 3** depending on the conditions. Alternative seed mixes may be used with prior approval from the Department or Delegated Agency.
- b. Apply seed uniformly with a broadcast seeder, drill, cultipacker seeder or hydroseeder. All seed will be applied at the recommended rate and planting depth.
- c. Seed that has been broadcast should be covered by raking or dragging and then lightly tamped into place using a roller or cultipacker. If hydroseeding is used and the seed and fertilizer is mixed, they will be mixed on site and the seeding shall be done immediately and without interruption.

5. Mulching

All mulching shall be done in accordance with detail **DE-ESC-3.4.5**.

Source: Delaware ESC Handbook	Symbol:	Detail No. DE-ESC-3.4.3 Sheet 4 of 4 Effective July 2023
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STANDARD AND SPECIFICATIONS FOR STREAMBANK AND SHORELINE STABILIZATION



Definition: Using vegetation or structures to stabilize and protect banks of streams, lakes, estuaries, or excavated channels against scour and erosion.

Scope: This standard applies to measures used to stabilize and protect the banks of streams, lakes, estuaries, and excavated channels. It does not apply to erosion problems on main ocean fronts and similar areas of complexity. All revetments, bulkheads, or groins are to be no higher than 3 ft. above mean high tide or, in nontidal areas, no higher than 3 ft. above mean high water.

Purpose: To stabilize or protect banks of streams, lakes, estuaries, or excavated channels for one or more of the following purposes:

1. To prevent the loss of land or damage to utilities, roads, buildings, or other facilities adjacent to the banks,
2. To maintain the capacity of the channel,
3. To control channel meander that would adversely affect downstream facilities,
4. To reduce sediment loads causing downstream damages and pollution, or
5. To improve the stream for recreation or as a habitat for fish and wildlife.

Condition where Practice Applies:

This practice applies to natural or excavated channels where the streambanks are susceptible to erosion from the action of water, ice, or debris or to damage from livestock or vehicular traffic. It also applies to controlling erosion on shorelines where the problem can be solved with relatively simple structural measures, vegetation, or upland erosion control practices and where failure of structural measures will not create a hazard to life or result in serious damage to property.

Planning Considerations

Water Quantity

1. Effects on the water budget, especially on volumes and rates of runoff, infiltration, deep percolation, and ground water recharge.
2. Effects on downstream flows and aquifers that affect other uses and users.
3. Effects on the water table of adjoining fields.
4. Effects on the interflow discharge into streams.

Water Quality

1. Filtering effects of vegetation on movement of sediment, and sediment-attached and dissolved substances.
2. Effects on erosion and movement of sediment, and soluble and sediment-attached substances carried by runoff and streamflow.
3. Effects on the visual quality of onsite and downstream water resources.
4. Effects of construction and vegetation establishment on quality.
5. Effects of changes in water temperatures.
6. Short-term and long-term effects on wetlands and water-related wildlife habitats.

Design Criteria

Because each reach of a channel, lake, or estuary is unique, measures for streambank and shore protection must be installed according to a plan and adapted to the specific site. The Natural Resources Conservation Service (NRCS) has developed guidelines for streambank and shoreline stabilization in Chapter 16 of their Engineering Field Manual (refer to **Design Guide 3** of this handbook). However, applying these guidelines often requires specialized expertise in hydrology, hydraulics, geomorphology, geotechnology and the plant sciences. A poor design can lead to serious consequences, potentially worse than the original problem. *Therefore, practitioners are cautioned against designing streambank and shoreline stabilization measures without appropriate expertise.*

Designs for streambanks shall be according to the following principles:

1. Protective measures to be applied shall be compatible with improvements planned or being carried out by others.
2. The grade must be controlled, either by natural or artificial means, before any permanent type of bank protection can be considered feasible, unless the protection can be safely and economically constructed to a depth well below the anticipated lowest depth of bottom scour.
3. Streambank protection shall be started at a stabilized or controlled point and ended at a stabilized or controlled point on the stream.
4. Needed channel clearing to remove stumps, fallen trees, debris, and bars that force the streamflow into the streambank shall be an initial element of the work.
5. Changes in channel alignment shall be made only after an evaluation of the effect on the land use, interdependent water disposal systems, hydraulic characteristics, and existing structures.
6. Structural measures must be effective for the design flow and be able to withstand greater floods without serious damage. They shall also be designed to avoid an increase in erosion downstream of planned measures.
7. Vegetative protection shall be considered on the upper parts of eroding banks, especially on areas that are susceptible to infrequent inundation.

Streambank Protection Measures

The following is a partial list of elements that may be included in a plan for streambank protection. Figure 3.4.4a illustrates many of these measures and summarizes their key features.

1. Removal of fallen trees, stumps, debris, minor ledge outcroppings, and sand and gravel bars that may cause local current turbulence and deflection.
2. Removal of trees and brush that adversely affect the growth of desirable bank vegetation.
3. Reduction of the slope of streambanks to provide a suitable condition for vegetative protection or for the installation of structural bank protection.
4. Placed or dumped heavy stone, properly underlaid with a filter blanket, if necessary, to provide armor protection for streambanks.

-
5. Deflectors constructed of posts, piling, fencing, rock, brush, or the materials that project into the stream to protect banks at curves and reaches subjected to impingement by high velocity currents.
 6. Pervious or impervious structures built on or parallel to the stream to prevent scouring streamflow velocities adjacent to the streambank.
 7. Artificial obstructions, such as fences, to protect vegetation needed for streambank protection or to protect critical areas from damage from stock trails or vehicular traffic.

Designs for shoreline protection shall be according to the following principles:

1. Treatment depends on soil type and the slope characteristics both above and below the waterline. Slope characteristics below the waterline shall be representative of the slope for a minimum of 50 ft (15 m) distance from the shore.
2. End sections shall be adequately bonded to existing measures or terminate in stable areas.
3. Design water surface shall be mean high tide or in nontidal areas the mean high water.
4. Control of surface runoff and internal drainage shall be considered in the design and installation of all shore protection measures.

Shoreline Protection Measures

The following is a partial list of protection measures that may be used. **Figure 3.4.4a** illustrates many of these measures and summarizes their key features.

1. Bulkheads (timber, concrete, concrete block).
2. Revetments (prefabricated slope protection blocks, riprap, soil cement).
3. Groin systems (timber or concrete).
4. Vegetation of the type that will grow across or along the waterline.

Other Considerations

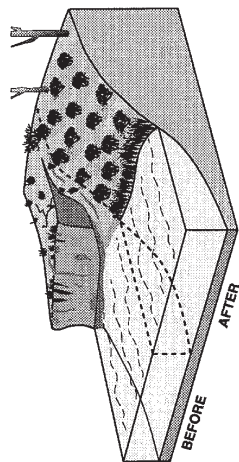
1. Special attention shall be given to maintaining or improving habitat for fish and wildlife.
2. Considerations shall be given to the use of construction materials, grading practices, vegetation, and other site development elements that minimize visual impacts and maintain or complement existing landscape uses such as pedestrian paths, climate controls, buffers, etc.

Standard Details and Specifications

As mentioned above, streambank and shoreline stabilization requires site specific plans. It is therefore impossible to develop a set of standard details and specifications which would meet the requirements of each situation. However, **Design Guide 3** does contain generic details of various measures which may serve as the basis for site specific plans.

STREAMBANK TREATMENT

BANK SHAPING AND PLANTING

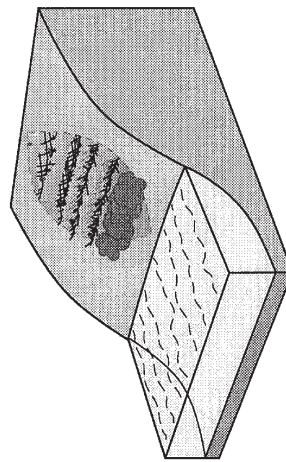


Regrading streambanks to a stable slope, placing topsoil and other materials needed for sustaining plant growth, and selecting, installing and establishing appropriate plant species.

Applications and Effectiveness

- Most successful on streambanks where moderate erosion and channel migration are anticipated.
- Reinforcement at the toe of the embankment is often needed.
- Enhances conditions for colonization of native species.
- Used in conjunction with other protective practices where flow velocities exceed the tolerance range for available plants, and where erosion occurs below base flows.
- Streambank soil materials, probable groundwater fluctuation, and bank loading conditions are factors for determining appropriate slope conditions.
- Slope stability analyses are recommended.

BRANCH PACKING



Alternate layers of live branches and compacted backfill which stabilize and revegetate slumps and holes in streambanks.

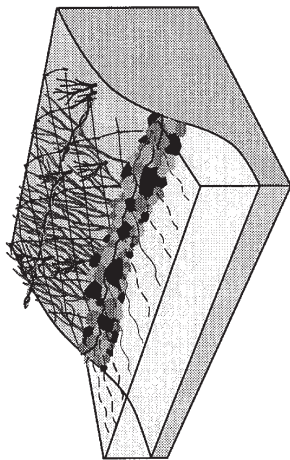
Applications and Effectiveness

- Commonly used where patches of streambank have been scoured out or have slumped leaving a void.
- Appropriate after stresses causing the slump have been removed.
- Less commonly used on eroded slopes where excavation is required to install the branches.
- Produces a filter barrier that prevents erosion and scouring from streambank or overbank flows.
- Rapidly establishes a vegetated streambank.
- Enhances conditions for colonization of native species.
- Provides immediate soil reinforcement.
- Live branches serve as tensile inclusions for reinforcement once installed.
- Typically not effective in slump areas greater than four feet deep or four feet wide.

Figure 3.4.4a, Sheet 1 of 8, Streambank and shoreline stabilization practices
Source: USDA-NRCS, Stream Corridor Restoration: Principles Processes, and Practices

STREAMBANK TREATMENT

BRUSH MATTRESSES

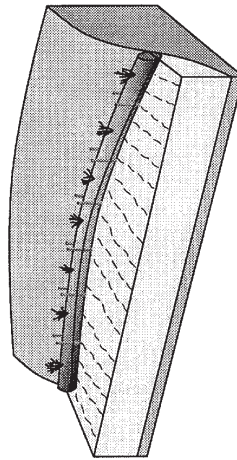


Combination of live stakes, live facines, and branch cuttings installed to cover and physically protect streambanks; eventually to sprout and establish numerous individual plants.

Applications and Effectiveness

- Form an immediate protective cover over the streambank.
- Capture sediment during flood flows.
- Provide opportunities for rooting of the cuttings over the streambank.
- Rapidly restores riparian vegetation and streamside habitat.
- Enhance conditions for colonization of native vegetation.
- Limited to the slope above base flow levels.
- Toe protection is required where toe scour is anticipated.
- Appropriate where exposed streambanks are threatened by high flows prior to vegetation establishment.
- Should not be used on slopes which are experiencing mass movement or other slope instability.

COCONUT FIBER ROLL



Cylindrical structures composed of coconut husk fibers bound together with twine woven from coconut material to protect slopes from erosion while trapping sediment which encourages plant growth within the fiber roll.

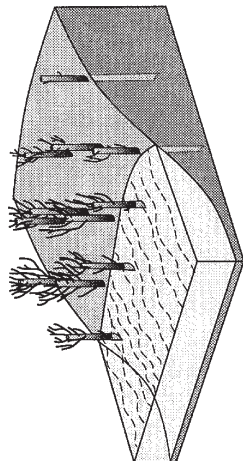
Applications and Effectiveness

- Most commonly available in 12 inch diameter by 20 foot lengths.
- Typically staked near the toe of the streambank with dormant cuttings and rooted plants inserted into slits cut into the rolls.
- Appropriate where moderate toe stabilization is required in conjunction with restoration of the streambank and the sensitivity of the site allows for only minor disturbance.
- Provide an excellent medium for promoting plant growth at the water's edge.
- Not appropriate for sites with high velocity flows or large ice build up.
- Flexibility for molding to the existing curvature of the streambank.
- Requires little site disturbance.
- The rolls are buoyant and require secure anchoring.
- Can be expensive.
- An effective life of 6 to 10 years.
- Should, where appropriate, be used with soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerative source of streamside vegetation.
- Enhances conditions for colonization of native vegetation.

Figure 3.4.4a, Sheet 2 of 8, Streambank and shoreline stabilization practices
Source: USDA-NRCS, Stream Corridor Restoration: Principles Processes, and Practices

STREAMBANK TREATMENT

DORMANT POST PLANTINGS

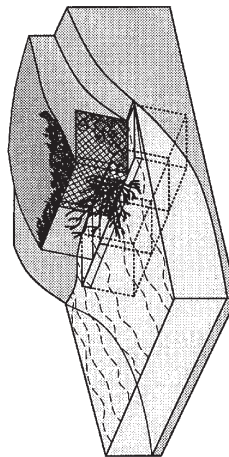


Plantings of cottonwood, willow, poplar, or other species embedded vertically into streambanks to increase channel roughness, reduce flow velocities near the slope face, and trap sediment.

Applications and Effectiveness

- Can be used as live piling to stabilize rotational failures on streambanks where minor bank sloughing is occurring.
- Useful for quickly establishing riparian vegetation, especially in arid regions where water tables are deep.
- Will reduce near bank stream velocities and cause sediment deposition in treated areas.
- Reduce streambank erosion by decreasing the near-bank flow velocities.
- Generally self-repairing and will restem if attacked by beaver or livestock; however, provisions should be made to exclude such herbivores where possible.
- Best suited to non-gravelly streams where ice damage is not a problem.
- Will enhance conditions for colonization of native species.
- Are less likely to be removed by erosion than live stakes or smaller cuttings.
- Should, where appropriate, be used with soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerative source of streamside vegetation.
- Unlike smaller cuttings, post harvesting can be very destructive to the donor stand, therefore, they should be gathered as 'salvage' from sites designated for clearing, or thinned from dense stands.

VEGETATED GABIONS



Wire-mesh, rectangular baskets filled with small to medium size rock and soil and laced together to form a structural toe or sidewall. Live branch cuttings are placed on each consecutive layer between the rock filled baskets to take root, consolidate the structure, and bind it to the slope.

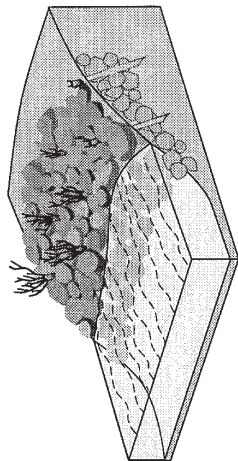
Applications and Effectiveness

- Useful for protecting steep slopes where scouring or undercutting is occurring or there are heavy loading conditions.
- Can be a cost effective solution where some form of structural solution is needed and other materials are not readily available or must be brought in from distant sources.
- Useful when design requires rock size greater than what is locally available.
- Effective where bank slope is steep and requires moderate structural support.
- Appropriate at the base of a slope where a low toe wall is needed to stabilize the slope and reduce slope steepness.
- Will not resist large, lateral earth stresses.
- Should, where appropriate, be used with soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerative source of streambank vegetation.
- Require a stable foundation.
- Are expensive to install and replace.
- Appropriate where channel side slopes must be steeper than appropriate for riprap or other material, or where channel toe protection is needed, but rock riprap of the desired size is not readily available.
- Are available in vinyl coated wire as well as galvanized steel to improve durability.
- Not appropriate in heavy bedload streams or those with severe ice action because of serious abrasion damage potential.

Figure 3.4.4a, Sheet 3 of 8, Streambank and shoreline stabilization practices
Source: USDA-NRCS, Stream Corridor Restoration: Principles Processes, and Practices

STREAMBANK TREATMENT

JOINT PLANTINGS

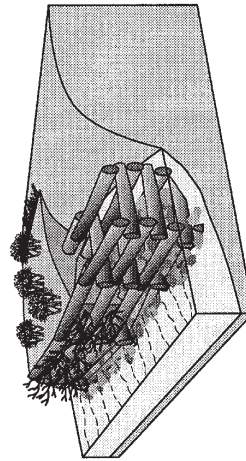


Live stakes tamped into joints or openings between rock which have previously been installed on a slope or while rock is being placed on the slope face.

Applications and Effectiveness

- Appropriate where there is a lack of desired vegetative cover on the face of existing or required rock riprap.
- Root systems provide a mat upon which the rock riprap rests and prevents loss of fines from the underlying soil base.
- Root systems also improve drainage in the soil base.
- Will quickly establish riparian vegetation.
- Should, where appropriate, be used with other soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerative source of streambank vegetation.
- Have few limitations and can be installed from base flow levels to top of slope, if live stakes are installed to reach ground water.
- Survival rates can be low due to damage to the cambium or lack of soil/stake interface.
- Thick rock riprap layers may require special tools for establishing pilot holes.

LIVE CRIBWALLS



Hollow, box-like interlocking arrangements of untreated log or timber members filled above baseflow with alternate layers of soil material and live branch cuttings that root and gradually take over the structural functions of the wood members.

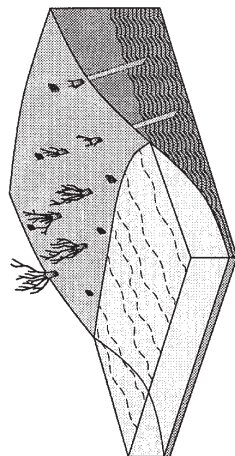
Applications and Effectiveness

- Provide protection to the streambank in areas with near vertical banks where bank sloping options are limited.
- Afford a natural appearance, immediate protection and accelerate the establishment of woody species.
- Effective on outside of bends of streams where high velocities are present.
- Appropriate at the base of a slope where a low wall might be required to stabilize the toe and reduce slope steepness.
- Appropriate above and below water level where stable streambeds exist.
- Don't adjust to toe scour.
- Can be complex and expensive.
- Should, where appropriate, be used with soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerative source of streambank vegetation.

Figure 3.4.4a, Sheet 4 of 8, Streambank and shoreline stabilization practices
Source: USDA-NRCS, Stream Corridor Restoration: Principles Processes, and Practices

STREAMBANK TREATMENT

LIVE STAKES

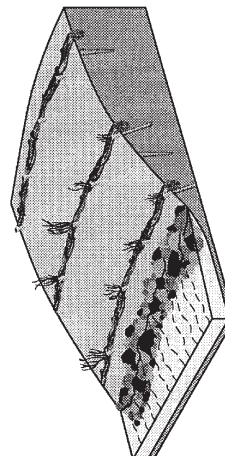


Live, woody cuttings which are tamped into the soil to root, grow and create a living root mat that stabilizes the soil by reinforcing and binding soil particles together, and by extracting excess soil moisture.

Applications and Effectiveness

- Effective where site conditions are uncomplicated, construction time is limited, and an inexpensive method is needed.
- Appropriate for repair of small earth slips and slumps that are frequently wet.
- Can be used to stake down surface erosion control materials.
- Stabilize intervening areas between other soil bioengineering techniques.
- Rapidly restores riparian vegetation and streamside habitat.
- Should, where appropriate, be used with other soil bioengineering systems and vegetative plantings.
- Enhance conditions for colonization of vegetation from the surrounding plant community.
- Requires toe protection where toe scour is anticipated.

LIVE FASCINES



Dormant branch cuttings bound together into long sausage-like, cylindrical bundles and placed in shallow trenches on slopes to reduce erosion and shallow sliding.

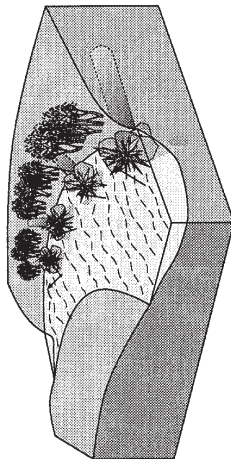
Applications and Effectiveness

- Can trap and hold soil on streambank by creating small dam-like structures and reducing the slope length into a series of shorter slopes.
- Facilitate drainage when installed at an angle on the slope.
- Enhance conditions for colonization of native vegetation.
- Should, where appropriate, be used with other soil bioengineering systems and vegetative plantings.
- Requires toe protection where toe scour is anticipated.
- Effective stabilization technique for streambanks, requiring a minimum amount of site disturbance.
- Not appropriate for treatment of slopes undergoing mass movement.

Figure 3.4.4a, Sheet 5 of 8, Streambank and shoreline stabilization practices
Source: USDA-NRCS, Stream Corridor Restoration: Principles Processes, and Practices

STREAMBANK TREATMENT

LOG, ROOTWAD, AND BOULDER REVETMENTS

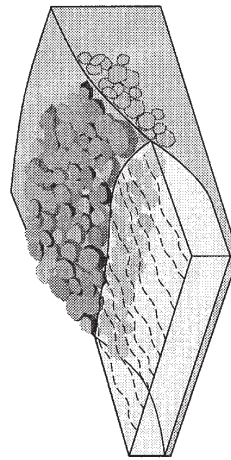


Boulders and logs with root masses attached placed in and on streambanks to provide streambank erosion, trap sediment, and improve habitat diversity.

Applications and Effectiveness

- Will tolerate high boundary shear stress if logs and rootwads are well anchored.
- Suited to streams where fish habitat deficiencies exist.
- Should, where appropriate, be used with soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerative source of streambank vegetation.
- Will enhance diversity in riparian areas when used with soil bioengineering systems.
- Will have limited life depending on climate and tree species used. Some species, such as cottonwood or willow, often sprout and accelerate colonization.
- Might need eventual replacement if colonization does not take place or soil bioengineering systems are not used.
- Use of native materials can sequester sediment and woody debris, restore streambanks in high velocity streams, and improve fish rearing and spawning habitat.
- Site must be accessible to heavy equipment.
- Materials might not be readily available at some locations.
- Can create local scour and erosion.
- Can be expensive.

RIPRAP



A blanket of appropriately sized stones extending from the toe of slope to a height needed for long term durability.

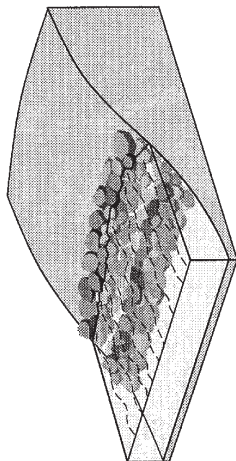
Applications and Effectiveness

- Can be vegetated (see joint plantings).
- Appropriate where long term durability is needed, design discharge are high, there is a significant threat to life or high value property, or there is no practical way to otherwise incorporate vegetation into the design.
- Should, where appropriate, be used with soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerative source of streambank vegetation.
- Flexible and not impaired by slight movement from settlement or other adjustments.
- Should not be placed to an elevation above which vegetative or soil bioengineering systems are an appropriate alternative.
- Commonly used form of bank protection.
- Can be expensive if materials are not locally available.

Figure 3.4.4a, Sheet 6 of 8, Streambank and shoreline stabilization practices
Source: USDA-NRCS, Stream Corridor Restoration: Principles Processes, and Practices

STREAMBANK TREATMENT

STONE TOE PROTECTION

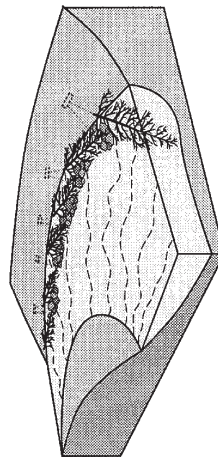


A ridge of quarried rock or stream cobble placed at the toe of the streambank as an armor to deflect flow from the bank, stabilize the slope and promote sediment deposition.

Applications and Effectiveness

- Should be used on streams where banks are being undermined by toe scour, and where vegetation cannot be used.
- Stone prevents removal of the failed streambank material that collects at the toe, allows revegetation and stabilizes the streambank.
- Should, where appropriate, be used with soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerated source of streamside vegetation.
- Can be placed with minimal disturbance to existing slope, habitat, and vegetation.

TREE REVETMENTS



A row of interconnected trees attached to the toe of the streambank or to deadmen in the streambank to reduce flow velocities along eroding streambanks, trap sediment, and provide a substrate for plant establishment and erosion control.

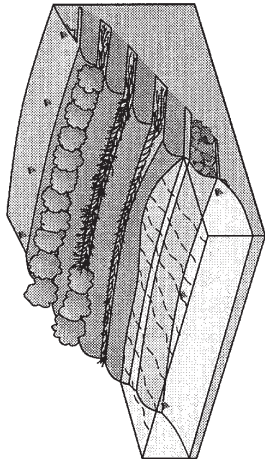
Applications and Effectiveness

- Design of adequate anchoring systems is necessary.
- Wire anchoring systems can present safety hazards.
- Work best on streams with streambank heights under 12 feet and bankfull velocities under 6 feet per second.
- Use inexpensive, readily available materials.
- Capture sediment and enhances conditions for colonization of native species particularly on streams with high bed material loads.
- Limited life and must be replaced periodically.
- Might be severely damaged by ice flows.
- Not appropriate for installation directly upstream of bridges and other channel constrictions because of the potential for downstream damages should the revetment dislodge.
- Should not be used if they occupy more than 15 percent of the channel's cross sectional area at bankfull level.
- Not recommended if debris jams on downstream bridges might cause subsequent problems.
- Species that are resistant to decay are best because they extend the establishment period for planted or volunteer species that succeed them.
- Requires toe protection where toe scour is anticipated.
- Should, where appropriate, be used with soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerated source of streamside vegetation.

Figure 3.4.4a, Sheet 7 of 8, Streambank and shoreline stabilization practices
Source: USDA-NRCS, Stream Corridor Restoration: Principles Processes, and Practices

STREAMBANK TREATMENT

VEGETATED GEOGRIDS



Alternating layers of live branch cuttings and compacted soil with natural or synthetic geotextile materials wrapped around each soil lift to rebuild and vegetate eroded streambanks.

Applications and Effectiveness

- Quickly establish riparian vegetation if properly designed and installed.
- Can be installed on a steeper and higher slope and has a higher initial tolerance of flow velocity than brush layering.
- Can be complex and expensive.
- Produce a newly constructed, well-reinforced streambank.
- Useful in restoring outside bends where erosion is a problem.
- Capture sediment and enhances conditions for colonization of native species.
- Slope stability analyses are recommended.
- Can be expensive.
- Require a stable foundation.

Figure 3.4.4a, Sheet 8 of 8, Streambank and shoreline stabilization practices
Source: USDA-NRCS, Stream Corridor Restoration: Principles Processes, and Practices

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STANDARD AND SPECIFICATIONS FOR MULCHING

Definition: The application of a protective layer of straw or other suitable material to the soil surface.

Purpose: To protect the soil surface from the forces of raindrop impact and overland flow. Mulch helps to conserve moisture, reduce runoff and erosion, control weeds, prevent soil crusting and promote the establishment of desired vegetation.



Conditions Where Practice Applies:

Mulching can be used at anytime where protection of the soil surface is desired. The primary purpose of mulching is to provide protection for newly seeded disturbed areas. However, it can also be used for stand-alone protection of the soil surface under adverse weather conditions when seed germination could be jeopardized.

Site Preparation

Prior to mulching, install any needed erosion and sediment control practices such as diversions, grade stabilization structures, berms, channels and sediment basins. For maximum performance, apply mulch in a two-step process.

Step One: Apply seed and soil amendments at required rates.

Step Two: Apply mulch at required rates. Depending on site conditions, hydraulically applied mulches may be applied in a one-step process where all components may be mixed together in single tank loads. Consult with the manufacturer for further details.

Mulching Procedures

1. Materials and Amounts

- a. *Straw* - Straw shall be unrotted small grain straw applied at the rate of 1-1/2 to 2 tons per acre, or 70 to 90 pounds (two bales) per 1,000 square feet. Mulch materials shall be relatively free of weeds and shall be free of noxious weeds such as; thistles, Johnsongrass, and quackgrass. Spread mulch uniformly by hand or mechanically. For uniform distribution of hand spread mulch, divide area into approximately 1,000 square foot sections and place 70-90 pounds (two bales) of mulch in each section.
- b. *Wood chips* - Apply at the rate of approximately 6 tons per acre or 275 pounds per 1,000 square feet when available and when feasible. These are particularly well suited for utility and road rights-of-way. If wood chips are used, increase the application rate of nitrogen fertilizer by 20 pounds of N per acre (200 pounds of 10-10-10 or 66 pounds of 30-0-0 per acre).

c. *Hydraulically applied mulch* -The following conditions apply to hydraulically applied mulch:

i. Definitions:

- a. Wood fiber mulch shall consist of specially prepared wood that has been processed to a uniform state, is packaged for sale as a hydraulic mulch for use with hydraulic seeding equipment, and consists of a minimum of 70% virgin or recycled wood fiber combined with 30% paper fiber and additives.
- b. Blended fiber mulch shall consist of any hydraulic mulch that contains greater than 30% paper fiber. The paper component must consist of specially prepared paper that has been processed to a uniform fibrous state and is packaged for sale as a hydraulic mulch for use with hydraulic seeding equipment.
- c. A bonded fiber matrix (BFM) consists of long strand, specially prepared wood fibers that have been processed to a uniform state held together by a water resistant bonding agent. BFMs shall contain no paper (cellulose) mulch but may contain small percentages of synthetic fibers to enhance performance.
- d. Refer to **Figure 3.4.5a** for conditions and limitations of use for each of the above categories of hydraulic mulch.

ii. All components of the hydraulically applied mulches shall be pre-packaged by the manufacturer to assure material performance. Field mixing of the mulch components is acceptable, but must be done per manufacturers recommendations to ensure the proper results.

iii. Hydraulic mulches shall be applied with a viable seed and at manufacturer's recommended rates. Increased rates may be necessary based on site conditions.

iv. Hydraulically applied mulches and additives shall be mixed according to manufacturers recommendations.

iv. Materials within this category shall only be used when hydraulically applied mulch has been specified for use on the approved Sediment and Stormwater Plan, or supplemental approval from the plan approval agency has been obtained in writing for a specific area.

v. Application:

- a. Apply product to geotechnically stable slopes that have been designed and constructed to divert runoff away from the face of the slope.
- b. Do not apply to saturated soils, or if precipitation is anticipated within 24-48 hours.
- c. During the spring (March 1 to May 31) and fall (September 1 to November 30) seasons, hydraulic mulches may be applied in a one-step process where all components are mixed together in single-tank loads. It is recommended that the product be applied from opposing directions to achieve optimum soil coverage.
- d. During the summer (June 1 to August 31) and winter (December 1 to February 28) seasons, the following two-step process is required:

Step One– Mix and apply seed and soil amendments with a small amount of mulch for visual metering.

Step Two – Mix and apply mulch at manufacturers recommended rates over freshly seeded surfaces. Apply from opposing directions to achieve optimum soil coverage.

- e. Minimum curing temperature is 40° F (4° C). The best results and more rapid curing are achieved at temperatures exceeding 60° F (15° C). Curing times may be accelerated in high temperature, low humidity conditions on dry soils.

vi. Recommended application rates are for informational purposes only. Conformance with this standard and specification shall be performance-based and requires **100% soil coverage**. Any areas with bare soil showing shall be top dressed until full coverage is achieved.

- d. *Compost blanket (CB)* - Loosely applied with a pneumatic blower so that a 1" compost blanket uniformly covers the **soil with 100% coverage**. This application can be used with seed to promote germination by applying the approved seed mix directly into the loosely blown compost. The compost blanket performs best on slopes less than 2:1 and requires no mulch anchoring.

2. Anchoring mulch - Mulch must be anchored immediately to minimize loss by wind or water. This may be done by one of the following methods, depending upon size of area, erosion hazard, and cost.

- a. *Crimping* - A crimper is a tractor drawn implement designed to punch and anchor mulch into the top two (2) inches of soil. This practice affords maximum erosion control but is limited to flatter slopes where equipment can operate safely. On sloping land, crimping should be done on the contour whenever possible.
- b. *Tracking* - Tracking is the process of cutting mulch (usually straw) into the soil using a bulldozer or other equipment that runs on cleated tracks. Tracking is used primarily on slopes 3:1 or steeper and should be done up and down the slope with cleat marks running across the slope.
- c. *Liquid mulch binders* - Applications of liquid mulch binders should be heavier at edges, in valleys, and at crests of banks and other areas where the mulch will be moved by wind or water. All other areas should have a uniform application of binder. The use of synthetic binders is the preferred method of mulch binding and should be applied at the rates recommended by the manufacturer.
- d. *Paper fiber* - The fiber binder shall be applied at a net dry weight of 750 lbs/ac. The wood cellulose fiber shall be mixed with water, and the mixture shall contain a maximum of 50 lbs. of wood cellulose fiber per 100 gallons.
- e. *Nettings* - Biodegradable nettings may be used to secure straw mulch. Install and secure according to the manufacturer's recommendations. Photodegradable or synthetic nettings are not acceptable.

MULCHING MATERIAL SELECTION GUIDE					
Percent Slope	Type of Mulch / App. Rate *	Dec. 1 to Feb. 28(29)	March 1 to May 31	June 1 to Aug. 31	Sept. 1 to Nov. 30
Less than 2%	Blended Fiber @ 2000 lbs/ac. minimum	xxxxxxxxxxxxxxxxxxxxxx	OK (≤ 1 ac.)	xxxxxxxxxxxxxxxxxxxxxx	OK (≤ 1 ac.)
	Wood Fiber @ 2000 lbs/ac. min.	xxxxxxxxxxxxxxxxxxxxxx	OK	xxxxxxxxxxxxxxxxxxxxxx	OK
	BFM @ 3000 lbs/ac. min.	OK	OK	OK	OK
	Straw @ 2 Tons/ac. Min.	OK	OK	OK	OK
	Stabilization Matting**	OK	OK	OK	OK
2% to 5.9%	1" Compost Blanket (CB)	OK	OK	OK	OK
	Wood Fiber @ 2000 lbs/ac. min.	xxxxxxxxxxxxxxxxxxxxxx	OK	xxxxxxxxxxxxxxxxxxxxxx	OK
	BFM @ 3000-3500 lbs/ac. min	OK	OK	OK	OK
	Straw @ 2 Tons/ac. min.	OK	OK	OK	OK
	Stabilization Matting**	OK	OK	OK	OK
6% to 10.9%	1" Compost Blanket (CB)	OK	OK	OK	OK
	Wood Fiber @ 2000-2500 lbs/ac. min.	xxxxxxxxxxxxxxxxxxxxxx	OK	xxxxxxxxxxxxxxxxxxxxxx	OK
	BFM @ 3500-4000 lbs/ac. min.	OK	OK	OK	OK
	Straw @ 2 Tons/ac. min.	OK	OK	OK	OK
	Stabilization Matting**	OK	OK	OK	OK
11% to 24.9%	1" Compost Blanket (CB)	OK	OK	OK	OK
	Wood Fiber @ 2500-3000 lbs/ac. min.	xxxxxxxxxxxxxxxxxxxxxx	OK	xxxxxxxxxxxxxxxxxxxxxx	OK
	BFM @ 3500-4000 lbs/ac. min.	OK	OK	OK	OK
	Straw @ 2 Tons/ac. min.	OK	OK	OK	OK
	Stabilization Matting**	OK	OK	OK	OK
25% to 33%	1" Compost Blanket (CB)	OK	OK	OK	OK
	Wood Fiber @ 2500-3000 lbs/ac. min.	xxxxxxxxxxxxxxxxxxxxxx	OK	xxxxxxxxxxxxxxxxxxxxxx	OK
	BFM @ 4000 lbs/ac. min.	xxxxxxxxxxxxxxxxxxxxxx	OK	xxxxxxxxxxxxxxxxxxxxxx	OK
	Straw @ 2 Tons/ac. min.	OK	OK	OK	OK
	Stabilization Matting**	OK	OK	OK	OK
33% and up	1" Compost Blanket (CB)	OK	OK	OK	OK
	BFM @ 4000-4500 lbs/ac. min.	xxxxxxxxxxxxxxxxxxxxxx	OK	xxxxxxxxxxxxxxxxxxxxxx	OK
	Straw @ 2 Tons/ac. min.***	OK	OK	OK	OK
	Stabilization Matting**	OK	OK	OK	OK
	1" Compost Blanket (CB)	2:1 Max.	2:1 Max.	2:1 Max.	2:1 Max.

* Note: Manufacturers Recommended Rates for informational purposes only. Performance standard requires 100% soil coverage.

** Note: Stabilization Matting must be applied in accordance with Section 3.4.6 of the Delaware ESC Handbook.

***Note: Straw applied on slopes greater than 33% must be netted (this does not apply to topsoil stockpiles).

OK = Acceptable to use during this time period.

xxx = Not acceptable to use during this time period.

All application rates are minimums

Figure 3.4.5a Mulching material selection guide

Standard Detail & Specifications

Mulching

1. Materials and Amounts

- a. *Straw* - Straw shall be unrotted small grain straw applied at the rate of 1-1/2 to 2 tons per acre, or 70 to 90 pounds (two bales) per 1,000 square feet. Mulch materials shall be relatively free of weeds and shall be free of noxious weeds such as; thistles, Johnsongrass, and quackgrass. Spread mulch uniformly by hand or mechanically. For uniform distribution of hand spread mulch, divide area into approximately 1,000 square feet sections and place 70-90 pounds (two bales) of mulch in each section.
- b. *Wood chips* - Apply at the rate of approximately 6 tons per acre or 275 pounds per 1,000 square feet when available and when feasible. These are particularly well suited for utility and road rights-of-way. If wood chips are used, increase the application rate of nitrogen fertilizer by 20 pounds of N per acre (200 pounds of 10-10-10 or 66 pounds of 30-0-0 per acre).
- c. *Hydraulically applied mulch* - The following conditions apply to hydraulically applied mulch:
 - i. Definitions:
 - a. Wood fiber mulch shall consist of specially prepared wood that has been processed to a uniform state, is packaged for sale as a hydraulic mulch for use with hydraulic seeding equipment, and consists of a minimum of 70% virgin or recycled wood fiber combined with 30% paper fiber and additives.
 - b. Blended fiber mulch shall consist of any hydraulic mulch that contains greater than 30% paper fiber. The paper component must consist of specially prepared paper that has been processed to a uniform fibrous state and is packaged for sale as a hydraulic mulch for use with hydraulic seeding equipment.
 - c. A bonded fiber matrix (BFM) consists of long strand, specially prepared wood fibers that have been processed to a uniform state held together by a water resistant bonding agent. BFMs shall contain no paper (cellulose) mulch but may contain small percentages of synthetic fibers to enhance performance.
 - d. Refer to **Figure 3.4.5a** for conditions and limitations of use for each of the above categories of hydraulic mulch.
 - ii. All components of the hydraulically applied mulches shall be pre-packaged by the manufacturer to assure material performance. Field mixing of the mulch components is acceptable, but must be done per manufacturers recommendations to ensure the proper results.
 - iii. Hydraulic mulches shall be applied with a viable seed and at manufacturer's recommended rates. Increased rates may be necessary based on site conditions.
 - iv. Hydraulically applied mulches and additives shall be mixed according to manufacturers recommendations.
 - iv. Materials within this category shall only be used when hydraulically applied mulch has been specified for use on the approved Sediment and Stormwater Plan, or supplemental approval from the plan approval agency has been obtained in writing for a specific area.

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Sheet 1 of 3

Effective July 2023

Standard Detail & Specifications

Mulching

v. Application:

- a. Apply product to geotechnically stable slopes that have been designed and constructed to divert runoff away from the face of the slope.
- b. Do not apply to saturated soils, or if precipitation is anticipated within 24-48 hours.
- c. During the spring (March 1 to May 31) and fall (September 1 to November 30) seasons, hydraulic mulches may be applied in a one-step process where all components are mixed together in single-tank loads. It is recommended that the product be applied from opposing directions to achieve optimum soil coverage.
- d. During the summer (June 1 to August 31) and winter (December 1 to February 28) seasons, the following two-step process is required:

Step One— Mix and apply seed and soil amendments with a small amount of mulch for visual metering.

Step Two – Mix and apply mulch at manufacturers recommended rates over freshly seeded surfaces. Apply from opposing directions to achieve optimum soil coverage.

- e. Minimum curing temperature is 40° F (4° C). The best results and more rapid curing are achieved at temperatures exceeding 60° F (15° C). Curing times may be accelerated in high temperature, low humidity conditions on dry soils.
- vi. Recommended application rates are for informational purposes only. Conformance with this standard and specification shall be performance-based and requires **100% soil coverage**. Any areas with bare soil showing shall be top dressed until full coverage is achieved.
- d. *Compost blanket (CB)* - Loosely applied with a pneumatic blower so that a 1" compost blanket uniformly covers the **soil with 100% coverage**. This application can be used with seed to promote germination by applying the approved seed mix directly into the loosely blown compost. The compost blanket performs best on slopes less than 2:1 and requires no mulch anchoring.

2. Anchoring mulch - Mulch must be anchored immediately to minimize loss by wind or water. This may be done by one of the following methods, depending upon size of area, erosion hazard, and cost.

- a. *Crimping* - A crimper is a tractor drawn implement designed to punch and anchor mulch into the top two (2) inches of soil. This practice affords maximum erosion control but is limited to flatter slopes where equipment can operate safely. On sloping land, crimping should be done on the contour whenever possible.
- b. *Tracking* - Tracking is the process of cutting mulch (usually straw) into the soil using a bulldozer or other equipment that runs on cleated tracks. Tracking is used primarily on slopes 3:1 or steeper and should be done up and down the slope with cleat marks running across the slope.
- c. *Liquid mulch binders* - Applications of liquid mulch binders should be heavier at edges, in valleys, and at crests of banks and other areas where the mulch will be moved by wind or water. All other areas should have a uniform application of binder. The use of synthetic binders is the preferred method of mulch binding and should be applied at the rates recommended by the manufacturer.
- d. *Paper fiber* - The fiber binder shall be applied at a net dry weight of 750 lbs/ac. The wood cellulose fiber shall be mixed with water, and the mixture shall contain a maximum of 50 lbs. of wood cellulose fiber per 100 gallons.
- e. *Nettings* - Biodegradable nettings may be used to secure straw mulch. Install and secure according to the manufacturer's recommendations. Photodegradable or synthetic nettings are not acceptable.

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DE-ESC-3.4.5

Sheet 2 of 3

Effective July 2023

Standard Detail & Specifications

Mulching

MULCHING MATERIAL SELECTION GUIDE						
Percent Slope	Type of Mulch / App. Rate*	Dec. 1 to Feb. 28(29)	March 1 to May 31	June 1 to Aug. 31	Sept. 1 to Nov. 30	
Less than 2%	Blended Fiber @ 2000 lbs/ac. minimum	xxxxxxxxxxxxxxxxxxxx	OK (< 1 ac.)	xxxxxxxxxxxxxxxxxxxx	OK (< 1 ac.)	
	Wood Fiber @ 2000 lbs/ac. min.	xxxxxxxxxxxxxxxxxxxx	OK	xxxxxxxxxxxxxxxxxxxx	OK	
	BFM @ 3000 lbs/ac. min.	OK	OK	OK	OK	
	Straw @ 2 Tons/ac. Min.	OK	OK	OK	OK	
	Stabilization Matting**	OK	OK	OK	OK	
2% to 5.9%	1" Compost Blanket (CB)	OK	OK	OK	OK	
	Wood Fiber @ 2000 lbs/ac. min.	xxxxxxxxxxxxxxxxxxxx	OK	xxxxxxxxxxxxxxxxxxxx	OK	
	BFM @ 3000-3500 lbs/ac. min.	OK	OK	OK	OK	
	Straw @ 2 Tons/ac. min.	OK	OK	OK	OK	
	Stabilization Matting**	OK	OK	OK	OK	
6% to 10.9%	1" Compost Blanket (CB)	OK	OK	OK	OK	
	Wood Fiber @ 2000-2500 lbs/ac. min.	xxxxxxxxxxxxxxxxxxxx	OK	xxxxxxxxxxxxxxxxxxxx	OK	
	BFM @ 3500-4000 lbs/ac. min.	OK	OK	OK	OK	
	Straw @ 2 Tons/ac. min.	OK	OK	OK	OK	
	Stabilization Matting**	OK	OK	OK	OK	
11% to 24.9%	1" Compost Blanket (CB)	OK	OK	OK	OK	
	Wood Fiber @ 2500-3000 lbs/ac. min.	xxxxxxxxxxxxxxxxxxxx	OK	xxxxxxxxxxxxxxxxxxxx	OK	
	BFM @ 3500-4000 lbs/ac. min.	OK	OK	OK	OK	
	Straw @ 2 Tons/ac. min.	OK	OK	OK	OK	
	Stabilization Matting**	OK	OK	OK	OK	
25% to 33%	1" Compost Blanket (CB)	OK	OK	OK	OK	
	Wood Fiber @ 2500-3000 lbs/ac. min.	xxxxxxxxxxxxxxxxxxxx	OK	xxxxxxxxxxxxxxxxxxxx	OK	
	BFM @ 4000 lbs/ac. min.	xxxxxxxxxxxxxxxxxxxx	OK	xxxxxxxxxxxxxxxxxxxx	OK	
	Straw @ 2 Tons/ac. min.	OK	OK	OK	OK	
	Stabilization Matting**	OK	OK	OK	OK	
33% and up	1" Compost Blanket (CB)	OK	OK	OK	OK	
	BFM @ 4000-4500 lbs/ac. min.	xxxxxxxxxxxxxxxxxxxx	OK	xxxxxxxxxxxxxxxxxxxx	OK	
	Straw @ 2 Tons/ac. min.***	OK	OK	OK	OK	
	Stabilization Matting**	OK	OK	OK	OK	
	1" Compost Blanket (CB)	2:1 Max.	2:1 Max.	2:1 Max.	2:1 Max.	

* Note: Manufacturers Recommended Rates for informational purposes only. Performance standard requires 100% soil coverage.

** Note: Stabilization Matting must be applied in accordance with Section 3.4.6 of the Delaware ESC Handbook.

***Note: Straw applied on slopes greater than 33% must be netted (this does not apply to topsoil stockpiles).

OK = Acceptable to use during this time period.

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All application rates are minimums

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Sheet 3 of 3

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STANDARD AND SPECIFICATIONS FOR STABILIZATION MATTING

Definition: The installation of a protective covering on a prepared planting area of a steep slope, channel or shoreline.



Purpose: To aid in controlling erosion on critical areas by providing a microclimate which protects young vegetation and promotes its establishment. In addition, some types of soil stabilization mats are also used to raise the maximum permissible velocity of turf grass linings in vegetated channels by reinforcing the turf to resist erosive forces during storm events.

Conditions Where Practice Applies:

Stabilization mats are recommended for the following conditions

:

1. On short, steep slopes where erosion hazard is high and planting is likely to be too slow in providing adequate protective cover.
2. In vegetated channels where the velocity of design flow exceeds the allowable velocity for vegetation alone.
3. On streambanks or tidal shorelines where moving water is likely to wash out new plantings.
4. In areas where the forces of wind prevent standard mulching practices from remaining until vegetation becomes established.

Planning Considerations:

Stabilization mats can be applied to problem areas to aid in the initial establishment of vegetation and protect the soil from erosion due to high velocity stormwater runoff. These materials have been improved to the point that they are now being used in many applications where structural linings would have been required in the past. Care must be taken to choose the type of material which is most appropriate for the specific needs of a project. With the large selection of materials available today and constant improvements in the technology, it is impossible to cover them all with this standard and specification, nor to keep it current. Although some general guidelines are provided, the designer should always consult the manufacturer's recommendations for final selection and design.

Selection Guidelines:

Stabilization mats generally fall under one of two categories:

Mulching

These mats are typically combination blankets consisting of biodegradable netting and some type of natural organic or man-made mulch. The mulch material may be sandwiched between the netting or the netting may

be intertwined with the mulch. Jute mesh and similar products may also act as stabilization mats. In either case, these mats are usually intended to degrade as vegetation becomes established. The benefits of these types of stabilization mats include:

1. Protection of the seed and soil from raindrop impact and subsequent displacement.
2. Thermal consistency and moisture retention for seedbed area.
3. Stronger and faster germination of grasses and legumes.
4. Planing off excess stormwater runoff.
5. Prevention of sloughing of topsoil added to steeper slopes.

Reinforcement

Mats in this class typically consist of a non-degradable, 3-dimensional plastic structure which can be filled with soil prior to planting. This configuration provides a matrix for root growth where the matting becomes entangled and penetrated by roots, forming continuous anchorage for surface growth and promoting enhanced energy dissipation. Reinforcement mats are used in stormwater conveyance channels as well as to stabilize slopes. Benefits of these mats include:

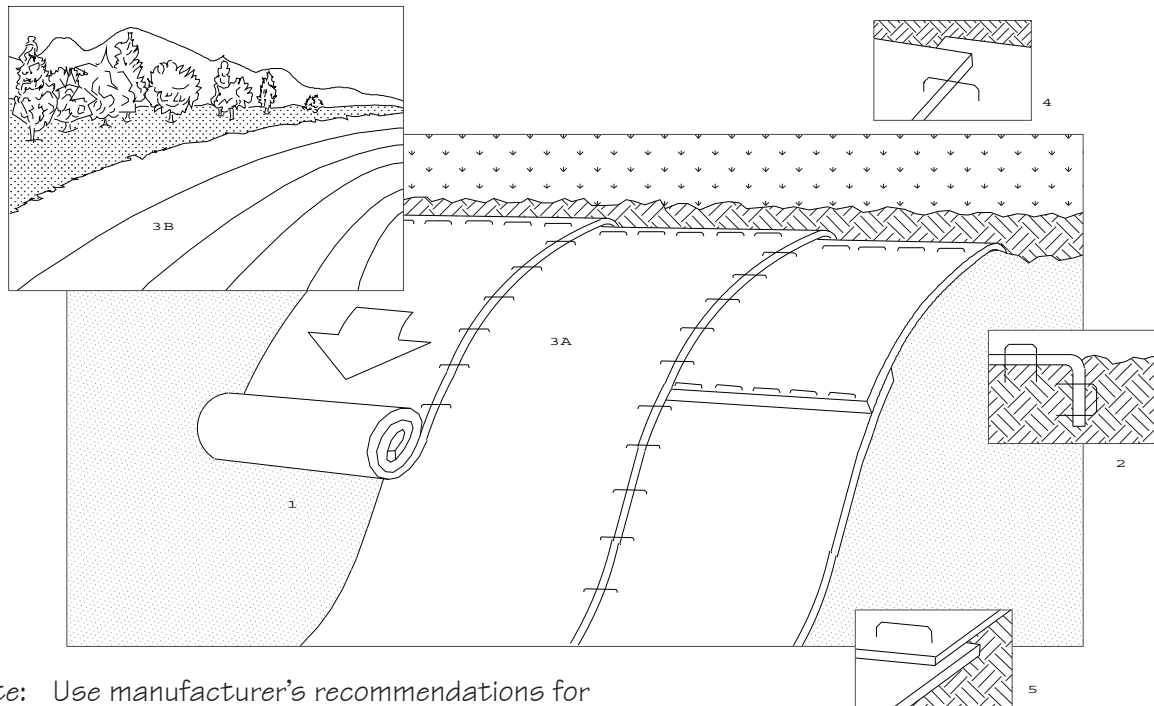
1. Allows the use of vegetated linings under conditions which would normally require concrete or riprap.
2. Traps entrained soil in stormwater runoff and allows it to fill the matrix, thus becoming a growth medium for the development of roots.
3. When embedded in the soil within stormwater channels, it acts with the vegetative root system to form an erosion resistant cover which resists hydraulic lift and shear forces.
4. For slope stability problems, can improve the geotechnical performance of the native soil.

Design Criteria:

1. Slope stability - Stabilization matting is required on disturbed slopes steeper than 3:1. Refer to **Appendix A-4, Stabilization Matting Application Guide** for recommendations for appropriate material selection.
2. Channel stability - Design for channel stabilization shall be based on the tractive force method (refer to **Design Guide 1**). For maximum design shear stresses less than 2 psf, a temporary material may be used. Permanent materials must be used for design shear stresses equal to or greater than 2 psf. Once the hydraulic design has been completed, refer to **Appendix A-4, Stabilization Matting Application Guide** for recommendations for appropriate material selection.

Standard Detail & Specifications

Stabilization Matting - Slope



Note: Use manufacturer's recommendations for stapling patterns for slope installations.

Perspective

Construction Notes:

1. Prepare soil before installing matting, including application of lime, fertilizer, and seed.
2. Begin at the top of the slope by anchoring the mat in a 6" deep X 6" wide trench. Backfill and compact trench after stapling.
3. Roll the mats (A) down or (B) horizontally across the slope.
4. The edges of parallel mats must be stapled with approx. 2" overlap.
5. When mats must be spliced down the slope, place mats end over end (shingle style) with approx. 4" overlap. Staple through overlapped area, approx. 12" apart.

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Adapted from
North American Green, Inc.

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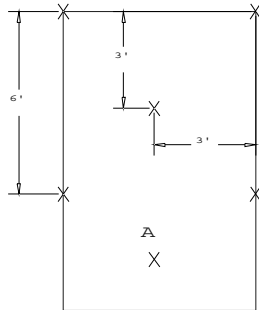
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Sheet 1 of 2

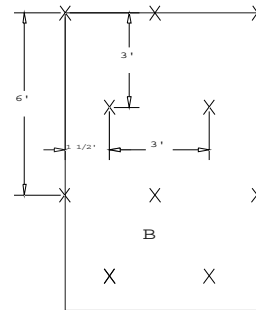
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Standard Detail & Specifications

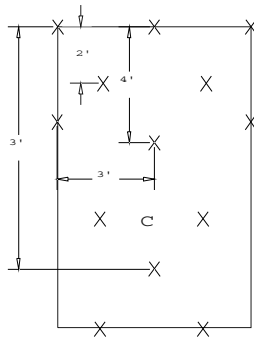
Stabilization Matting - Slope



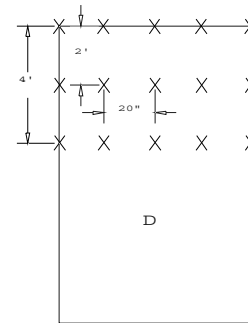
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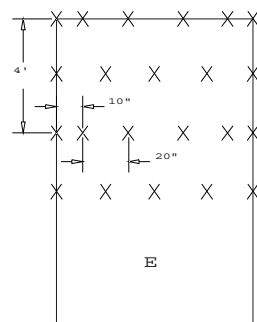
1.2 Staples per Sq. Yd.



1.75 Staples per Sq. Yd.



3.5 Staples per Sq. Yd.



3.75 Staples per Sq. Yd.

NOTE: These patterns are provided for general guidance only. They shall not be used as a substitute for manufacturer's recommendations.

Stapling Patterns

Source:

Adapted from
North American Green, Inc.

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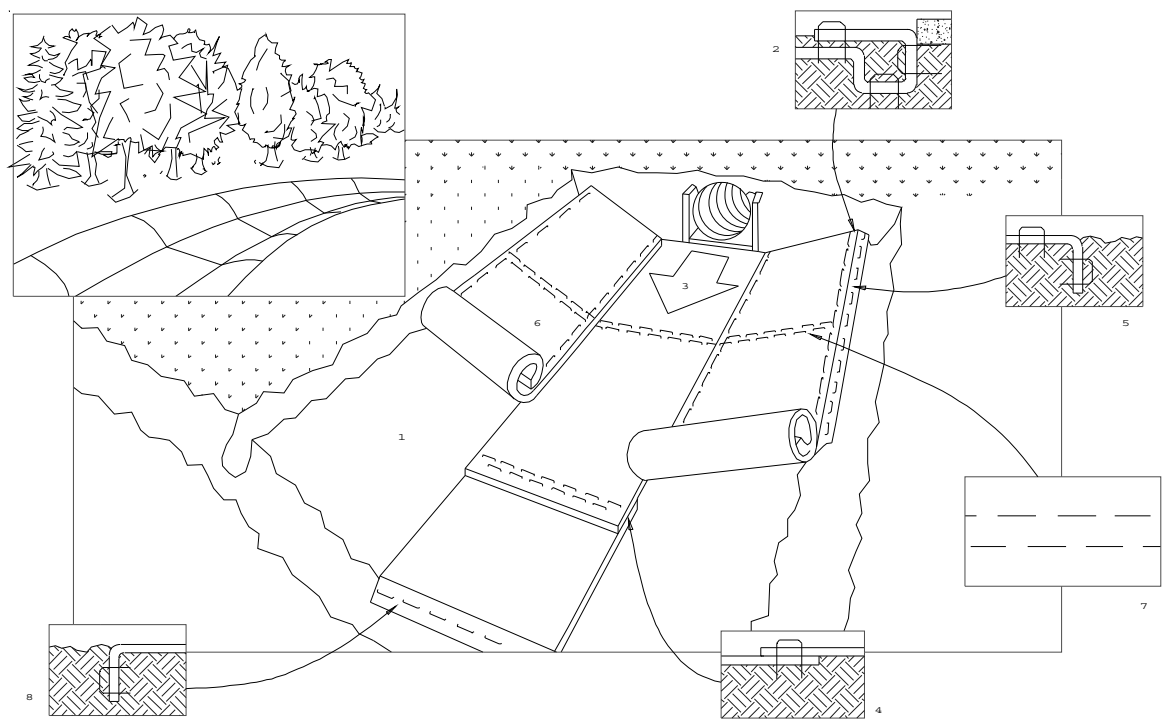
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Sheet 2 of 2

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Standard Detail & Specifications

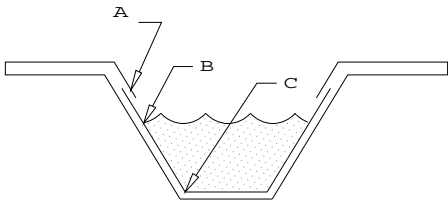
Stabilization Matting - Channel



Perspective

CRITICAL POINTS

- A. Overlaps and seams
- B. Projected waterline
- C. Channel bottom/side slope vertices



Note: Horizontal staple spacing should be altered if necessary to allow staples to secure the critical points along the channel surface.

Use manufacturer’s recommendations for stapling patterns for channel installations.

Source: Adapted from North American Green, Inc.	Symbol: 	Detail No. DE-ESC-3.4.6.2 Sheet 1 of 3 Effective July 2023
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Stabilization Matting - Channel

Construction Notes:

1. Prepare soil before installing matting, including application of lime, fertilizer, and seed.
2. Begin at the top of the channel by anchoring the mat in a 6" deep X 6" wide trench. Backfill and compact the trench after stapling.
3. Roll center mat in direction of water flow on bottom of channel.
4. Place mats end over end (shingle style) with a 6" overlap, use a double row of staggered staples 4" apart to secure mats.
5. Full Length edge of mats at top of side slopes must be anchored in 6" deep X 6" wide trench; backfill and compact the trench after stapling.
6. Mats on side slopes must be overlapped 4" over the center mat and stapled.
7. In high flow channel applications, a staple check slot is recommended at 30 to 40 foot intervals. Use a row of staples 4" apart over entire width of the channel. Place a second row 4" below the first row in a staggered pattern.
8. The terminal end of the mats must be anchored in a 6" X 6" wide trench. Backfill and compact the trench after stapling.

Source:

Adapted from
North American Green, Inc.

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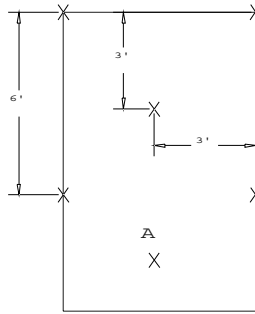
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Sheet 2 of 3

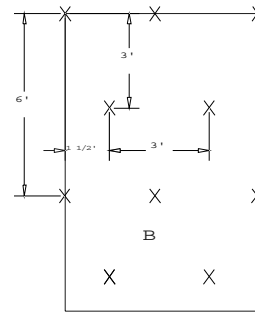
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Standard Detail & Specifications

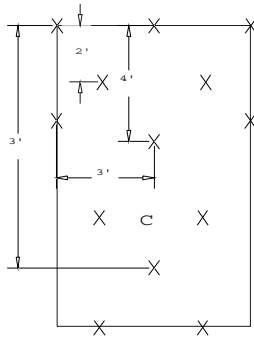
Stabilization Matting - Channel



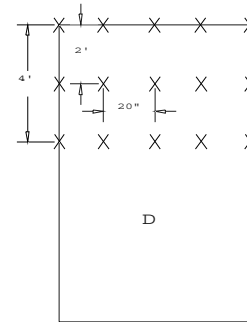
0.7 Staples per Sq. Yd.



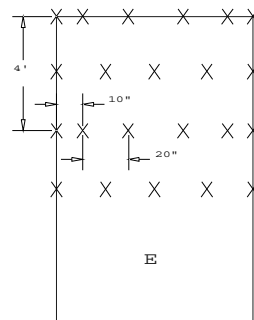
1.2 Staples per Sq. Yd.



1.75 Staples per Sq. Yd.



3.5 Staples per Sq. Yd.



3.75 Staples per Sq. Yd.

NOTE: These patterns are provided for general guidance only. They shall not be used as a substitute for manufacturer's recommendations.

Stapling Patterns

Source:

Adapted from
North American Green, Inc.

Symbol:



Detail No.

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Sheet 3 of 3

Effective July 2023

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STANDARD AND SPECIFICATIONS FOR STABILIZED CONSTRUCTION ENTRANCE

Definition: A stabilized pad of aggregate on a geotextile fabric base located at any point where traffic will be entering a construction site to or from a public right-of-way, street, alley, sidewalk or parking area.



Purpose: To prevent site access points from becoming sediment sources.

Conditions Where Practice Applies:

A stabilized construction entrance shall be used at all points of construction ingress and egress.

Design Criteria

See Standard Detail.

Geotextile Fabric

Geotextiles used for stabilized construction entrances shall be **Type GS-1** (see **Appendix A-3**.)

Maintenance Criteria

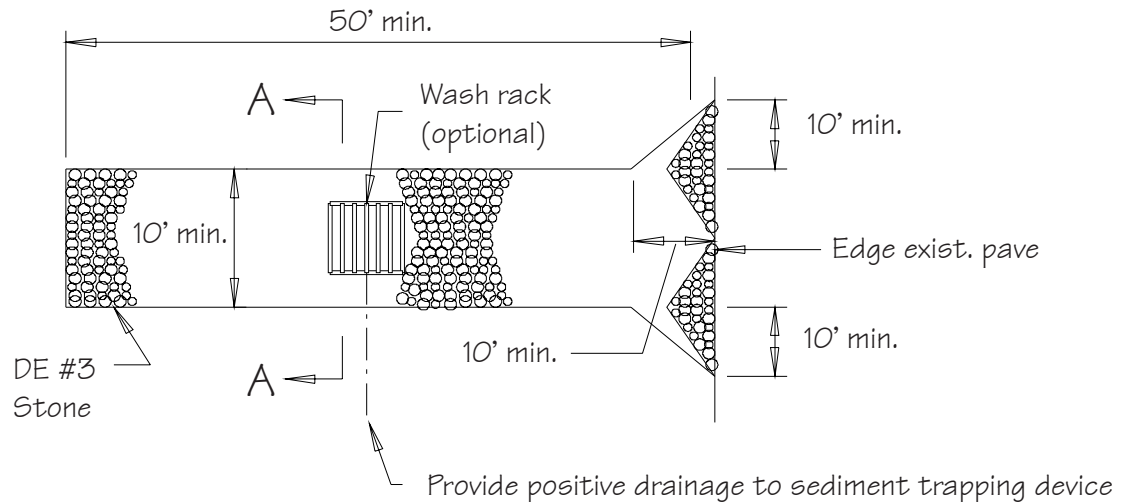
The entrance shall be maintained in a condition which will prevent tracking of sediment onto public rights-of-way or streets. This may require periodic top dressing with additional aggregate. All sediment spilled, dropped, or washed onto public rights-of-way must be removed immediately.

When necessary, wheels must be cleaned to remove sediment prior to entrance onto public rights-of-way. When washing is required, it shall be done on an area stabilized with aggregate which drains into an approved sediment trapping device. All sediment shall be prevented from entering storm drains, ditches, or watercourses.

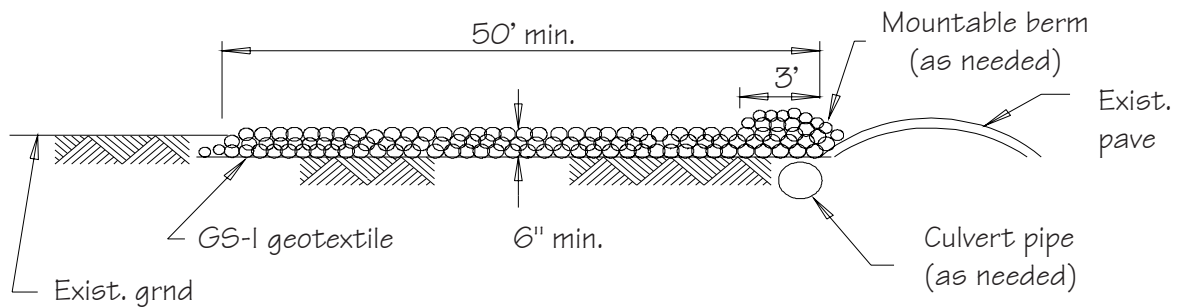
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Standard Detail & Specifications

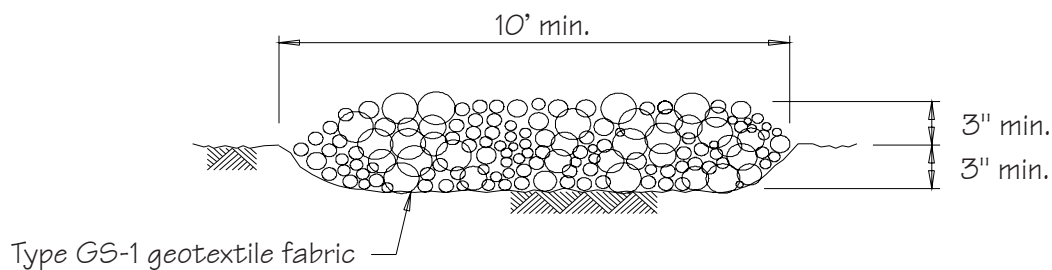
Stabilized Construction Entrance



Plan



Profile



Section A-A (Std.)

Source:

Adapted from
VA ESC Handbook

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SCE

Detail No.

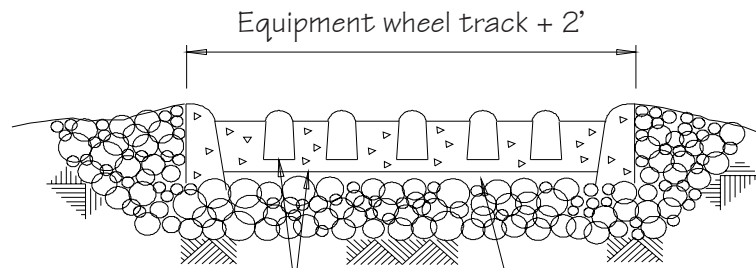
DE-ESC-3.4.7

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Stabilized Construction Entrance



Metal bars set in reinforced conc. (traffic bearing grates, timber mats or other approved equiv. may be substituted)

Provide space for drainage

Section A-A (Opt.)

Construction Notes:

1. Stone size - Use DE #3 stone.
2. Length - As required, but not less than 50 feet (except on a single residence lot where a 30 foot minimum length would apply).
3. Thickness - Not less than size (6) inches.
4. Width - Ten (10) foot minimum, but not less than the full width at points where ingress or egress occurs.
5. Geotextile - Type GS-I; placed over the entire area prior to placing of stone.
6. Surface Water - All surface water flowing or diverted toward construction entrances shall be piped across the entrance. If piping is impractical, a mountable berm with 5:1 slopes will be permitted.
7. Maintenance - The entrance shall be maintained in a condition which will prevent tracking or flowing of sediment onto public rights-of-way. This may require periodic top dressing with additional stone as conditions demand and repair and/or cleanout of any measures used to trap sediment. All sediment spilled, dropped, washed or tracked onto public rights-of-way must be removed immediately.
8. Washing - Vehicle wheels shall be cleaned to remove sediment prior to entrance onto public rights-of-way. When washing is required, it shall be done on an area stabilized with stone and which drains into an approved sediment trapping device.
9. Inspection - Periodic inspection and needed maintenance shall be provided after each rain.

Source:

Adapted from
VA ESC Handbook

Symbol:



Detail No.

DE-ESC-3.4.7
Sheet 2 of 2

Effective July 2023

STANDARD AND SPECIFICATIONS FOR DUST CONTROL

Definition: Controlling dust blowing and movement on construction sites and roads.

Purpose: To prevent or reduce the movement of dust from disturbed soil surfaces that may create health hazards, traffic safety problems and off-site damage.



Conditions Where Practice Applies

This practice is applicable to areas subject to dust blowing and movement where on and off-site damage is likely to occur if dust is not controlled. Under certain conditions, some of the chemicals used for dust control may also be used for bare soil stabilization in situations in which the introduction of organic materials would be undesirable, such as road beds and structural fill. This latter condition requires prior approval from the appropriate authority.

Types of Temporary Methods

1. Mulches - See **Section 3.4.5, Standard and Specifications for Mulching.**
2. Vegetation - See **Section 3.4.3.2, Standard and Specifications for Temporary Vegetative Stabilization.**
3. Adhesives - Use on mineral soils only (not effective on muck soils). These are generally synthetic materials that are applied to the soil surface to act as binding agents. Asphalt-based materials are no longer accepted. See **DE-ESC-3.4.5, Standard Detail and Specification for Dust Control** for some typical application rates. Traffic should be kept off these areas once they have been treated.
4. Tillage - This is an emergency temporary practice that will scarify the soil surface and prevent or reduce the amount of blowing dust until a more appropriate solution can be implemented. The tillage operation should begin on the windward side of the site. Chisel-type plows produce the best results.
5. Sprinkling - This is the most commonly used dust control practice. The site should be sprinkled with water until the surface is moist and repeated as needed. This practice can be particularly effective for road construction.
6. Calcium Chloride - Can be applied as flakes or granular material with a mechanical spreader at a rate that will keep the soil surface moist, but not so high as to cause water pollution or plant damage. Can be reapplied as necessary.
7. Barriers - Solid board fences, snow fences, hay bales an similar material can be used to control air currents and soil blowing. Barriers placed at right angles to the prevailing air currents at intervals of about 10 times their height are effective in controlling soil blowing.

Types of Permanent Methods:

1. Vegetation - See **Section 3.4.3.3, Standard and Specifications for Permanent Vegetative Stabilization.**
2. Topsoiling - See **Section 3.4.1, Standard and Specifications for Topsoiling.**
3. Stone - Surface can be protected with crushed stone or coarse gravel.

Standard Detail & Specifications

Dust Control

Temporary Methods:

1. Mulches - See **DE-ESC-3.4.5**, Standard Detail and Specifications for Mulching.
2. Vegetative cover - See **DE-ESC-3.4.3**, Std. Detail and Specifications for Vegetative Stabilization.
3. Adhesives - Use on mineral soils only (not effective on muck soils). Keep traffic off these areas. The following table may be used for general guidance.

Type of Emulsion	Water Dilution	Type of Nozzle	Apply Gal/Ac.
Latex emulsion	12.5:1	Fine spray	235
Resin-in-water emulsion	4:1	Fine spray	300
Acrylic emulsion (non-traffic)	7:1	Coarse spray	450
Acrylic emulsion (traffic)	3.5:1	Coarse spray	350

4. Tillage - For emergency temporary treatment, scarify the soil surface to prevent or reduce the amount of blowing dust until a more appropriate solution can be implemented. Begin the tillage operation on the windward side of the site using a chisel-type plow for best results.
5. Sprinkling - Sprinkle site with water until the surface is moist . Repeat as needed.
6. Calcium Chloride - Apply as flakes or granular material with a spreader at a rate that will keep the soil surface moist. Re-apply as necessary.
7. Barriers - Place barriers such as solid board fences, snow fences, hay bales, etc. at right angles to the prevailing air currents at intervals of approx. 10X their height.

Permanent Methods:

1. Vegetative cover - See **DE-ESC-3.4.3**, Std. Detail and Specifications for Vegetative Stabilization.
2. Stone - Apply layer of crushed stone or coarse gravel to protect soil surface.

Source:

Adapted from
VA ESC Handbook

Symbol:

Detail No.

DE-ESC-3.4.8

Sheet 1 of 1

Effective July 2023

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STANDARD AND SPECIFICATIONS FOR TEMPORARY CROSSINGS

Definition: A temporary crossing is a structure placed across a waterway to provide access for construction purposes for a period of less than one year. Temporary access crossings shall not be utilized to maintain traffic for the general public.



Purpose: The purpose of the temporary access waterway crossing is to provide safe, pollution free access across a waterway for construction equipment by establishing minimum standards and specifications for the design, construction, maintenance, and removal of the structure. Temporary access waterway crossings are necessary to prevent construction equipment from damaging the waterway, blocking fish migration, and tracking sediment and other pollutants into the waterway. This standard and specification may represent a channel constriction thus the *temporary* nature of waterway access crossings must be stressed. They should be planned to be in service for the shortest practical period of time and removed as soon as their function is completed.

Conditions Where Practice Applies

The following standard and specifications for temporary access waterway crossings are applicable in both tidal and non-tidal waterways. These standard and specifications provide designs based on waterway geometry rather than the drainage area contributing to the point of crossing.

The principal consideration for development of the standard and specifications is concern for erosion and sediment control. Structural utility and safety must also be considered when designing temporary access waterway crossings to withstand expected loads.

The three types of standard temporary access waterway crossings are bridges, culverts, and fords.

1. General Requirements

- a. In-Stream Excavation - In-Stream excavation shall be limited to only that necessary to allow installation of the standard methods as presented in Part II.
- b. Elimination of Fish Migration Barriers - Of the three basic methods presented in Part 2, bridges pose the least potential for creating barriers to aquatic migration. The construction of any specific crossing method as presented in Part 2, shall not cause a significant water level difference between the upstream and downstream water surface elevations.
- c. Crossing Alignment - The temporary waterway crossing shall be at right angles to the stream. Where approach conditions dictate, crossing may vary 15° from a line drawn perpendicular to the centerline of the stream at the intended crossing location.
- d. Road Approaches - The centerline of both roadway approaches shall coincide with the crossing alignment centerline for a minimum distance of 50 feet from each bank of the waterway being

crossed. If physical or right-of-way restraints preclude the 50 feet minimum, a shorter distance may be provided. All fill materials associated with the roadway approach shall be limited to a maximum height of 2 feet above the existing floodplain elevation.

- e. Surface Water Diverting Structure - A water diverting structure such as a swale shall be constructed (across the roadway on both roadway approaches) 50 feet (maximum) on either side of the waterway crossing. This will prevent roadway surface runoff from directly entering the waterway. The 50 feet is measured from the top of the waterway bank. Design criteria for this diverting structure shall be in accordance with the "Standard and Specifications" for the individual design standard of choice. If the roadway approach is constructed with a reverse grade away from the waterway, a separate diverting structure is not required.
- f. Road Width - All crossings shall have one traffic lane. The minimum width shall be 12 feet with a maximum width of 20 feet.
- g. Time of Operation - All temporary crossings shall be removed within 14 calendar days after the structure is no longer needed. Unless prior written approval is obtained from the Delaware Department of Natural Resources and Environmental Control, or the local conservation district, as appropriate; all structures shall be removed within one year from the date of the installation.
- h. Materials
 - i. Aggregate - There shall be no earth or soil materials used for construction within the waterway channel. DE #3 stone shall be the minimum acceptable aggregate size for temporary crossings. Larger aggregates will be allowed.
 - ii. Geotextile - Geotextile is a fabric consisting of either woven or nonwoven plastic, polypropylene, or nylon used to distribute the load, retain fines, allow increased drainage of the aggregate and reduce mixing of the aggregate with the subgrade soil. Geotextiles shall be **Type GS-I** in accordance with the specifications contained in **Appendix A-3**.

2. Considerations for Choosing a Specific Method

The following criteria for erosion and sediment control shall be considered when selecting a specific temporary access waterway crossing standard method:

- a. Site aesthetics - Select a standard design method that will least disrupt the existing terrain of the stream reach. Consider the effort that will be required to restore the area after the temporary crossing is removed.
- b. Site Location - Locate the temporary crossing where there will be the least disturbance to the soils of the existing waterway banks. When possible locate the crossing at a point receiving minimal surface runoff.
- c. Physical site constraints - The physical constraints of a site may preclude the selection of one or more of the standard methods.
- d. Time of Year - The time of year may preclude the selection of one or more of the standard methods due to fish spawning or migration restrictions.
- e. Vehicular loads and traffic patterns - Vehicular loads, traffic patterns, and frequency of crossings should be considered in choosing a specific method.
- f. Maintenance of crossing - The standard methods will require various amounts of maintenance. The bridge method should require the least maintenance where as the ford method will probably require more intensive maintenance.
- g. Removal of the structure - Ease of removal and subsequent damage to the waterway should be primary factors in considering the choice of a standard method.

ADDITIONAL STANDARD AND SPECIFICATIONS FOR TEMPORARY CULVERT CROSSING

Definition: A temporary access culvert is a structure consisting of a section(s) of circular pipe, pipe arches, or oval pipe of reinforced concrete, corrugated metal, or structural plate, which is used to convey flowing water through the crossing.

Considerations

1. Temporary culverts are used where:
 - a. the channel is too wide for normal bridge construction,
 - b. anticipated loading may prove unsafe for single span bridges, or
 - c. access is not needed from bank to bank.
2. This temporary waterway crossing method is normally preferred over a ford type of crossing, since disturbance to the waterway is only during construction and removal of the culvert.
3. Temporary culverts can be salvaged and reused.

Culvert Strength

All culverts shall be strong enough to support their cross sectional area under maximum expected loads.

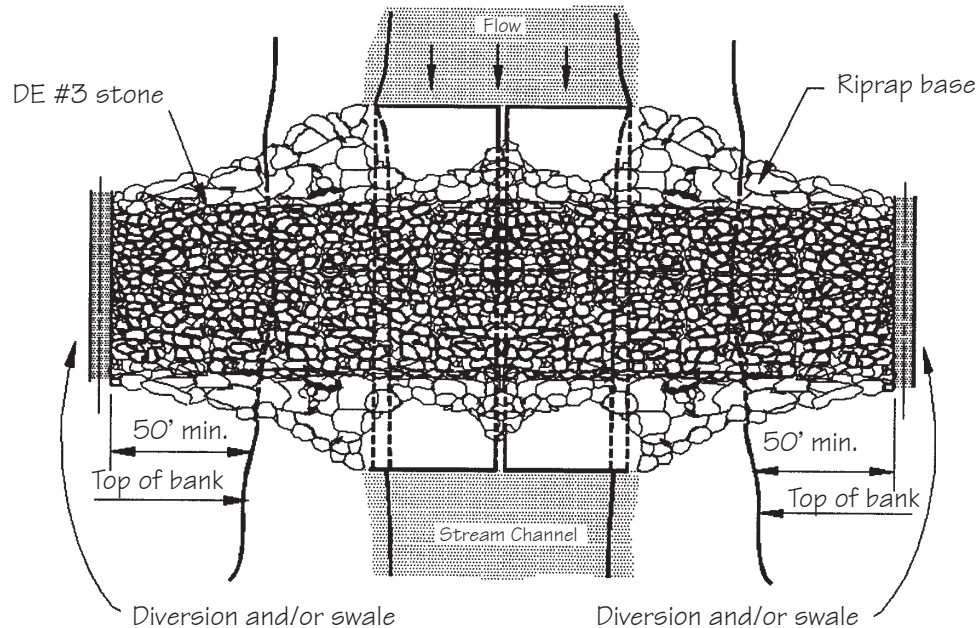
Culvert Size

The size of the culvert pipe shall be the largest pipe diameter that will fit into the existing channel without major excavation of the waterway channel or without major approach fills. If a channel width exceeds 3 feet, additional pipes may be used until the cross sectional area of the pipes is greater than the percent of the cross sectional area of the existing channel. The minimum size culvert that may be used is a 12" diameter pipe.

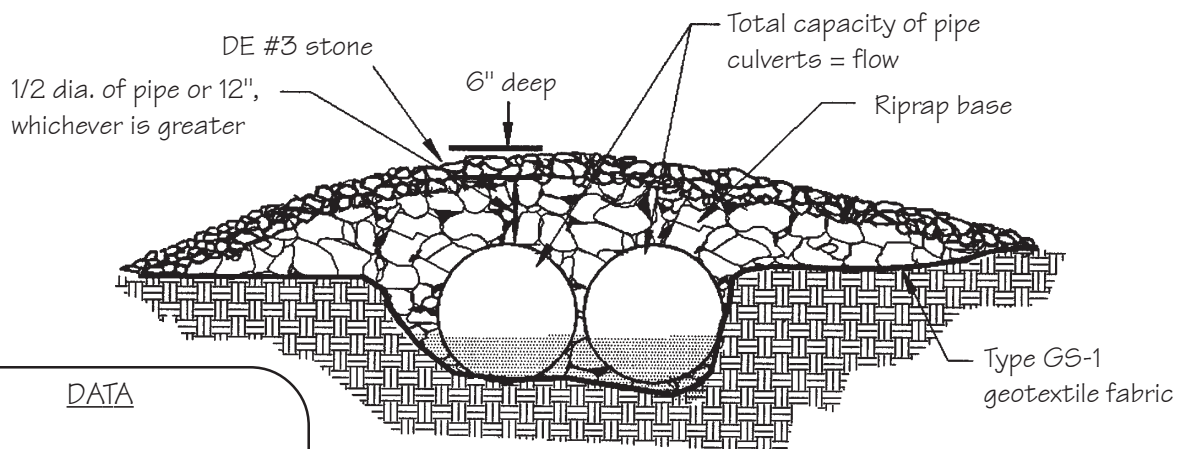
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Standard Detail & Specifications

Temporary Crossing - Culvert



Plan



Typical Section

DATA

Pipe diameter (D)
Number of pipes (No.)
Pipe material & thickness
Riprap size (R No.)

Source:

Adapted from
VA ESC Handbook

Symbol:

TC-C

Detail No.

DE-ESC-3.5.1.1

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Temporary Crossing - Culvert

Construction Notes:

1. **Restrictions** - No construction or removal of a temporary access culvert will be permitted from March 15 through June 15 to minimize interference with fish spawning and migration. Further restrictions may apply in accordance with other State and/or Federal permits.
2. **Installation**
 - a. **Culvert Length** - The culvert(s) shall extend a minimum of one foot beyond the upstream and downstream toe of the aggregate placed around the culvert. In no case shall the culvert exceed 40 feet length.
 - b. **Geotextile** - Type GS-1 geotextile shall be placed so as to cover the streambed and extend minimum six inches and a maximum one foot beyond the end of the culvert prior to installing the bedding material. Geotextile fabric reduces settlement and improves crossing stability.
 - c. **Culvert Placement** - The invert elevation of at least 1 (one) culvert shall be installed 1 (one) foot below the natural streambed grade to minimize interference with fish migration.
 - d. **Culvert Protection** - The culvert(s) shall be covered with a minimum of one foot of riprap with a 6 inch top layer of coarse aggregate. If multiple culverts are used they shall be separated by at least 12" of compacted aggregate fill.
 - e. **Stabilization** - All areas disturbed during culvert installation shall be stabilized within 14 calendar days in accordance with the Standard and Specifications for Temporary Vegetative Stabilization.
3. **Maintenance**
 - a. **Inspection** - Periodic inspection shall be performed to ensure that the culverts, stream bed, and streambanks are not damaged, and that sediment is not entering the stream or blocking fish passage or migration.
 - b. **Maintenance** - Maintenance shall be performed as needed, in a timely manner to ensure that structures are in compliance with this standard and specification. This shall include removal and disposal of any trapped sediment or debris. Sediment shall be disposed of and stabilized outside the waterway floodplain.
4. **Restoration**
 - a. **Removal** - When the crossing has served its purpose, all structures including culverts, bedding and filter cloth materials shall be removed within 14 calendar days. In all cases, the culvert materials shall be removed within one year of installation.
 - b. **Final Clean-up** - Final clean-up shall consist of removal of the temporary structure from the waterway, removal of all construction materials, restoration of original stream channel cross section, and protection of the streambanks from erosion. Removed materials shall be stored outside of the waterway floodplain.
 - c. **Method** - Removal of the structure and clean up of the area shall be accomplished without construction equipment working in the waterway channel.
 - d. **Final Stabilization** - All areas disturbed during culvert removal shall be stabilized within 14 calendar days in accordance with the Standard and Specifications for Permanent Vegetative Stabilization.

Source:

Adapted from
VA ESC Handbook

Symbol:

TC-C

Detail No.

DE-ESC-3.5.1.1

Sheet 2 of 2

Effective July 2023

ADDITIONAL STANDARD AND SPECIFICATIONS FOR TEMPORARY TIMBER MAT CROSSING

Definition: A temporary timber mat is a shallow structure placed in the bottom of a waterway over which water flows while still allowing traffic to cross the waterway.

Considerations

Temporary timber mats are typically used where the streambanks are less than a few feet above the invert of the stream. However, timber mats are generally preferred over other temporary crossings which require the placing of stone in the streambed. Therefore, the use of timber mats may be approved for higher stream banks if adequate approaches can be provided.

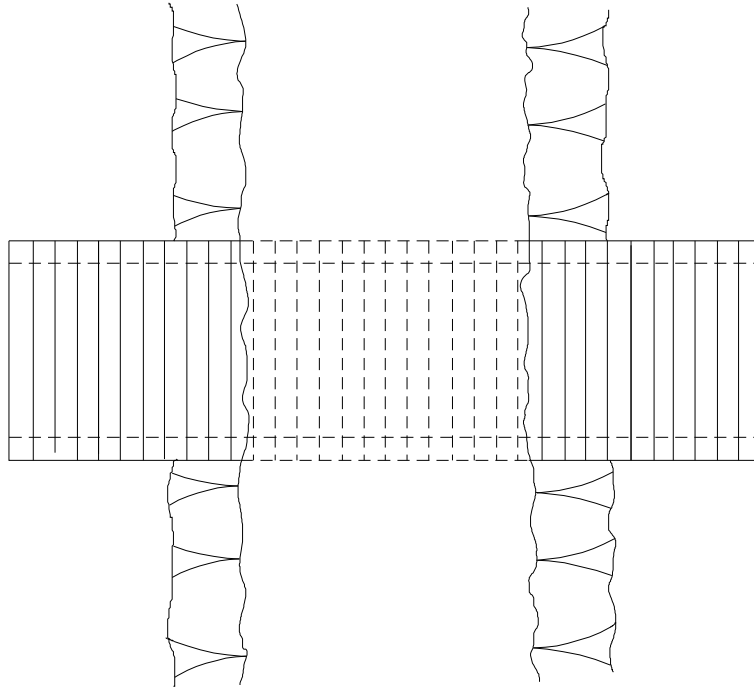
Design Criteria

The timbers used for temporary mat crossings shall be of adequate size to support the equipment intended to cross it. Rods or cable links must be adequate to remain serviceable during continuous use and to resist breaking during handling.

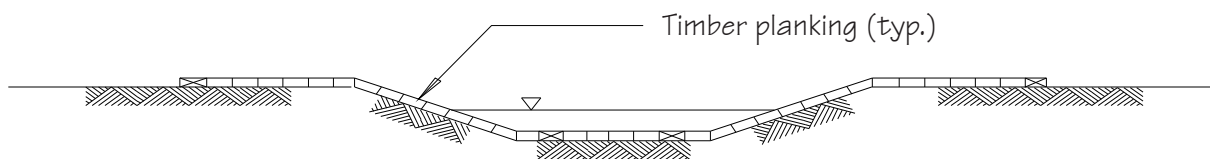
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Standard Detail & Specifications

Temporary Crossing - Timber Mat



Plan



Profile

Source:

Delaware ESC Handbook

Symbol:



Detail No.

DE-ESC-3.5.1.2

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Temporary Crossing - Timber Mat

Construction Notes:

1. **Restrictions** - No installation or removal of a temporary timber mat crossing will be permitted from March 15 through June 15 to minimize interference with fish spawning and migration. Further restrictions may apply in accordance with other State and/or Federal permits.
2. **Installation**
 - a. Placement - Mats shall be placed only in those areas designated on the approved plan.
 - b. Stabilization - All areas disturbed during the installation shall be stabilized within 14 calendar days of the disturbance in accordance with the Standard and Specifications for Temporary Vegetative Stabilization.
3. **Maintenance**
 - a. Inspection - Periodic inspection shall be performed to ensure that the crossing, stream bed, and streambanks are not damaged, and that sediment is not entering the stream or blocking fish passage or migration.
 - b. Maintenance - Maintenance shall be performed as needed, in a timely manner to ensure that structures are in compliance with this standard and specification. This shall include removal and disposal of any trapped sediment or debris. Sediment shall be disposed of and stabilized outside the waterway floodplain.
4. **Restoration**
 - a. Removal - It may be necessary to temporarily remove a timber mat crossing in anticipation of unusual storm events. When the crossing has served its purpose, all components shall be removed within 14 calendar days. In all cases, the crossing materials shall be removed within one year of installation.
 - b. Final Clean-up - Final clean-up shall consist of removal of the temporary structure from the waterway, removal of all construction materials, restoration of original stream channel cross-section, and protection of the streambanks from erosion. Removed materials shall be stored outside of the waterway floodplain.
 - c. Method - Removal of the structure and clean up of the area shall be accomplished without construction equipment working in the waterway channel.
 - d. Final Stabilization - All areas disturbed during culvert removal shall be stabilized within 14 calendar days of the disturbance in accordance with the Standard and Specifications for Permanent Vegetative Stabilization.

Source:

Delaware ESC Handbook

Symbol:



Detail No.

DE-ESC-3.5.1.2

Sheet 2 of 2

Effective July 2023

ADDITIONAL STANDARD AND SPECIFICATIONS FOR TEMPORARY BRIDGE CROSSING

Definition: A temporary access bridge is a structure made of wood, metal, or other materials which provides access across and stream or waterway.

Considerations

1. Temporary access bridges are the preferred structures for providing temporary waterway crossings. Normally, bridge construction causes the least disturbance to the waterway bed and banks when compared to the other access waterway crossings.
2. Most bridges can be quickly removed and reused.
3. Temporary access bridges pose the least chance for interference with fish migration when compared to the other temporary access waterway crossings.

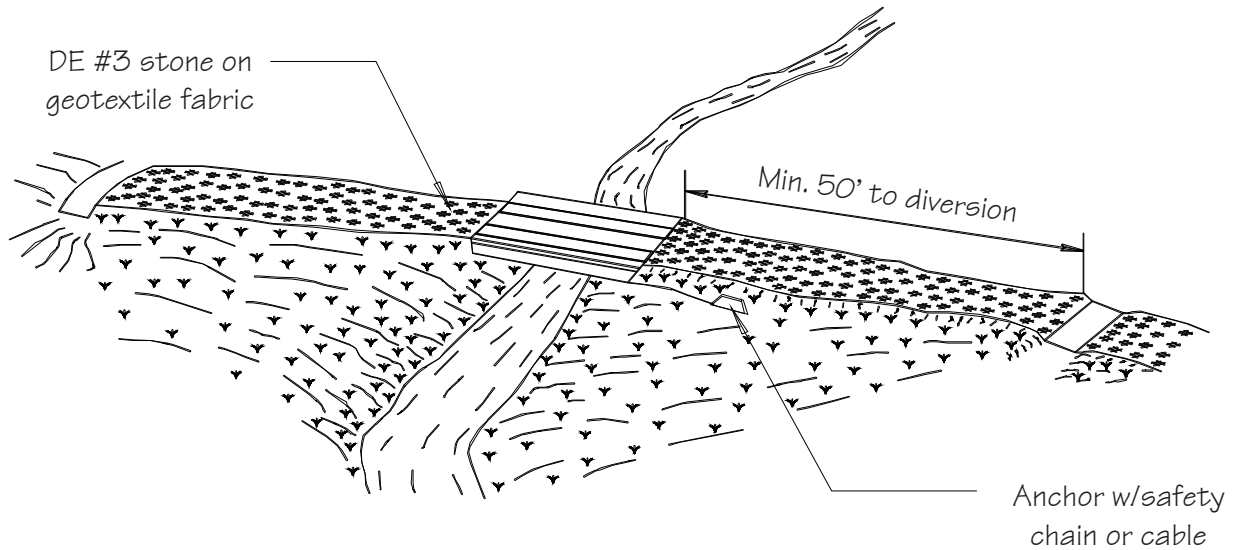
Design Criteria

1. Stringers - Stringers shall either be logs, sawn timber, prestressed concrete beams, metal beams, or other approved materials.
2. Decking materials - Decking materials shall be of sufficient strength to support the anticipated load.

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Standard Detail & Specifications

Temporary Crossing - Bridge



Perspective

DATA

Stringer material
Stringer dimensions
Decking material
Decking dimensions

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:



Detail No.

DE-ESC-3.5.1.3

Sheet 1 of 3

Effective July 2023

Standard Detail & Specifications

Temporary Crossing - Bridge

Construction Notes:

1. **Restrictions** - No construction or removal of a temporary access bridge will be permitted from March 15 through June 15 to minimize interference with fish spawning and migration. Further restrictions may apply in accordance with other State and/or Federal permits.
2. **Installation**
 - a. **Bridge Placement** - A temporary bridge structure shall be constructed at or above bank elevation to prevent the entrapment of floating materials and debris.
 - b. **Abutments** - Abutments shall be placed parallel to and on stable banks.
 - c. **Bridge Span** - Bridges shall be constructed to span the entire channel. If the channel width exceeds 8 feet (as measured from top-of-bank to top-of-bank) then a footing, pier or bridge support may be constructed within the waterway. One additional footing, pier or bridge support will be permitted for each additional 8 foot width of the channel. However, no footing, pier or bridge support will be permitted within the channel for waterways less than 8 feet wide.
 - d. **Deck Material** - All decking members shall be placed perpendicular to the stringers, butted tightly, and securely fastened to the stringers. Decking materials must be butted tightly to prevent any soil material tracked onto the bridge from falling into the waterway below.
 - e. **Run Planks (optional)** - Run planking shall be securely fastened to the length of the span. One run plank shall be provided for each track of the equipment wheels. Although run planks are optional, they may be necessary to properly distribute loads.
 - f. **Curbs or fenders** - Curbs or fenders may be installed along the outer sides of the deck. Curbs or fenders are an option which will provide additional safety.
 - g. **Bridge Anchors** - Bridges shall be securely anchored at only one end using steel cable or chain. Anchoring at only one end will prevent channel obstruction in the event that floodwaters float the bridge. Acceptable anchors are large trees, large boulders, or driven steel anchors. Anchoring shall be sufficient to prevent the bridge from floating down stream and possibly causing an obstruction to the flow.
 - h. **Stabilization** - All areas disturbed during bridge installation shall be stabilized within 14 calendar days of the disturbance in accordance with the Standard and Specifications for Temporary Vegetative Stabilization.

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:



Detail No.

DE-ESC-3.5.1.3

Sheet 2 of 3

Effective July 2023

Standard Detail & Specifications

Temporary Crossing - Bridge

Construction Notes (cont.)

3. Maintenance

- a. Inspection - Periodic inspection shall be performed to ensure that the structure, streambed, and streambanks are not damaged, and that sediment is not entering the stream or blocking fish passage or migration.
- b. Maintenance - Maintenance shall be performed as needed, in a timely manner to ensure that structures are in compliance with this standard and specification. This shall include removal and disposal of any trapped sediment or debris. Sediment shall be disposed of and stabilized outside the waterway floodplain.

4. Restoration

- a. Removal - When the crossing has served its purpose, all structures including bedding and filter cloth materials shall be removed within 14 calendar days. In all cases, the structure shall be removed within one year of installation.
- b. Final Clean-up - Final clean-up shall consist of removal of the temporary structure from the waterway, removal of all construction materials, restoration of original stream channel cross section, and protection of the streambanks from erosion. Removed materials shall be stored outside of the waterway floodplain.
- c. Method - Removal of the structure and clean up of the area shall be accomplished without construction equipment working in the waterway channel.
- d. Final Stabilization - All areas disturbed during removal shall be stabilized within 14 calendar days of the disturbance in accordance with the Standard and Specifications for Permanent Vegetative Stabilization.

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:



Detail No.

DE-ESC-3.5.1.3

Sheet 3 of 3

Effective July 2023

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ADDITIONAL STANDARD AND SPECIFICATIONS FOR TEMPORARY FORD CROSSING

Definition: A temporary ford is a shallow structure placed in the bottom of a waterway over which water flows while still allowing traffic to cross the waterway.

Considerations

Temporary fords may be used where the streambanks are less than 4 feet above the invert of the stream, and the streambed is armored with naturally occurring bedrock, or can be protected with an aggregate layer in accordance with these specifications.

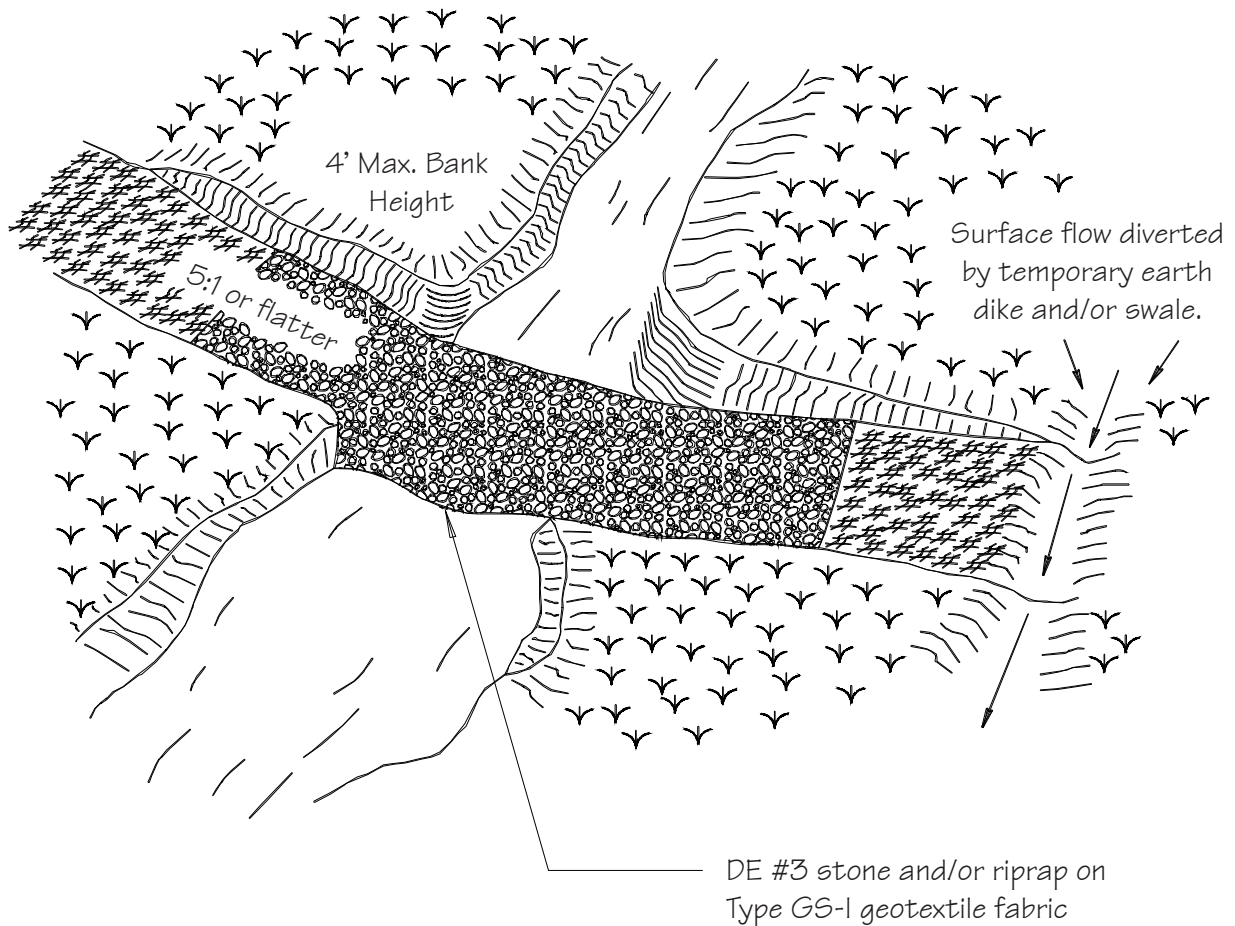
Design Criteria

1. Stone - The stone used for temporary fords shall be of adequate size and weight to resist anticipated storm flows. This would typically be based on the 2-year return period event. However, for work near certain highly sensitive protected areas, design storms of greater magnitude may be warranted.
2. Surface flow - Provisions shall be made to direct surface flow away from the ford and its approaches. This can be accomplished through the use of temporary earth dikes and/or swales in accordance with the appropriate Design Standards and Specifications.

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Standard Detail & Specifications

Temporary Crossing - Stone Ford



Perspective

DATA

Median stone size (d_{50})

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:



Detail No.

DE-ESC-3.5.1.4

Sheet 1 of 3

Effective July 2023

Standard Detail & Specifications

Temporary Crossing - Stone Ford

Construction Notes:

1. **Restrictions** - No construction or removal of a temporary access ford will be permitted from March 15 through June 15 to minimize interference with fish spawning and migration. Further restrictions may apply in accordance with other State and/or Federal permits.
2. **Installation**
 - a. The approaches, bedding, and ford shall be constructed of DE #3 stone as a minimum. Larger riprap may be placed as a surface layer, as needed, where higher flows are anticipated.
 - b. The entire ford approach (where banks were cut) shall be covered with filter cloth and have four (4) inches of aggregate placed on top of the filter cloth.
 - c. Fords shall not be installed when the streambanks are 4 feet or more in height above the invert of the stream.
 - d. The approach roads at the cut banks shall be no steeper than 5:1. Spoil material from the banks shall be stored out of the floodplain and stabilized.
 - e. One layer of Type GS-I geotextile fabric shall be placed on the streambed, streambanks and the road approaches prior to placing the bedding material on the streambed or approaches. The filter cloth shall extend a minimum of 6 inches and a maximum 1 foot beyond bedding material.
 - f. If needed, temporary dikes and/or swales shall be constructed in accordance with the appropriate Standard Detail and Specifications to divert surface flow away from the ford and its approaches.
 - g. Stone used in ford construction shall meet the minimum requirements of the Del-DOT.
 - h. All fords shall be constructed to minimize the blockage of stream flow and shallow flow over the ford. The placing of any material in the waterway bed will cause some upstream ponding. The depth of this ponding will be equivalent to the depth of the material placed within the stream and therefore should be kept to a minimum height. However, in no case will the bedding material be placed deeper than 12 inches or one-half (1/2) the height of the existing banks, whichever is smaller.

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:



Detail No.

DE-ESC-3.5.1.4

Sheet 2 of 3

Effective July 2023

Standard Detail & Specifications

Temporary Crossing - Stone Ford

Construction Notes (cont.)

- i. All areas disturbed during ford installation shall be stabilized within 14 calendar days of the disturbance in accordance with the Standard and Specifications for Temporary Vegetative Stabilization.

3. Maintenance

- a. Inspection - Periodic inspection shall be performed to ensure that the ford, streambed, and streambanks are not damaged, and that sediment is not entering the stream or blocking fish passage or migration.
- b. Maintenance - Maintenance shall be performed as needed, in a timely manner to ensure that structures are in compliance with this standard and specification. This shall include removal and disposal of any trapped sediment or debris. Sediment shall be disposed of and stabilized outside the waterway floodplain.

4. Restoration

- a. Removal - When the temporary structure has served its purpose, excess material used for this structure need not be removed. Care should be taken so that any aggregate left does not create an impoundment or impede fish passage.
- b. Final Clean-up - Final clean-up shall consist of removal of excess temporary ford materials from the waterway. All materials shall be stored outside the waterway floodplain.
- c. Method - Clean up shall be accomplished without construction equipment working in the stream channel.
- d. Approach Disposition - The approach slopes of the cut banks shall not be backfilled.
- e. Final Stabilization - All areas disturbed during ford removal shall be stabilized within 14 calendar days of that disturbance in accordance with the Standard and Specifications for Permanent Vegetative Stabilization.

Source:

Adapted from
MD Stds. & Specs. for ESC

Symbol:



Detail No.

DE-ESC-3.5.1.4

Sheet 3 of 3

Effective July 2023

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STANDARD AND SPECIFICATIONS FOR STREAM DIVERSION

Definition: A strategy for controlling construction activities in or adjacent to streams.

Purpose: To prevent sediment from entering a water body due to construction within approach areas and to minimize the amount of disturbance within the stream itself.



Conditions Where Practice Applies:

Generally applicable to flowing streams with *drainage areas less than one square mile*. Structures or methodology for crossing streams with larger drainage areas require project specific plans which are designed using methods which more accurately define the actual hydrologic and hydraulic parameters which will affect the functioning of the structure. Some practices, such as cofferdams, might also be applicable to construction activities in or adjacent to larger bodies of water such as ponds or lakes under certain circumstances.

Planning Considerations:

Construction activity, by virtue of its very nature, occasionally crosses and impacts free-flowing streams. There is a potential for excessive sediment loss into a stream by both the disturbance of the approach areas and by the work within the stream-bed and banks.

It is often a difficult task to decide what type of control to use under such circumstances. A method such as "boring and jacking" of utilities below a streambed, which would prevent disturbance within the watercourse, is the preferred method whenever practical. However, in cases where in-stream work is unavoidable, consideration must be given to providing adequate mitigation of sediment loss while minimizing the amount of encroachment and time spent working in the channel. There is some flexibility in the implementation of these controls. For example, in some cases it may be more environmentally beneficial to provide substantial controls for the approach areas rather than install extensive measures in the stream itself which would extend the exposure time of the disturbance. However, when construction activities within streambed and banks will take an extended period of time, consideration should be given to substantial in-stream controls or use of a stream diversion in order to prevent excessive sedimentation damage.

Because of the difficulty in choosing the right method for in-stream activities, designers and plan reviewers should always make site visits of the proposed area to ensure that the most appropriate method is chosen. The designer and plan reviewer should also be aware that such modifications are subject to other state and federal construction permits.

Design Criteria:

Stream diversions under this standard and specification shall be designed in accordance with the following guidelines:

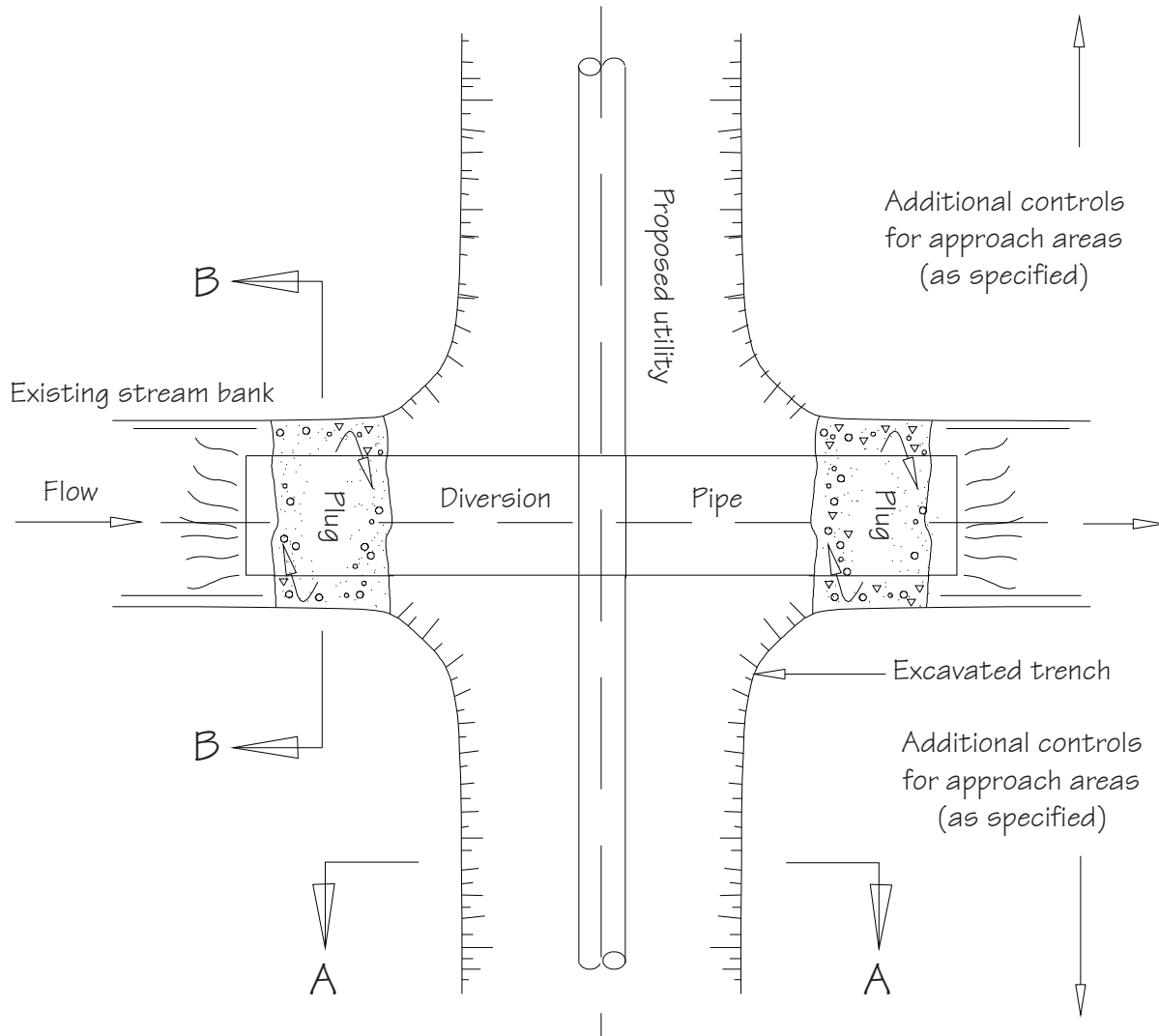
1. The drainage area should be no greater than one (1) square mile (640 acres).
2. Stream diversions shall be designed so as not to alter the flow either upstream or downstream from the work area.
3. Temporary diversion pipes shall be limited to use in situations where they will remain in place no more than 14 days. The pipe should be large enough to convey the design flow without appreciably altering the stream flow characteristics. The design flow shall be determined based on the expected construction time, as follows:
 - a. 1 day: Existing flow of the watercourse.
 - b. 2 - 14 days: 2-year frequency storm.
4. Temporary diversion channels shall be stabilized with a lining capable of withstanding expected erosive forces. The following linings are acceptable for the max. velocities indicated:
 - a. Polyethylene or vegetation: 0 - 2.5 f.p.s.
 - b. Geotextile fabric: 2.5 - 9.0 f.p.s.
 - c. Riprap or sandbag: 9.0 - 13.0 f.p.s.
5. All materials used in the construction of the stream diversion (i.e., pipe, stone, geotextile fabric, etc.) must generally conform to the Standards and Specifications for Temporary Crossings.
6. Surface water diverting structures should be used at all trenching and/or construction road approaches within 50 feet on either side of the crossing.

Maintenance:

Care must be taken to inspect any stream diversion at the end of each day to make sure that the construction materials are positioned securely. This will ensure the work area remains dry and that no construction materials float downstream. If a runoff event is anticipated, construction materials which could become floatable debris should be moved to higher ground.

Standard Detail & Specifications

Utility Crossing Diversion Pipe



DATA

Diversion pipe diameter (D)
Plug material
Impermeable material
Dewatering practice

Plan

Source:

Adapted from
VA ESC Handbook

Symbol:

DP

Detail No.

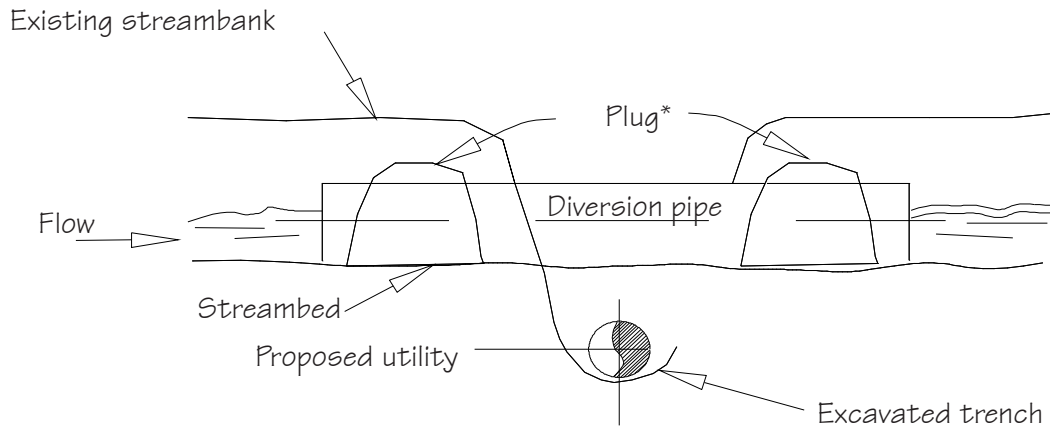
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Sheet 1 of 3

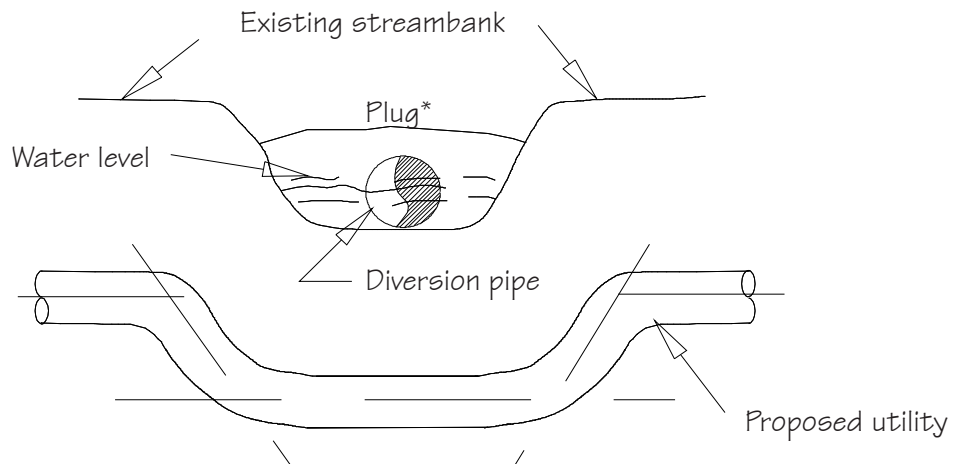
Effective July 2023

Standard Detail & Specifications

Utility Crossing Diversion Pipe



Section A-A



Section B-B

*NOTE: Plug shall consist of coarse aggregate, riprap, sandbags or other material capable of resisting expected flows. Upstream plug shall be made waterproof using Type GS-I geotextile or other means, as specified.

Source:

Adapted from
VA ESC Handbook

Symbol:



Detail No.

DE-ESC-3.5.2.1

Sheet 2 of 3

Effective July 2023

Standard Detail & Specifications

Utility Crossing Diversion Pipe

Construction Notes:

1. Pipe diversion shall be operational prior to start of in-stream construction.
2. Controls for approach areas shall be provided in accordance with the approved plan.
3. All materials used must be adequate to withstand expected hydraulic and equipment loads.
4. Pipe shall be of adequate size to convey the normal water channel flow and shall be installed in the stream bed across the proposed utility trench centerline.
5. Impervious plug shall be placed near each end of pipe so as to dam off the channel flow and force it into the diversion pipe.
6. Water trapped between the plugs shall be pumped to an approved dewatering practice prior to excavation of the utility trench.
7. Once the diversion pipe has been made operational and checked for water tightness, excavation of the utility trench may begin. Installation of the utility shall proceed in a timely manner so as to minimize in-stream construction.
8. Once the utility has been installed, trench shall be backfilled and stabilized in accordance with the approved plan.
9. Diversion pipe shall remain in-place until stream bed and banks have been stabilized.

This practice limited to streams less than 10' wide; in-stream construction periods shall be less than 72 hours.

Source:

Adapted from
VA ESC Handbook

Symbol:



Detail No.

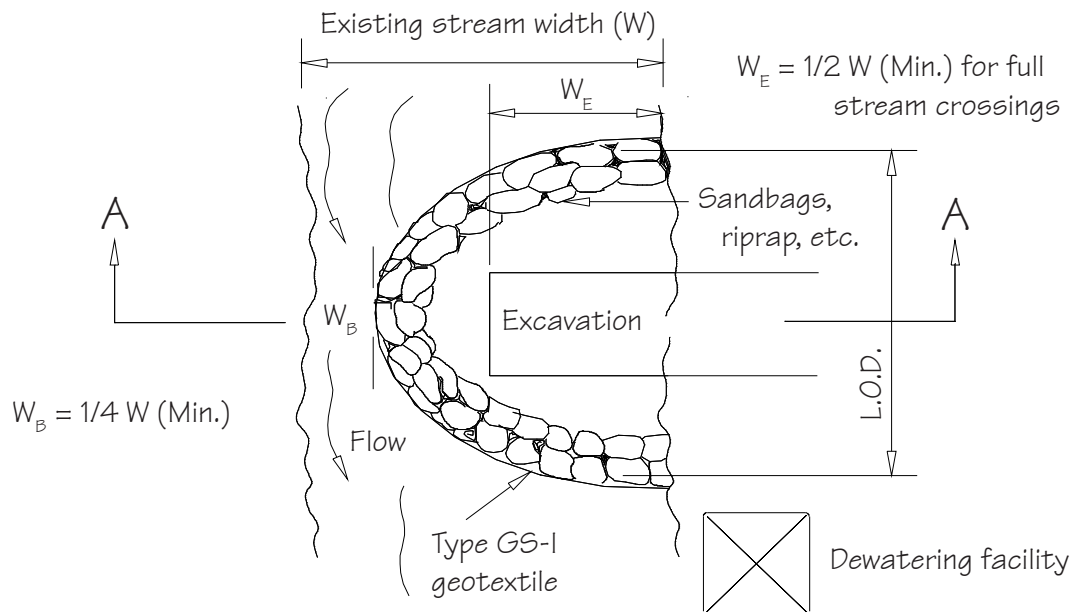
DE-ESC-3.5.2.1
Sheet 3 of 3

Effective July 2023

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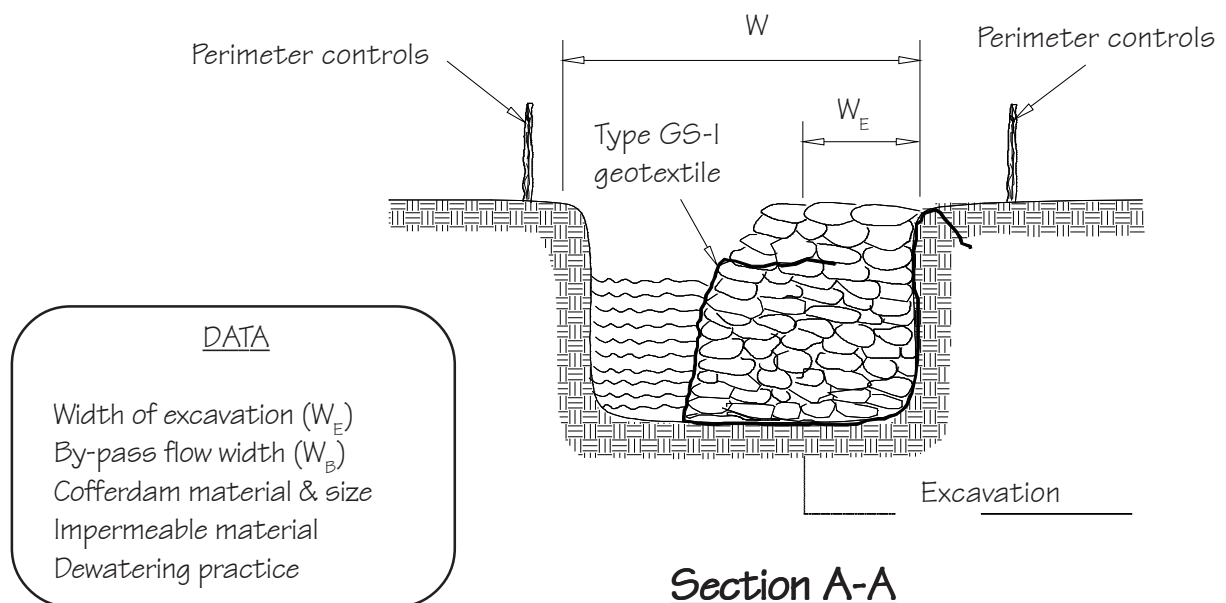
Standard Detail & Specifications

Cofferdam Stream Diversion



NOTE: For full stream crossings, separate cofferdams shall be constructed from each bank.

Plan



Source:

Adapted from
VA ESC Handbook

Symbol:

CD

Detail No.

DE-ESC-3.5.2.2

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Cofferdam Stream Diversion

Construction Notes:

1. Construction shall be performed during low flow conditions.
2. Cofferdam shall not impede the flow of the stream in any way.
3. Controls for approach areas shall be provided in accordance with the approved plan.
4. Large rocks, woody vegetation, or other material in the streambed and banks which may preclude proper installation of the cofferdam materials and/or impede the proposed construction shall be removed.
5. Cofferdam shall be formed by placing riprap, sandbags, sheet metal or wood planks in a semi-circle around the proposed work area. Height of the cofferdam shall be adequate to keep water from overtopping the dam and flooding the work area.
6. Water in the work area shall be pumped to an approved dewatering practice.
7. Once adequately dewatered, in-stream construction may begin from the first bank and proceed to the centerline of the stream, as required.
8. If a full stream crossing is required, all disturbed areas within the first work area shall be stabilized in accordance with the approved plan prior to dismantling and reconstructing the cofferdam on the opposite bank.
9. Repeat the operation from the opposite bank.

Source:

Adapted from
VA ESC Handbook

Symbol:



Detail No.

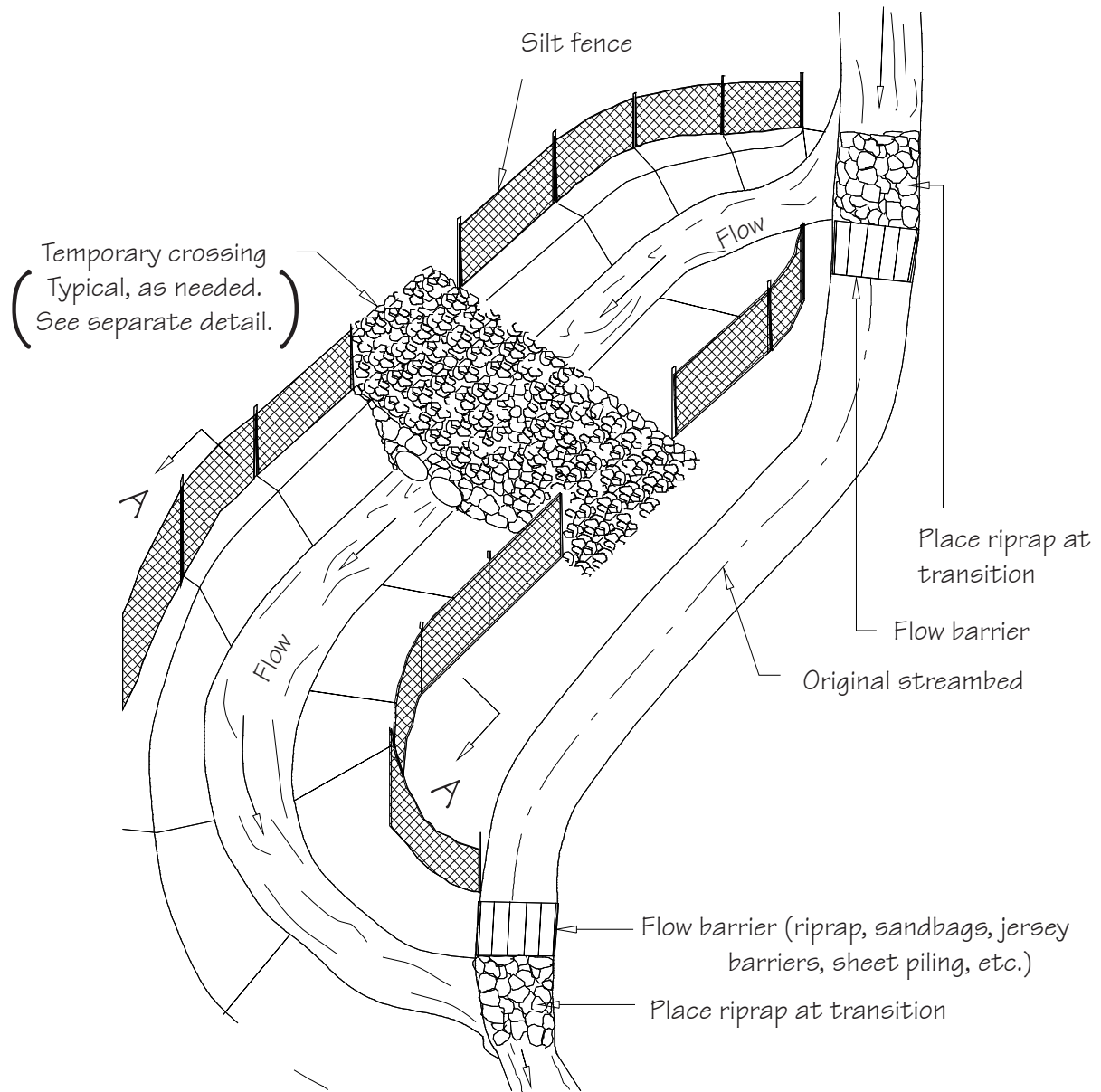
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Sheet 2 of 2

Effective July 2023

Standard Detail & Specifications

Stream Diversion Channel



Perspective

Source:

Adapted from
VA ESC Handbook

Symbol:



Detail No.

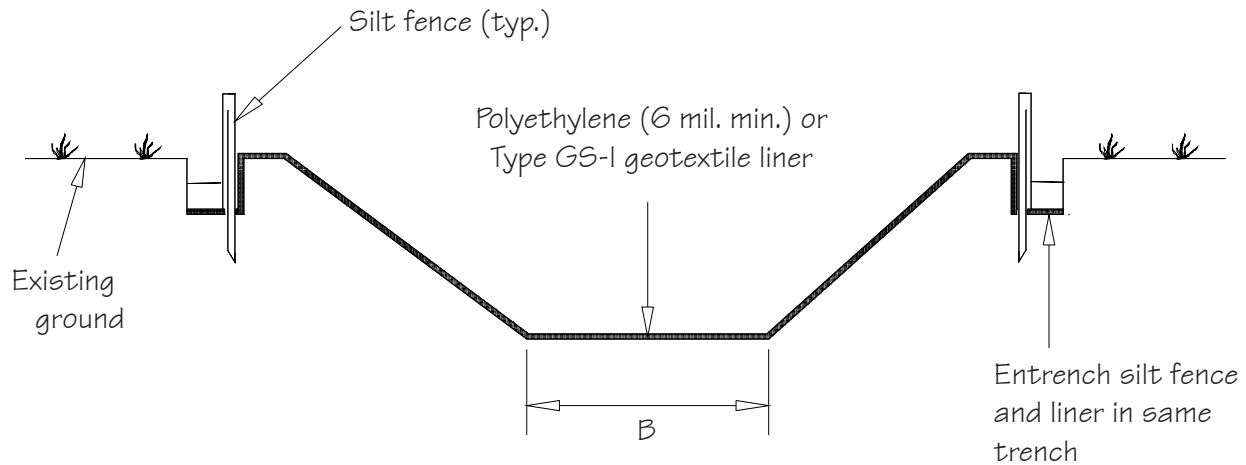
DE-ESC-3.5.2.3

Sheet 1 of 3

Effective July 2023

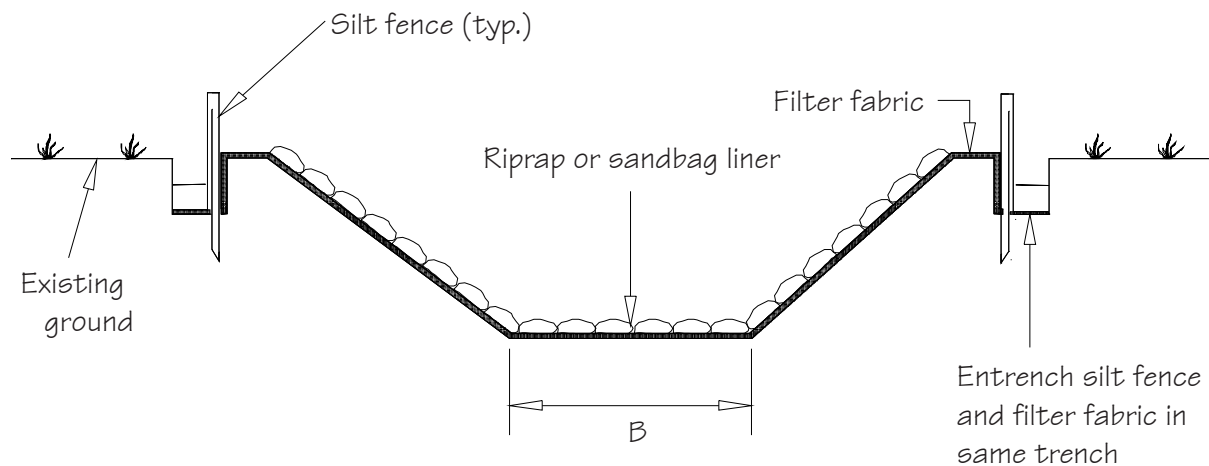
Standard Detail & Specifications

Stream Diversion Channel



Section A-A (Low velocity lining)

NOTE: Channel bottom width (B) to be 6' min. or width of exist. stream, which ever is less.



Section A-A (High velocity lining)

DATA

Channel bottom width (B)

Lining specification

Source:

Adapted from
VA ESC Handbook

Symbol:



Detail No.

DE-ESC-3.5.2.3

Sheet 2 of 3

Effective July 2023

Standard Detail & Specifications

Stream Diversion Channel

Construction Notes:

1. Diversion channel shall be operational prior to any in-stream construction.
2. Minimum width of bottom shall be 6' or equal to the bottom width of the existing streambed, whichever is less.
3. Maximum steepness of sideslopes shall be 2:1. Depth and grade may be variable, depending on site conditions, but shall be sufficient to ensure continuous flow of water in the diversion.
4. Channel lining shall be as specified and installed in accordance with the appropriate detail. Liners shall be secured at the upstream and downstream ends with riprap or other non-erodible material which will allow normal flow of the stream. This material shall not have soil mixed in. Additional material may be placed along the length of the diversion, as needed, to secure the liner.
5. If a single or continuous liner is not available or is impractical, upstream sections shall overlap downstream sections by a min. of 18".
6. Liner shall be entrenched at the top of the slope or slope break as shown in the detail. Silt fence or other perimeter control shall be provided unless the liner is extended far enough to prevent sediment from reaching the stream.
7. Liners shall be secured to the side slopes of the diversion channel using staples and patterns similar to those used for erosion control matting; wooden stakes shall not be used for this purpose.
8. Stream flow shall be diverted away from the work area in the original streambed using non-erodible, impervious materials such as riprap with geotextile, jersey barriers, sandbags, wood planking, sheet pile, etc. These materials shall be placed so as to prevent or reduce water backing up into the construction area.
9. Water in the construction area shall be pumped to an approved dewatering practice.
10. Once in-stream construction has been completed and all disturbed areas stabilized, the downstream flow barrier in the original stream shall be removed first. The upstream flow barrier shall then be removed and the material placed in the upstream end of the diversion, thus redirecting flow back to the original stream channel. The diversion shall then be sealed at the downstream end.
11. Once the diversion has been sealed at both ends, backfilling of the diversion channel may begin. Liner material, if used, shall be buried or removed and properly disposed of in accordance with the job specifications.
12. All disturbed areas shall be stabilized in accordance with the approved plan.

Source:

Adapted from
VA ESC Handbook

Symbol:



Detail No.

DE-ESC-3.5.2.3

Sheet 3 of 3

Effective July 2023

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STANDARD AND SPECIFICATIONS FOR TURBIDITY CURTAIN

Definition: A floating geotextile material which minimizes sediment transport from a disturbed area adjacent to, or within a body of water.



Purpose: To provide sedimentation protection for a watercourse from up-slope land disturbance or from dredging or filling within the watercourse.

Conditions Where Practice Applies:

Applicable to non-tidal and tidal watercourses where intrusion into the watercourse by construction activities and subsequent sediment movement is unavoidable.

Planning Considerations:

Soil loss into a watercourse results in long-term suspension of sediment. In time, the suspended sediment may travel large distances and affect wide-spread areas. A turbidity curtain is designed to deflect and contain sediment within a limited area and provide enough residence time so that soil particles will fall out of suspension and not travel to other areas.

Turbidity curtain types must be selected based on the flow conditions within the water body - whether it be flowing channel, lake, pond, or a tidal watercourse. The specifications contained within this practice pertain to minimal and moderate flow conditions where the velocity of flow may reach *5 feet per second (or a current of approx. 3 knots)*. For situations where there are greater flow velocities or currents, a qualified engineer and product manufacturer should be consulted.

Consideration must also be given to the direction of water movement in channel flow situations. Turbidity curtains are not designed to act as water impoundment dams and cannot be expected to stop the flow of a significant volume of water. They are designed and installed to trap sediment, not to halt the movement of the water itself. In most situations, *turbidity curtains should not be installed across channel flows*.

In tidal or moving water conditions, provisions must be made to allow the volume of water contained within the curtain to change. Since the bottom of the curtain is weighted and external anchors are frequently added, the volume of water contained within the curtain will be much greater at high tide versus low tide and measures must be taken to prevent the curtain from submerging. In addition to allowing for slack in the curtain to rise and fall, water must be allowed to flow through the curtain if the curtain is to remain in roughly the same spot and to

maintain the same shape. Normally, this is achieved by constructing part of the curtain from a heavy woven geotextile fabric. The fabric allows the water to pass through the curtain, but retains the sediment pollutants. Consideration should be given to the volume of water that must pass through the fabric and sediment particle size when specifying fabric permeability.

Sediment which has been deflected and settled out by the curtain may be removed if so directed by the on-site inspector or the plan approval agency. However, consideration must be given to the probable outcome of the procedure. It is possible that the resuspension of particles and/or the accidental dumping of the material could create a more serious problem than leaving it in place. It is therefore recommended that the soil particles trapped by a turbidity curtain only be removed if there has been a significant change in the original contours of the affected area in the watercourse. Regardless of the decision made, soil particles should always be allowed to settle for a *minimum of 6-12 hours* prior to their removal by equipment or prior to removal of the curtain.

The principal strategy for a project involving disturbances along or within a water body should be to *keep sediment out of the watercourse*. However, when proximity to the watercourse makes successfully mitigating sediment loss impossible, the use of the turbidity curtain during land disturbance is essential.

Design Criteria:

1. The Type 1 configuration should be used in protected areas where there is no current and the area is sheltered from wind and waves.
2. The Type 2 configuration should be used in areas where there may be small to moderate current running (up to 2 knots or 3.5 feet per second) and/or wind and wave action can affect the curtain.
3. The Type 3 configuration should be used in areas where considerable current (up to 3 knots or 5 feet per second) may be present and/or where the curtain is potentially subject to wind and wave action.
4. Turbidity curtains should extend the entire depth of the watercourse whenever the watercourse in question is not subject to tidal action and/or significant wind and wave forces.
5. In tidal and/or wind and wave action situations, the curtain should never be so long as to touch the bottom. A minimum 1-foot gap should exist between the weighted lower end of the skirt and the bottom at mean low water. Movement of the lower skirt over the bottom due to tidal reverses or wind and wave action on the flotation system may fan and stir sediments already settled out.
6. In tidal and/or wind and wave action situations, it is seldom practical to extend a turbidity curtain depth lower than 10 to 12 feet below the surface, even in deep water. Curtains which are installed deeper than this will be subject to very large loads with subsequent strain on curtain materials and the mooring system. In addition, a curtain installed in such a manner can "billow up" towards the surface under the pressure of the moving water, which will result in an effective depth which is significantly less than the skirt depth.
7. Turbidity curtains should be located parallel to the direction of flow of a moving body of water. *Turbidity curtains should not be placed across the main flow of a significant body of moving water.*
8. When sizing the length of the floating curtain, allow an additional 10-20% variance in the straight-line measurements. This will allow for measuring errors, make installing easier and reduce stress from potential wave action during high winds.

-
9. An attempt should be made to avoid an excessive amount of joints (anchor or stake locations) in the curtain; a minimum continuous span of 50 feet between joints is a good "rule of thumb".
 10. For stability reasons, a maximum span of 100 feet between joints is also a good rule to follow.

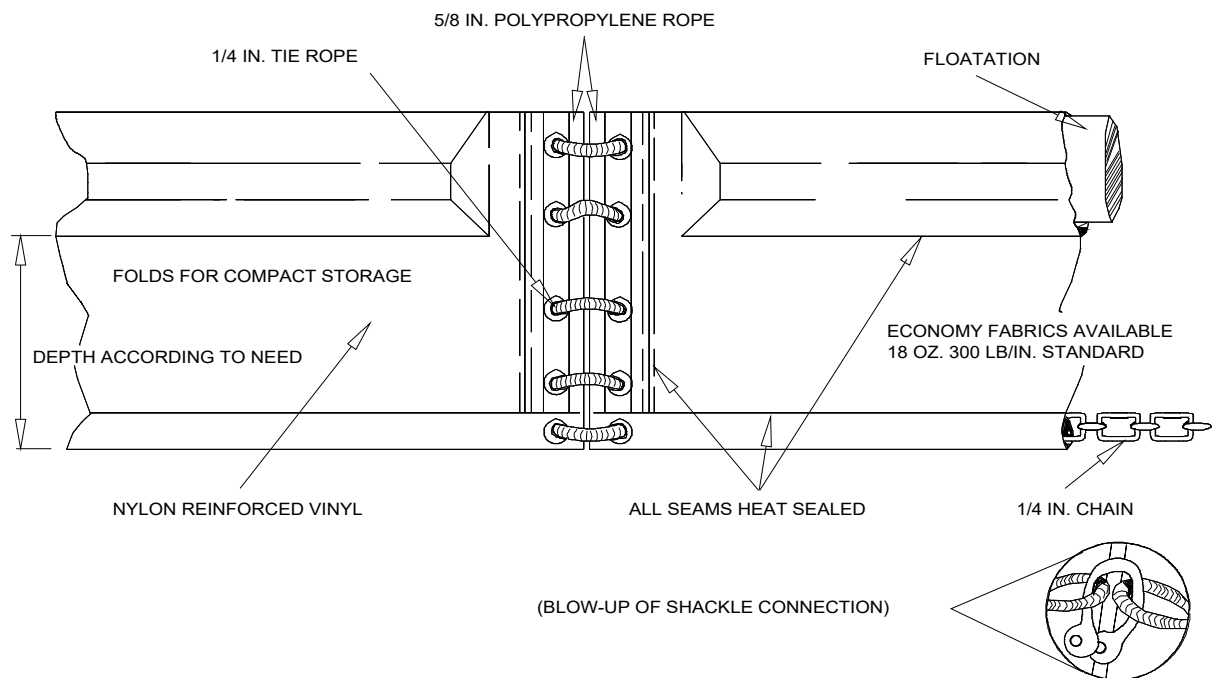
Maintenance:

1. The individual(s) identified on the plan as responsible for maintenance of the curtain shall do so for the duration of the project in order to ensure the continuous protection of the watercourse.
2. Should repairs to the geotextile fabric become necessary, repair kits are generally available from the manufacturer. The manufacturer's instructions must be followed to ensure the adequacy of the repair.
3. When the curtain is no longer required as determined by the inspector, the curtain and related components shall be removed in such a manner as to minimize turbidity. Remaining sediment shall be sufficiently settled before removing the curtain. Sediment may be removed and the original depth (or plan elevation) restored. Any spoils must be taken to an approved upland disposal area and stabilized in accordance with the approved plan.

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Standard Detail & Specifications

Turbidity Curtain



Typical Section - Type 1

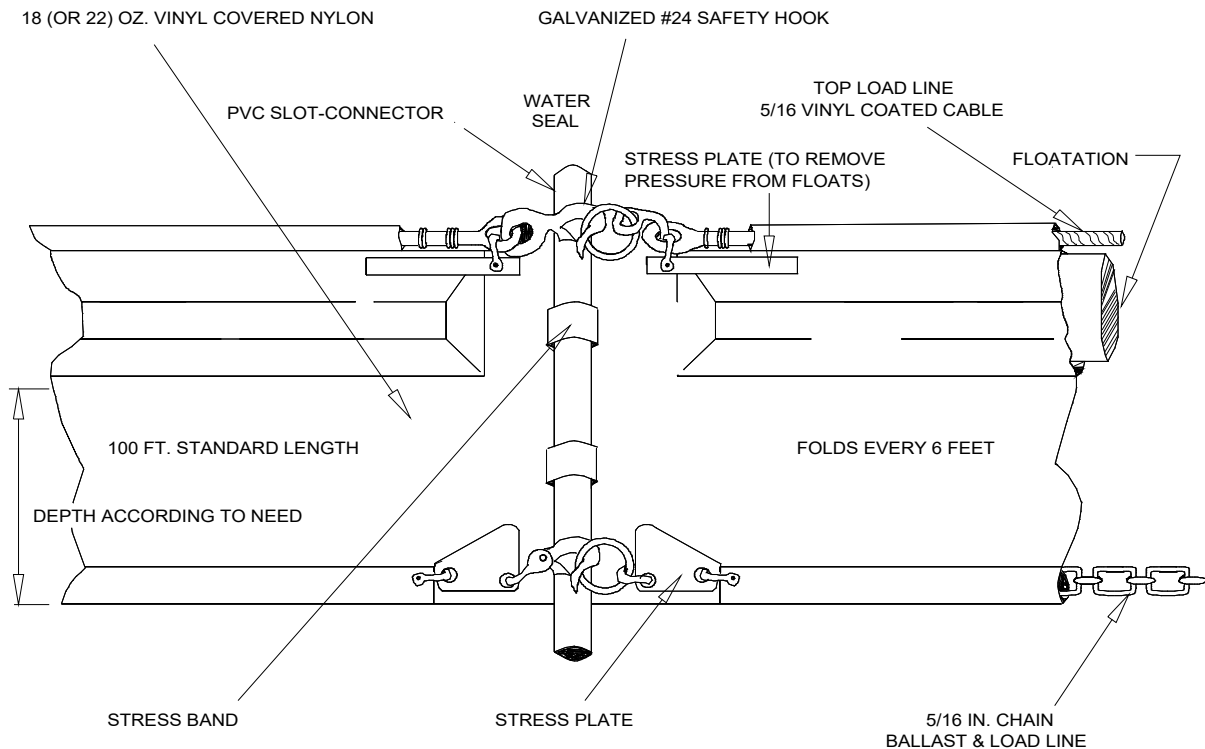
DATA

Curtain type (1,2, or 3)
Layout (Std. or Alt.)

Source: Adapt. from Amer. Boom and Barrier Corp.	Symbol: <div>TC-(1/2/3)</div> <div>(Std/Alt)</div>	Detail No. <div>DE-ESC-3.5.3</div> <div>Sheet 1 of 8</div> <div>Effective July 2023</div>
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Standard Detail & Specifications

Turbidity Curtain



Typical Section - Type 2

DATA

Curtain type (1, 2, or 3)
Layout (Std. or Alt.)

Source:

Adapt. from Amer. Boom and
Barrier Corp.

Symbol:

TC-(1/2/3)
(Std/Alt)

Detail No.

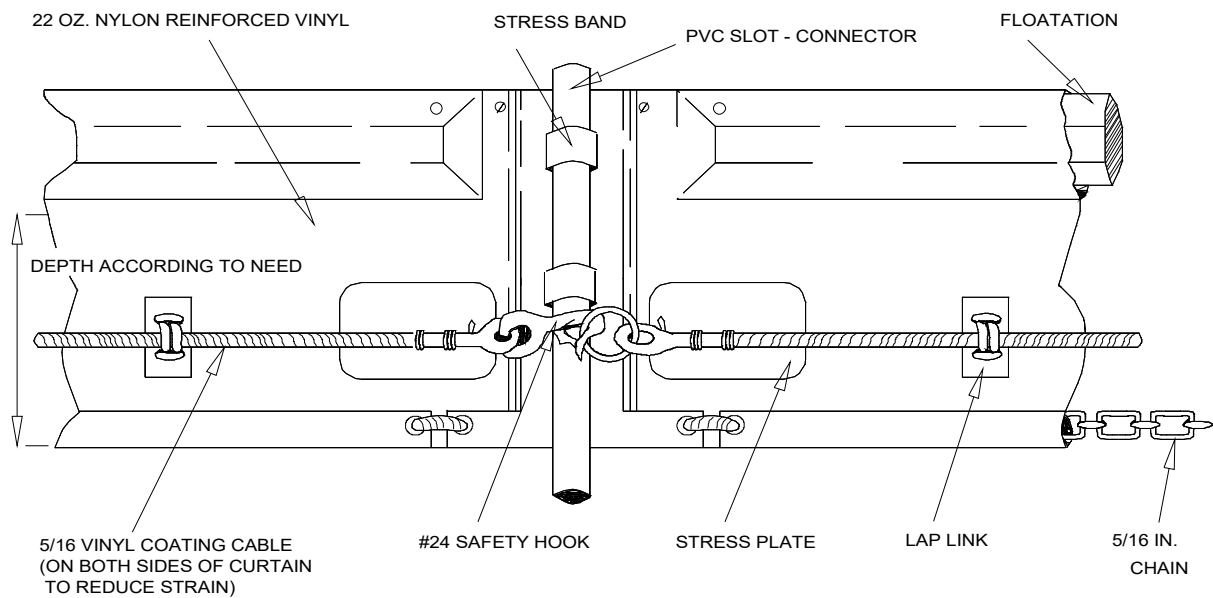
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Sheet 2 of 8

Effective July 2023

Standard Detail & Specifications

Turbidity Curtain



Typical Section - Type 3

DATA

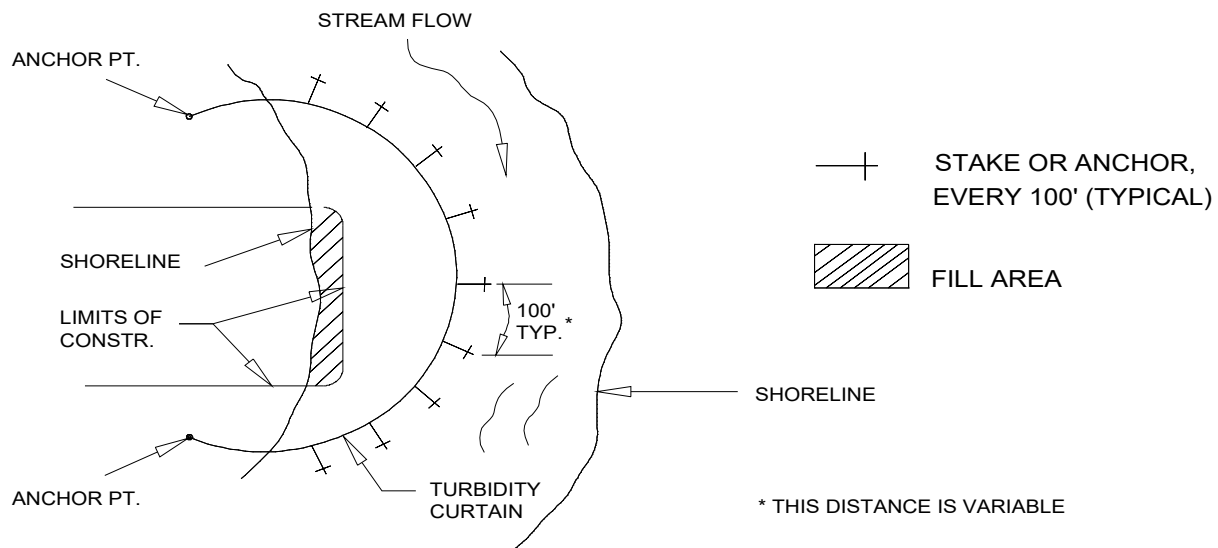
Curtain type (1, 2, or 3)
Layout (Std. or Alt.)

Source: Adapt. from Amer. Boom and Barrier Corp.	Symbol: <div>TC-(1/2/3)</div> <div>(Std/Alt)</div>	Detail No. <div>DE-ESC-3.5.3</div> <div>Sheet 3 of 8</div> <div>Effective July 2023</div>
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Standard Detail & Specifications

Turbidity Curtain

NOTE: The standard layout shown is intended for use in streams, ponds and other non-tidal waters



Plan - Std. Layout

Source:

Adapt. from Amer. Boom and
Barrier Corp.

Symbol:

TC-(1/2/3)
(Std/Alt)

Detail No.

DE-ESC-3.5.3

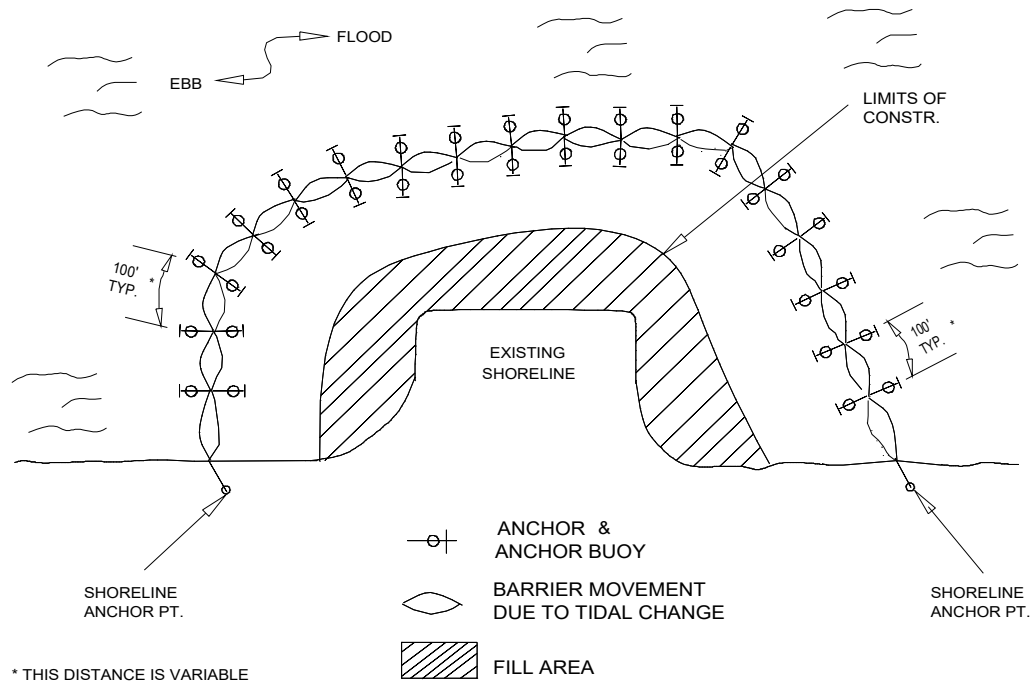
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Effective July 2023

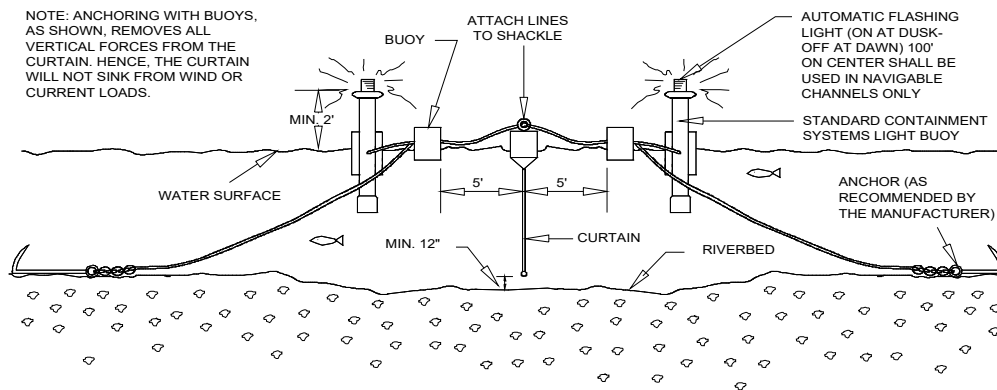
Standard Detail & Specifications

Turbidity Curtain

NOTE: The alternative layout shown is intended for tidal waters and/or heavy wind and wave action



Plan - Alt. Layout



Additional Requirements for Navigable Waters

Source:

Adapt. from Amer. Boom and
Barrier Corp.

Symbol:

TC-(1/2/3)
(Std/Alt)

Detail No.

DE-ESC-3.5.3

Sheet 5 of 8

Effective July 2023

Standard Detail & Specifications

Turbidity Curtain

Construction Notes:

1. Materials

- a. Barriers should be a bright color (yellow or "international" orange are recommended) that will attract the attention of nearby boaters.
- b. The curtain fabric shall meet manufacturer's recommendations for the application.
- c. Seams in the fabric shall be either vulcanized welded or sewn and shall develop the full strength of the fabric.
- d. Floatation devices shall be flexible, buoyant units contained in an individual floatation sleeve or collar attached to the curtain. Buoyancy provided by the floatation units shall be sufficient to support the weight of the curtain and maintain a freeboard of at least 3 inches above the water surface level.
- e. Load lines must be fabricated into the bottom of all floating turbidity curtains. Type II and Type III must have load lines also fabricated into the top of the fabric. The top load line shall consist of woven webbing or vinyl-sheathed steel cable and shall have a break strength in excess of 10,000 pounds. The supplemental (bottom) load line shall consist of a chain incorporated into the bottom hem of the curtain of sufficient weight to serve as ballast to hold the curtain in a vertical position. Additional anchorage shall be provided as necessary. The load lines shall have suitable connecting devices which develop the full breaking strength for connection to load lines in adjacent sections as shown in the detail.
- f. External anchors may consist of wooden or metal stakes (2- x 4-inch or 2-1/2-inch minimum diameter wood or 1.33 lbs/linear foot steel) when Type I installation is used; when Type II or Type III installations are used, bottom anchors should be used.
- g. Bottom anchors must be sufficient to hold the curtain in the same position relative to the bottom of the watercourse without interfering with the action of the curtain. The anchor may dig into the bottom (grappling hook, plow or fluke-type) or may be weighted (mushroom type) and should be attached to a floating anchor buoy via an anchor line. The anchor line should then run from the buoy to the to load line of the curtain. When used with Type III installations, these lines must contain enough slack to allow the buoy and curtain to float freely with tidal changes without pulling the buoy or curtain down and must be checked regularly to make sure they do not become entangled with debris. As previously noted, anchor spacing will vary with current velocity and potential wind and wave action; manufacturer's recommendations should be followed. See detail for orientation of external anchors and anchor buoys for tidal installations.

Source:

Adapt. from Amer. Boom and
Barrier Corp.

Symbol:

TC-(1/2/3)
(Std/Alt)

Detail No.

DE-ESC-3.5.3

Sheet 6 of 8

Effective July 2023

Standard Detail & Specifications

Turbidity Curtain

Construction Notes (cont.)

2. Installation

- a. In the calm water of lakes or ponds (Type I installation) it is usually sufficient to set the curtain end stakes or anchor points (using anchor buoys if bottom anchors are employed), then tow the curtain in the furled condition out and attach it to the stakes or anchor points. Following this, any additional stakes or buoyed anchors required to maintain the desired location of the curtain may be set and these anchor points made fast to the curtain. Only then shall the furling lines be cut to allow the curtain skirt to drop.
- b. In rivers or in other moving waters (Type II and Type III installations) it is important to set all curtain anchor points. Care must be taken to ensure that anchor points are of sufficient holding power to retain the curtain under the existing current conditions, prior to putting the furled curtain into the water. Anchor buoys should be employed on all anchors to prevent the current from submerging the flotation at the anchor points. If the curtain is being installed into tidal areas which would be subject to currents in both directions, anchors should be provided on both sides of the curtain. This will minimize curtain movement and prevent the curtain from overrunning the anchors during tide reversals. After the anchors have been secured, the furled curtain should be secured to the upstream anchor point and then sequentially attached to each next downstream anchor point until the entire curtain is in position. Before unfurling, the "lay" of the curtain should be assessed and any necessary adjustments made to the anchors. Once the location has been deemed adequate, the furling lines may be cut to allow the skirt to drop.
- c. Anchor lines should be attached to the flotation device, not to the bottom of the curtain. The anchoring line attached to the flotation device on the downstream side will provide support for the curtain. Attaching the anchors to the bottom of the curtain could cause premature failure of the curtain due to the stresses imparted on the middle section of the curtain.
- d. Turbidity curtain shall not be installed across channel flows unless there is a danger of causing sediment deposition to occur in the middle of a watercourse, thereby blocking access or creating a sand bar. In such situations, the curtain may be installed so as to form a long-sided, sharp "V" to deflect clean water around a work site, confining most of the silt-laden water to the work area inside the "V" and directing it to the shoreline. In no case shall the curtain be installed perpendicular to the channel flow.

Source:

Adapt. from Amer. Boom and
Barrier Corp.

Symbol:

TC-(1/2/3)
(Std/Alt)

Detail No.

DE-ESC-3.5.3

Sheet 7 of 8

Effective July 2023

Standard Detail & Specifications

Turbidity Curtain

Construction Notes (cont.)

3. Maintenance

- a. The individual(s) identified on the plan as responsible for maintenance of the curtain shall do so for the duration of the project in order to ensure the continuous protection of the watercourse.
- b. Should repairs to the geotextile fabric become necessary, repair kits are generally available from the manufacturer. The manufacturer's instructions must be followed to ensure the adequacy of the repair.
- c. When the curtain is no longer required as determined by the inspector, the curtain and related components shall be removed in such a manner as to minimize turbidity. Remaining sediment shall be sufficiently settled before removing the curtain. Sediment may be removed and the original depth (or plan elevation) restored. Any spoils must be taken to an approved upland disposal area and stabilized in accordance with the approved plan.

4. Removal

- a. Care shall be taken to protect the skirt from damage as the turbidity curtain is dragged from the watercourse.
- b. The site selected to bring the curtain ashore should be free of sharp rocks, broken cement, debris, etc. so as to minimize damage when hauling the curtain over the area.
- c. If the curtain has a deep skirt, it can be further protected by running a small boat along its length with a crew installing furling lines before attempting to remove the curtain from the water.

Source:

Adapt. from Amer. Boom and
Barrier Corp.

Symbol:

—— **TC-(1/2/3)** ——
(Std/Alt)

Detail No.

DE-ESC-3.5.3

Sheet 8 of 8

Effective July 2023

STANDARD AND SPECIFICATIONS FOR CONSTRUCTION SITE POLLUTION PREVENTION



Definition: Practices implemented to reduce the potential for stormwater runoff to transport construction site wastes that may contaminate surface or ground water. In the event of a spill, control the source of the spill, remediate, and properly dispose of hazardous substances.

Purpose: To prevent the generation of nonpoint source pollution from construction sites through effective handling, storage and disposal of building materials and other construction site wastes. To prevent hazardous wastes from contaminating surface and ground water, remediate spills, and dispose of contaminated substances/materials properly.

Conditions Where Practice Applies: All earth disturbing activities which disturb greater than 5000 square feet where hazardous substances/materials are stored and used.

Planning Considerations:

Many potential pollutants other than sediment are associated with construction activities. These include pesticides (insecticides, fungicides, herbicides, and rodenticides); fertilizers used for the establishment of vegetation; petrochemicals (oils, fuels and asphalt degreasers); construction chemicals (concrete products, sealers, and paints); wash water associated with these products; paper; wood; garbage and sanitary wastes. Targeting potential spill areas, minimizing exposure to rainfall, and lengthening flow paths to receiving waters are essential when developing a spill prevention and control plan.

The variety of pollutants present, spill potential and the severity of their effects are dependent on a number of factors:

1. **The nature of the construction activity.** For example, potential pollution associated with fertilizer usage may be greater along a highway or at a housing development than it would be at a shopping center development due to greater landscaping requirements. Most large construction sites will have fuel tanks on-site for re-fueling construction vehicles and equipment.
2. **The physical characteristics of the construction site.** The majority of pollutants generated at construction sites are carried to surface waters via runoff. Therefore, the factors affecting runoff volume, such as the amount, intensity, and frequency of rainfall; soil infiltration rates; surface roughness; slope length and steepness; and area denuded, all contribute to pollutant loadings.

-
3. **The proximity of surface waters to the nonpoint pollutant source.** As the distance separating pollutant-generating activities from surface waters decreases, the likelihood of water quality impacts increases.

Practices

The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above. On all construction sites, an individual should be designated to oversee and enforce waste management procedures and spill prevention practices.

1. Construction site wastes - general

- a. Designate a waste collection area onsite that does not receive a substantial amount of runoff and does not drain directly to a waterbody. Storage areas should not be located near inlets or stormwater management conveyance systems.
- b. Reduce the sources of waste to the greatest extent possible.
- c. Ensure that containers have watertight lids so they can be covered before periods of rain, and keep containers in a covered area whenever possible. Dumpsters and other containers should not be hosed out. Let the trash-hauling contractor clean out containers.
- d. Schedule waste collection to prevent containers from overfilling. During the demolition phase of construction, provide extra containers and schedule more frequent pickups.
- e. Collect, remove and dispose of all construction site wastes at authorized disposal areas. A local environmental agency can be contacted to identify these disposal sites.
- f. Provide proper sanitary facilities for construction workers.

2. Hazardous Materials

- a. Local waste management authorities should be consulted about the requirements for handling and disposing of hazardous materials. Right-to-know and reporting requirements for chemicals and chemical compounds must be followed.
- b. The entire product should be used before disposing of the container. A hazardous waste container should be emptied and cleaned before it is disposed of to prevent leaks. If product remnants are wet or moist, let them dry before cleaning and disposing of the container.
- c. The original product label should never be removed from the container as it contains important safety information. Follow the manufacturers recommended safety measures and method of disposal, which should be printed on the label.
- d. If excess products need to be disposed of, they should never be mixed during disposal unless specifically recommended by the manufacturer.
- e. Hazardous waste containers should be placed in secondary containment.

-
- f. State or local solid waste regulatory agencies or private firms should be consulted to ensure the proper disposal of contaminated soils that have been exposed. Some landfills might accept contaminated soils, but they require laboratory tests first.

3. Pesticides

- a. Follow all federal, state, and local regulations that apply to the use, handling, or disposal of pesticides.
- b. Store pesticides in a cool, dry, covered area lined with plastic sheeting. Check containers for leaks or deterioration. Maintain a list of products in storage.
- c. Warning signs should be posted in storage areas, and areas recently treated.
- d. Follow the recommended application rates and methods.
- e. Applicators should wear suitable, protective clothing, in accordance with the law.
- f. Pesticides should be used only in conjunction with the principles of Integrated Pest Management (IPM). Pesticides should be a tool of last resort; methods that are the least disruptive to the environment and human health should be used first.
- g. Disposal of excess pesticides and pesticide related wastes must conform to registered label directions set forth in applicable federal, state and local regulations.
- h. Pesticides should be disposed of through either a licensed waste management firm or a treatment, storage, and disposal (TSD) facility. Containers should be triple-rinsed before disposal, and rinse waters should be reused as product.

4. Petroleum Products

- a. Store petroleum products and fuel for vehicles in covered areas, lined with a double layer of plastic sheeting or similar material.
- b. Vehicle fueling operations should be established in a designated area. The aboveground fueling tanks need to be set in an impervious berm with a capacity 10 percent greater than that of the largest container.
- c. Routine inspections of the tank and the secondary containment are required.
- d. Clearly label all products.
- e. Keep tanks off the ground with lids securely fastened.
- f. Oil and oily wastes such as crankcase oil, cans, rags, and paper dropped into oils and lubricants should be disposed of in proper receptacles or recycled.
- g. Waste oil for recycling should not be mixed with degreasers, solvents, antifreeze, or brake fluid.

5. Nutrient Management

- a. Store fertilizers in covered areas not subject to stormwater runoff.
- b. Apply fertilizers at the minimum rate and to the minimum area necessary, preferably based on soil tests.
- c. Work fertilizers and liming materials into the soil to depths of 4 to 6 inches.
- d. Use detergents only as recommended, and limit their use onsite. Wash water containing detergents should not be dumped into the storm drain system. It should be directed to a sanitary sewer or be otherwise contained so that it can be treated or properly disposed of.

6. Education

- a. Educate employees regarding the potential environmental impacts of improperly managed construction waste material.
- b. Educate workers on site about proper spill prevention.
- c. Train construction workers in proper materials storage, handling and disposal.
- d. Offer hands-on training classes in spill remediation.
- e. Distribute or post informational material regarding chemical control.

Maintenance:

Containers or equipment that may malfunction and cause leaks or spills should be identified through regular inspection of storage and use areas. Equipment and containers should be inspected regularly for leaks, corrosion, support or foundation failure, or any other signs of deterioration and should be tested for soundness. Any found to be defective should be repaired or replaced immediately. Ample supplies and spill kits need to be readily available on site for spill remediation. Perform periodic reconnaissance of the construction site to identify any additional waste material or waste sources that need to be addressed.

Standard Detail & Specifications

Construction Site Pollution Prevention

Delaware NPDES Discharge Permit

General Permit for Discharge of Stormwater from Construction Activities

((Project Name))

((NOI Permit Number))

((Agency Plan Approval ID))

((Contact Name & Number for Additional Site Information))

((Contact Name & Number to Obtain Copy of Approved Plan))

If you observe indicators of stormwater pollutants
in the discharge or in the receiving waterbody, call the
DNREC Spill Notification 24 HR Hotline at

1-800-662-8802

Example Construction General Permit (CGP) Signage

NOTES:

1. Minimum sign size 2' x 2'
2. Minimum text size 1"
3. Sign must be posted at a safe, publicly accessible location close to construction site
4. Sign must be visible from the public road nearest the active construction site
5. Signs posted within a DelDOT or other public road right-of-way (ROW) must be in accordance with all local and/or State requirements in regards to safety, location, orientation, etc.

Source:

Delaware ESC Handbook

Symbol:

Detail No.

DE-ESC-3.6.1

Sheet 1 of 4

Effective July 2023

Construction Site Pollution Prevention

Notes:

The Construction Site Pollution Prevention Plan includes the following elements:

1. Material Inventory

Document the storage and use of the following materials:

- a. Concrete
- b. Detergents
- c. Paints (enamel and latex)
- d. Cleaning solvents
- e. Pesticides
- f. Wood scraps
- g. Fertilizers
- h. Petroleum based products

2. Good housekeeping practices

- a. Store only enough product required to do the job.
- b. Store all materials in a neat, orderly manner in their original labeled containers and covered.
- c. Do not mix different substances.
- d. When possible, use all of a product prior to disposal of the container.
- e. Manufacturers' instructions for disposal should be strictly adhered to.
- f. Designate someone to inspect all BMPs daily.

3. Waste management practices

- a. Collect and store all waste materials in securely lidded dumpsters in a location that does not drain to a waterbody.
- b. Salvage and/or recycle waste materials whenever possible.
- c. The dumpsters shall be emptied a minimum of twice per week, or more if necessary. The licensed trash hauler is responsible for cleaning out dumpsters.

Source:

Adapted from USEPA
Pub. 840-B-92-002

Symbol:

Detail No.

DE-ESC-3.6.1

Sheet 2 of 4

Effective July 2023

Standard Detail & Specifications

Construction Site Pollution Prevention

Notes (cont.)

- d. Dispose of all trash in accordance with all applicable Delaware laws.
- e. Littering is strictly prohibited. Trash cans should be placed at all lunch spots and recycle bins should be placed near the construction trailer.
- f. If fertilizer bags can not be stored in a weather-proof location, they should be kept on a pallet and covered with plastic sheeting which is overlapped and anchored.

4. Equipment maintenance practices

- a. If possible, equipment should be taken to off-site commercial facilities for washing and maintenance.
- b. If performed on-site, wash vehicles with high-pressure water spray without detergents in an area contained by an impervious berm.
- c. Use drip pans for all equipment maintenance.
- d. Inspect equipment for leaks on a daily basis.
- e. Direct washout from concrete trucks into a temporary pit for hardening and proper disposal.
- f. Equip fuel nozzles with automatic shut-off valves.
- g. Dispose of all used products such as oil, antifreeze, solvents and tires in accordance with manufacturers' recommendations and local, state and federal laws and regulations.

5. Spill prevention practices

- a. Identify potential spill areas and contain them in covered areas with no connection to the storm drain system.
- b. Post warning signs in hazardous material storage areas.
- c. Perform preventive maintenance on all tanks, valves, pumps, pipes and other equipment as necessary.
- d. Prioritize low or non-toxic substances for use.

Source:

Adapted from USEPA
Pub. 840-B-92-002

Symbol:

Detail No.

DE-ESC-3.6.1

Sheet 3 of 4

Effective July 2023

Standard Detail & Specifications

Construction Site Pollution Prevention

Notes (cont.)

- e. Prominently post contact information for reporting spills through the DNREC 24-Hour Toll Free Number.

6. Education

- a. Include Best Management Practices (BMPs) for construction site pollution control as part of regular progress meetings.
- b. Information regarding waste management, equipment maintenance and spill prevention should be prominently posted in the construction trailer.

CONTACT INFORMATION

DNREC 24-Hour Toll Free Number **800-662-8802**

DNREC Solid & Hazardous Waste Management Section **302-739-9403**

Source:

Adapted from USEPA
Pub. 840-B-92-002

Symbol:

Detail No.

DE-ESC-3.6.1

Sheet 4 of 4

Effective July 2023

STANDARD AND SPECIFICATIONS FOR CONCRETE WASHOUT

Definition: A designated and protected area used to rinse out concrete mixers and pumps after delivery onsite.



Purpose: The wash water from concrete producing equipment is alkaline and contains high levels of chromium, which if not disposed of in a secure area, can leach into the ground or runoff into stormdrains or surface waters causing contamination, increased pH, and potential pipe clogging. The concrete washout station allows for the concrete to cure in the protected area and then to be buried or removed offsite (once the concrete has hardened it is no longer considered hazardous).

Conditions Where Practice Applies: Concrete washouts shall be designated for all jobsites that require concrete equipment to be cleaned onsite. They may vary in size for a single family lot versus a large commercial development, but should be utilized in all applications.

Design Criteria:

Location

Concrete washout facilities should not be located within 50 feet of stormdrain inlet, swales, wetlands or waterbodies. They should be placed so that it is convenient for the concrete trucks to access and utilize the station, yet not within highly active construction areas that the washout is accidentally damaged causing a leak or spill. They should also not be located in an area that receives a significant amount of runoff, i.e., in a sump or bottom of hill, which could cause capacity or leaching issues. The washout facility must have a paved or gravel access drive leading to it with a minimum width of 10 feet and sloped downwards towards the washout at 2% slope. The access drive shall connect to a paved or gravel surface. Signs should be placed designating the facility and throughout the construction site to direct traffic to its location.

Type

For an excavated concrete washout, the facility should be minimum 6'x6' at the bottom and 3' deep. The facility may be larger and should be sized per the expected loadings (i.e., if a pump truck is needed to install the concrete, then the increase in washout volume should be accounted for with a larger facility). The area should be excavated to the required depth with 2:1 side slopes. The excavated area should be lined with minimum 10mil of polyethylene fabric. The liner should be anchored in place by backfilling underneath a 1 foot high, 1 foot wide berm, located around the perimeter except for the access road. If anticipated to

empty out and reuse the washout, the liner may be draped over the berm and anchored on the downslope side with sandbags. The liner shall be free of holes, tears or other defects that would compromise the impermeability of the material. In high groundwater situations and permeable soils, the liner will prevent the concrete wastewater from leaching prior to it solidifying.

Prefabricated concrete washouts can also be used and are useful for site that cannot excavate below ground, or need the versatility of being able to move the station to different locations. A manufactured unit with minimum 4'x4' area and 12" depth should be placed on top of a wooden pallet. The unit should be lined with a minimum 4mil polyethylene liner (must meet manufacturer's recommendations) that can be tied off during rain events. After the washout unit is utilized it should remain exposed (except during rain events) so that the wastewater can evaporate, leaving only solid concrete residue. The pallet can then be picked up with a forklift and disposed of in a dump truck. A typical 4'x4' unit can accommodate 10 washouts before needing to be replaced. The unit size or disposal frequency should be adjusted depending on the expected frequency of use.

Maintenance and Disposal:

Concrete washout stations should be inspected regularly to ensure there are no leaks and that the facility has not reached 75 percent of its capacity. In addition, the site must be checked for evidence of concrete washout in non-designated washout areas. If non-designated areas are being utilized, additional education, signage and/or stations shall be provided.

When the facility has reached 75 percent of its capacity, or when desired to remove the concrete, the hardened solids can be discarded whole, or it can be broken up and reused on-site. If disposed of, a recycling center should be investigated that will reuse the discarded remains for road aggregate or other applications. If the facility is to be reused after disposal, then a new liner must be installed if the original has been compromised or removed. If the concrete is buried onsite, it should be covered with a minimum of 1' of clean, compacted fill that is stabilized to prevent erosion.

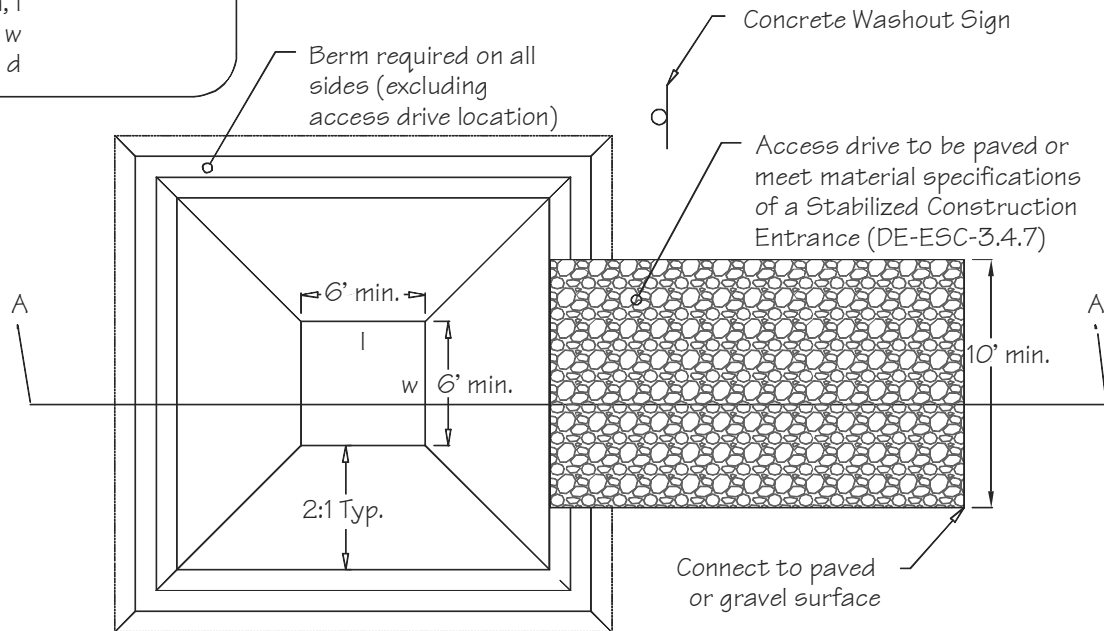
Standard Detail & Specifications

Concrete Washout

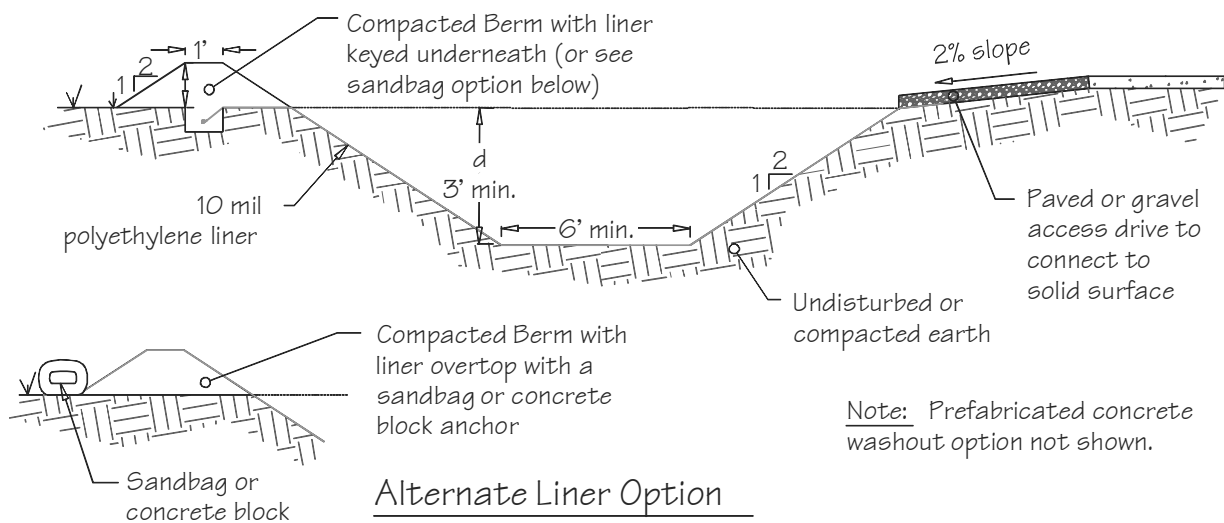
DATA TO BE PROVIDED

Length, l
Width, w
Depth, d

Plan View



Section A-A



Source:

Adapted from
Colorado Urban Storm Drain-
age Criteria Manual, Vol 3

Symbol:



Detail No.

DE-ESC-3.6.2

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Concrete Washout

Construction Notes:

1. Locate washout area a minimum of 50 feet from open channels, stormdrain inlets, wetlands or waterbodies.
2. Locate washout area so that it is accessible to concrete equipment (service with a minimum 10 foot wide gravel accessway), but so it is not in a highly active construction area causing accidental damage.
3. Minimum dimensions for prefabricated units are 4 feet by 4 feet by 1 foot deep with a minimum 4mil polyethylene plastic liner. Minimum dimensions for constructed concrete washout areas are 6 feet by 6 feet by 3 feet deep, with a minimum 10mil polyethylene liner, 2:1 side slopes, and a 1 foot high by 1 foot wide compacted fill berm.
4. The liner must be free of tears or holes and placed over smooth surfaces to prevent puncturing. For excavated washouts, anchor the liner underneath the berm or overtop with sandbags or concrete blocks to hold in place.
5. Provide a sign designating the washout area, and for large construction sites, provide signs throughout directing traffic to its location.
6. Allow washed out concrete mixture to harden through evaporation of the wastewater. Once the facility has reached 75 percent of its capacity, remove the hardened concrete by reusing the broken aggregate onsite, recycling, or disposing of offsite. The hardened material can be buried on site with minimum of 1 foot of clean, compacted fill.
7. Apply a new liner before reusing the station for additional washouts after maintenance has occurred.

Source:

Adapted from
Colorado Urban Storm Drain-
age Criteria Manual, Vol 3

Symbol:

CW

Detail No.

DE-ESC-3.6.2
Sheet 2 of 2
Effective July 2023

STANDARD AND SPECIFICATIONS FOR CONCRETE MIXING OPERATION



Definition: A designated and protected area to capture concrete slurry from operations that generate concrete or concrete products manufactured by mixing Portland cement, sand, aggregate, or similar materials utilizing onsite storage silos.

Purpose: The cementitious waste from concrete producing equipment is alkaline and contains high levels of chromium, which if not contained in a secure area, can leach into the ground or runoff into stormdrains or surface waters causing contamination, increased pH, and potential pipe clogging. A protected mixing area allows any residual by-product to be contained within a designated area instead of being washed into sensitive areas or leached into the ground.

Conditions Where Practice Applies: Construction site concrete mixing utilizing onsite storage silos regardless of location shall have designated controls to prevent liquid cementitious waste from coming into contact with surface water or soil. Containment areas may vary in size, but must be utilized in all applications where onsite mixing operations require bulk storage silos.

Design Criteria:

Location

Onsite concrete mixing operations should not be located within 50 feet of storm drain inlet, swales, wetlands or waterbodies. They should be placed so that it is convenient for the telescopic lifts to access and utilize the station, yet not within highly active construction areas that the containment area is accidentally damaged causing a leak or spill. The containment area should have a gravel or paved access drive leading to it with a minimum width of 10 feet.

Type

Bulk storage silos and mixing units may vary from project to project. The bulk storage silo and mixing unit area is to be underlain with a 10-mil poly liner, and must be contained on a minimum of three sides by a poly lined 12-inch high berm using DE #57 stone (or 18" lined compost log). The side not protected with a

border may only be the upslope side of the containment area. The containment area must be sized to allow for 3.5 cubic feet of storage per cubic foot size of the mixing unit, and fully surround the mixing silo. The silo and mixing unit should not be raised higher than the top of the perimeter berm. After the containment area is utilized it should remain exposed so that the wastewater can evaporate, leaving only solid concrete residue. The containment area may be excavated or the dimensions increased to allow for greater storage capacity and longer time between liner replacement.

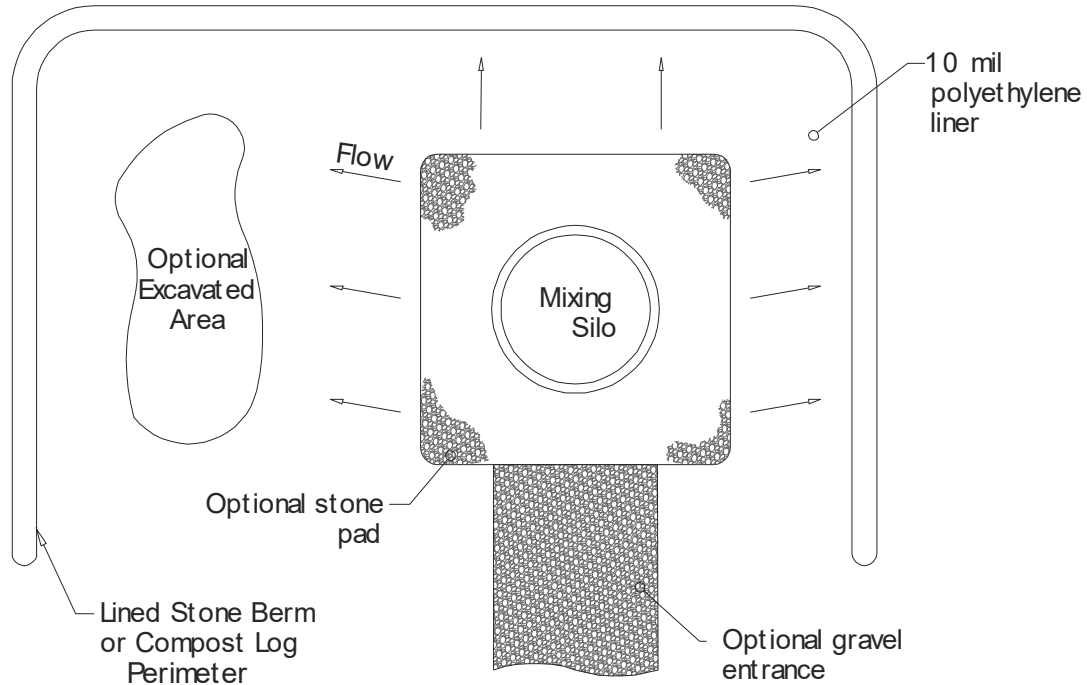
Maintenance and Disposal:

Inspect the containment area regularly to ensure that the liner is free of any rips or tears; if so, replace or patch the liner. Check the perimeter to ensure any liquid cementitious material has not traversed through the border; the stone berm or compost log may need amending if disturbed by construction equipment. If concrete has accumulated to 75% of the height of the border elevation, then the hardened concrete shall be removed, or the facility enlarged. If disposed of, a recycling center should be investigated that will reuse the discarded remains for road aggregate or other applications. If the facility is to be reused after disposal, then a new liner should be installed. If the concrete is buried onsite, it should be covered with a minimum of 1' of clean, compacted fill that is stabilized to prevent erosion.

Standard Detail & Specifications

Concrete Mixing Operation

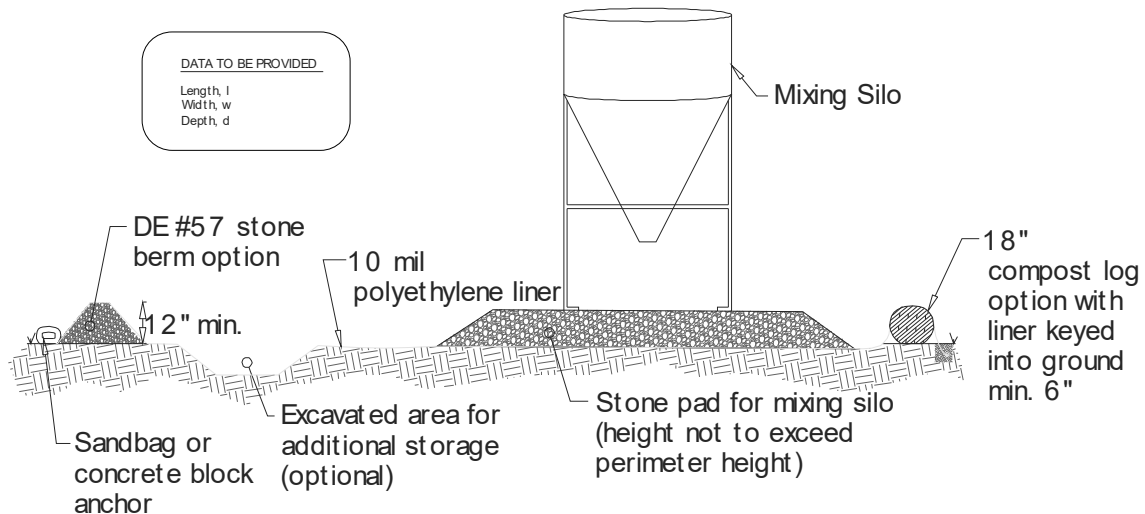
Plan View



NOTE: Berm required on all sides
(excluding access drive location)

DATA TO BE PROVIDED

Length, l
Width, w
Depth, d



Section View

Source:

Adapted from
MN/DOT Concrete Manual,
Chap. 4

Symbol:

CMO

Detail No.

DE-ESC-3.6.3

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Concrete Mixing Operation

Construction Notes:

1. Locate concrete mixing and containment area a minimum of 50 feet from open channels, stormdrain inlets, wetlands or waterbodies.
2. Locate concrete mixing and containment area so that it is accessible to telescopic lifts (service with a minimum 10 foot wide gravel or paved accessway), but so it is not in a highly active construction area causing accidental damage.
3. Minimum volume for installed containment areas are 3.5 cubic feet per cubic foot of mixing capacity. The installed containment area must encompass the storage silo and mixing unit, and be surround on three sides minimum by a 12" high stone berm (DE #57) or 18" compost log
4. The 10-mil poly liner must be free of tears or holes and placed over smooth surfaces to prevent puncturing. The liner shall cover the perimeter control and be secured on the backside using cement or sandbags, or keyed into the ground a minimum of 6".
5. Allow cementitious waste to harden through evaporation of the wastewater. Once the facility has reached 75 percent of its capacity, remove the hardened concrete by reusing the broken aggregate onsite, recycling, or disposing of offsite. The hardened material can be buried on site with minimum of 1 foot of clean, compacted fill.
6. Apply a new liner before reusing the station for additional mixing after maintenance has occurred.

Source:

Adapted from
MN/DOT Concrete Manual,
Chap. 4

Symbol:

CMO

Detail No.

DE-ESC-3.6.3

Sheet 2 of 2

Effective July 2023

STANDARD AND SPECIFICATIONS FOR FUELING & SPILL CONTROL

Definition: Practices that specify how and where vehicles and equipment will be cleaned, fueled, and maintained in a manner that minimizes risks for spills and runoff of pollutants.



Purpose: Vehicle and equipment cleaning, fueling, and maintenance should ideally be conducted at an off-site facility. When cleaning, fueling, or maintenance must be conducted at the construction site, properly trained employees should do it in designated areas. Practices to properly clean, fuel, and maintain vehicles and equipment will help prevent and minimize spills from these activities. This practice will also minimize the exposure of oil and grease, hydrocarbons, and other pollutants in runoff from the construction site.

Conditions Where Practice Applies:

All earth disturbing activities which disturb greater than 5000 square feet where fuel is stored and used.

Responsibilities:

Contractors have the primary responsibility for spill prevention and clean-up. Through the use of good fuel handling procedures, they can minimize their risk. If they have spills or other releases, they are responsible for reporting them to the proper regulatory agencies. The contractor has the ultimate responsibility for environmental clean-up, which must meet the regulatory requirements.

Practices:

The use of good fuel handling procedures, as well as inspections of tanks and preventive maintenance on equipment, can reduce both the frequency and the severity of fuel spills and releases. Contractors that store fuel on-site generally use skid tanks for fuel storage. The use of a secondary containment “tub” or berm around the tank can serve to catch any fuel releases that may occur. However, if these tanks are uncovered, as they generally will be at work sites, the containment will also capture rainfall. Therefore, there must be a method of releasing the captured rainfall. It is important to note that it is unlawful to release water with fuel sheen on it. The fuel should be absorbed with “oil only” absorbent pads or socks prior to release (these pads will not absorb water). The tank should be level and secure. As spills to paved or concrete surfaces are easier to clean-up, it is preferred that tanks are located on these types of surfaces. Contractors should inspect their tanks on a regular basis.

Tank Operation & Maintenance Guidelines:

Tank inspections should include the following items:

- Check for deterioration of tank, hoses, ancillary equipment, foundation, and safety equipment.
- Check vent pipes for restrictions such as bird or wasp nests; inspect pipes for damage.
- Check for operational malfunctions of ancillary equipment such as pumps, overfill prevention devices, etc.
- Check for evidence of a fuel release from the tank.
- Check for fire extinguisher.
- Check for conditions that may be a fire or safety hazard.

Tank filling operations should be supervised by a representative of the contractor. Tanks should be filled no more than 90-95%, as they can easily overflow from fuel expansion during hot weather. Any spills that occur during fueling must be promptly cleaned up and contaminated soil/gravel disposed of properly.

Vehicle/machinery fill-ups should always be done carefully to prevent overfills. No smoking is permitted during vehicle filling operations.

Inspections and preventive maintenance should be performed on all machinery used on-site.

As hydraulic hoses are especially prone to rupture, causing most of the construction site releases, attention to these should be stressed.

Spill Prevention and Control:

Leaks and spills can significantly pollute runoff from a construction site. Prepare for potential spills by reducing the chance for spills to occur, stopping the source of spills, containing and cleaning up spills, properly disposing of spill material, and training employees. Planning and prevention can minimize spills at a construction site. Trained employees with the proper spill response equipment can also prevent spills from polluting runoff. The following guidelines should be followed to minimize the potential for leaks and spills to become an environmental impact:

- Store materials away from waterways and storm drain inlets.
- Store hazardous or toxic materials indoors if possible, or in other areas safe from vehicular traffic, vandals and equipment movement.
- Place a stockpile of spill cleanup material where it can be easily accessed.
- Train employees and subcontractors on the need to prevent spills.
- Train employees on spill prevention and response.
- Fix leaks and clean up spills immediately.
- Use dry methods to clean up spills; never hose down or bury spill materials.
- Dispose of absorbent material properly. For small quantities, place in double plastic bagging and discard with solid waste. For larger quantities, refer to safety data sheets.

Spill Kits:

Each vehicle on site should carry a spill kit which meets the following specifications:

- Packaged spill kit to absorb up to 5 gallons of oil
- Absorbant mats/pads
- Temporary disposal bags
- Protective gloves

Vehicles and equipment with chronic leaking issues will be stored with drip pans or plastic sheeting under to catch any leaks until equipment can be repaired or removed from site.

Spill kits for overall site control should contain the following:

- Plastic/metal 55-gallon barrel or 40-gallon wheeled trash container with lid and label
- Bulk granular, diatomaceous earth, absorbant material
- Oil-absorbant pads and booms
- Large trash bags
- Rubber gloves
- Safety goggles
- Tyvek suits and coveralls

Reporting Spills:

Large spills, spills of any size that enter surface waters or storm water drainage systems, and spills or releases that create an emergency situation due to possible fire, explosion, or threat to the environment or the health and safety of people, must be reported to:

DNREC 24-Hour Toll Free Number: 800-662-8802.

Spills of petroleum products to soil of less than one quart that do not enter waterways, reporting is generally not required, although this in no ways impacts the requirement for clean-up. Spills of petroleum products to soil of one quart or more or any amount of petroleum product spilled that enters surface waters must be reported.

What to Report:

- Name and title of person reporting incident
- Date, time and location of incident
- Phone number where the reporting person can be reached
- Brief description of incident
- Names and phone numbers of other person(s) involved with the spill
- Amount and locations of contamination

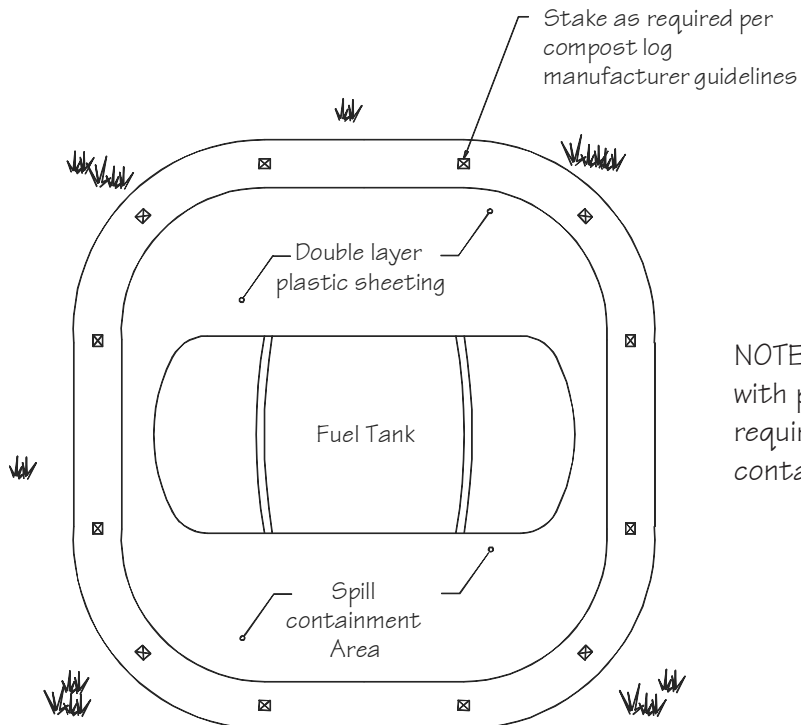
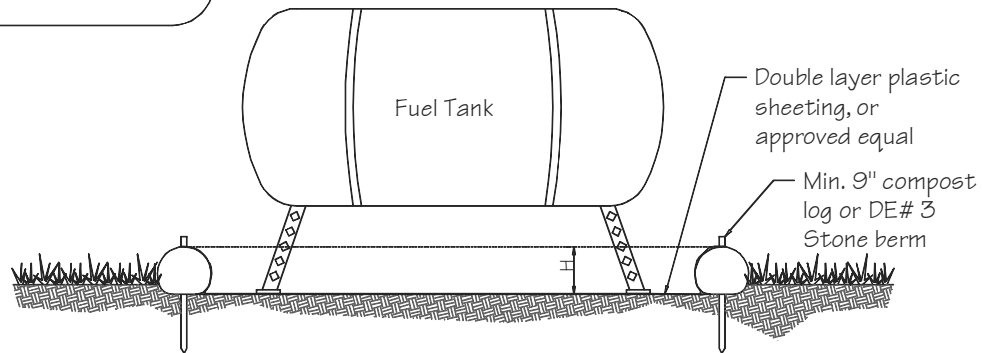
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Standard Detail & Specifications

Fueling & Spill Control

DATA TO BE PROVIDED

Volume of Potential
Pollution
Height of containment
Area of containment
Volume of containment



NOTE: Double-walled tanks with proper labeling meet EPA requirements for secondary containment.

Source:

Delaware ESC Handbook

Symbol:

Detail No.

DE-ESC-3.6.4

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Fueling & Spill Control

Pollution Prevention – Fueling & Spill Control

1. Fueling should only take place in signed designated areas, away from downstream drainage facilities and watercourses.
2. Fueling must be with nozzles equipped with automatic shut-off to control drips. Do not top off.
3. Protect the areas where equipment or vehicles are being repaired, maintained, fueled or parked from storm water run-on and runoff.
4. Use barriers such as berms to prevent storm water run-on and runoff, and to contain spills.
5. Place a “Fueling Area” sign next to each fueling area.
6. Store hazardous materials such as fuel, solvents, oil and chemicals in secondary containment.
7. Inspect vehicles and equipment for leaks on each day of use. Repair fluid and oil leaks immediately.
8. Absorbent spill clean-up materials and spill kits must be available in fueling areas and on fuel trucks.
9. If fueling is to take place at night, make sure the fueling area is sufficiently illuminated.
10. Properly dispose of used oil, fluids, lubricants and spill clean-up materials.

CLEAN UP SPILLS

1. If it is safe to do so, immediately contain and clean up any chemical and/or hazardous material spills.
2. Properly dispose of used oil, fluids, lubricants and spill clean-up materials.
3. Do not bury spills or wash them down with water.

LEAKS AND DRIPS

1. Use drip pans or absorbent pads at all times. Place under and around leaky equipment.
2. Do not allow oil, grease, fuel or chemicals to drip onto the ground.
3. Have spill kits and clean up material on-site.
4. Repair leaky equipment promptly or remove problem vehicles and equipment from the site. Clean up contaminated soil immediately.
5. Store contaminated waste in sealed containers constructed of suitable material. Label these containers properly.
6. Clean up all spills and leaks. Promptly dispose of waste and spent clean up materials.

Source:

Delaware ESC Handbook

Symbol:

Detail No.

DE-ESC-3.6.4

Sheet 2 of 2

Effective July 2023

STANDARD AND SPECIFICATIONS FOR ESC FOR MINOR DEVELOPMENT

Definition: Guidelines for controlling erosion and sediment during the development of relatively small sites.



Purpose: To prevent soil from eroding from a site and damaging adjacent properties or degrading nearby watercourses.

Conditions Where Practice Applies: This standard was primarily developed for sites that qualify for the issuance of a Standard Plan and which therefore lack detailed Erosion & Sediment Control Plans. However, the guidelines may also be applicable for controlling individual lots within larger sites having such plans.

Planning Considerations:

Erosion control is important on any building site regardless of its size. Usually, the principles and methods for controlling erosion and reducing off-site sedimentation are relatively simple and inexpensive. The following are four basics to be followed when developing a building site.

1. **Evaluate the site.** Inventory and evaluate the resources on the lot before building. Location of structures should be based, in large part, on the lot's natural features. Identify trees that you want to save and vegetation that will remain during construction. Also identify areas where you want to limit construction traffic. Wherever possible, preserve existing vegetation to help control erosion and off-site sedimentation.
2. **Select and install erosion/sediment control practices.** Determine the specific ones needed, and install them before clearing the site. Among the more commonly used practices are vegetative stabilization, silt fence, stabilized construction entrances, and runoff inlet protection.
3. **Develop a practice maintenance program.** Maintenance of all practices is essential for them to function properly. They should be inspected twice a week and after each rainfall event. When a problem is identified, repair the practice immediately. Also, any sediment that is tracked onto the street must be scraped and deposited in a stable area. Do not flush sediment from the street with water.
4. **Revegetate the site.** Do so as soon as possible. A well-maintained lot has a higher sale potential.

Guidelines for Building Lot Drainage

The best time to provide for adequate lot drainage is before construction begins. With proper planning, most drainage problems can be avoided. Correcting a problem after it occurs is usually much more difficult and costly. The following are some guidelines to ensure good lot surface and subsurface drainage.

1. Surface drainage

- a. Position the structure a minimum of 18 inches above street level.
- b. Divert storm water runoff away from the structure by grading the lawn in accordance with local building code requirements.
- c. Construct side and rear yard swales to take surface water away from the structure.
- d. Avoid filling in existing drainage channels and roadside ditches, since that could result in wetness problems on someone else's property and/or damage to adjacent road surfaces.

2. Subsurface drainage

- a. Provide an outlet for foundation or footer drains and for general lot drainage by using storm sewers (where allowed), or obtain drainage easements if you must cross adjoining properties.
- b. If an existing field drainage tile is accidentally cut, assume that it carries water even if currently dry; therefore, reroute it (using the equivalent pipe size) around the structure or septic field, then reconnect it.

Construction Sequence for Building Site Erosion Control Practices

It is important to note that the following construction sequence is meant to be for illustrative purposes only and may not be applicable for all building lots. An individual plan should be developed for specific site conditions which preclude the use of this standard.

1. Evaluate the site.

Before construction, evaluate the entire site, marking for protection any important trees and associated rooting zones, unique areas to be preserved, on-site septic system absorption fields, and vegetation suitable for filter strips, especially in perimeter areas.

a. *Identify vegetation to be saved*

Select and identify the trees, shrubs, and other vegetation that you want to save (see "Vegetative Filter Strips" under Step 2).

b. *Protect trees and sensitive areas*

To prevent root damage, do not grade, burn, place soil piles, or park vehicles near trees or in areas marked for preservation. Place plastic mesh or snow fence barriers around the trees' dripline to protect the area below their branches. Place a physical barrier, such as plastic fencing, around the area designated for a septic system absorption field (if applicable).

2. Install perimeter erosion and sediment controls.

Identify the areas where sediment-laden runoff could leave the construction site, and install perimeter controls to minimize the potential for off-site sedimentation. It's important that perimeter controls are in place before any other earth-moving activities begin.

- a. Protect down-slope areas with vegetative filter strips. On slopes of less than 6 percent, preserve a 20 to 30 foot wide vegetative buffer strip around the perimeter of the property, and use it as a filter strip for trapping sediment. Do not mow filter strip vegetation shorter than 4 inches.
- b. Protect down-slope areas with silt fence. Use silt fencing along the perimeter of the lot's downslope side(s) to trap sediment.
- c. Restrict all lot access to a stabilized entrance to prevent vehicles from tracking mud onto roadways.
- d. Protect storm drain inlets. Install inlet protection on nearby storm drain inlets.

3. Prepare the site for construction.

Prepare the site for construction and for installation of utilities. Make sure all contractors (especially the excavating contractor) are aware of areas to be protected.

4. Salvage and stockpile the topsoil/subsoil

Remove topsoil (typically the upper 4 to 6 inches of soil material) and stockpile. Remove subsoil and stockpile separately from the topsoil. Locate the stockpiles away from any downslope street, driveway, stream, lake, wetland, ditch, or drainageway. Immediately after stockpiling, temporary-seed the stockpiles with annual rye and/or place silt fence around the perimeter of the piles.

5. Build the structure(s) and install the utilities.

Construct the home and install the utilities; also install the sewage disposal system and drill the water well (if applicable); then consider the following.

6. Install downspout extenders

Downspout extenders are highly recommended as a means of preventing lot erosion from roof runoff. Add the extenders as soon as the gutters and downspouts are installed. Be sure the extenders have a stable outlet, such as the street, sidewalk, or a well vegetated area.

7. Maintain the control practices.

- a. Maintain all erosion and sediment control practices until construction is completed and the lot is stabilized.
- b. Inspect the control practices a minimum of twice a week and after each storm event, making any needed repairs immediately. Toward the end of each work day, sweep or scrape up any soil tracked onto roadways. Do not flush areas with water. By the end of the next work day after a storm event, clean up any soil washed off-site.

8. Revegetate the building site.

Immediately after all outside construction activities are completed, stabilize the lot with sod or seed and straw mulch.

a. *Redistribute the stockpiled subsoil and topsoil.*

Spread the stockpiled subsoil to rough grade. Spread the stockpiled topsoil to a depth of 4 to 6 inches over rough graded areas. Fertilize and lime according to soil test results or recommendations of a seed supplier or a professional landscaping contractor.

b. *Seed or sod bare areas.*

Contact local seed suppliers or professional landscaping contractors for recommended seeding mixtures and rates. Follow recommendations of a professional landscaping contractor for installation of sod. Water newly seeded/sodded areas every day or two to keep the soil moist. Less watering is needed once grass is 2 inches tall.

c. *Mulch newly seeded areas.*

Spread straw mulch on newly seeded areas, using 1 to 2 bales of straw per 1,000 square feet. On flat or gently sloping land, anchor the mulch by crimping it 2 to 4 inches into the soil or use a tackifier (adhesive binder). On steep slopes, anchor the mulch with netting or tackifiers. An alternative to anchored mulch would be the use of erosion control blankets.

9. Remove remaining temporary control measures.

Once the sod and/or vegetation is well established, remove any remaining temporary erosion and sediment control practices, such as:

a. *Downspout extenders.* (Or shorten to outlet onto the vegetated areas, allowing for maximum infiltration).

b. *Storm drain inlet protection measures.*

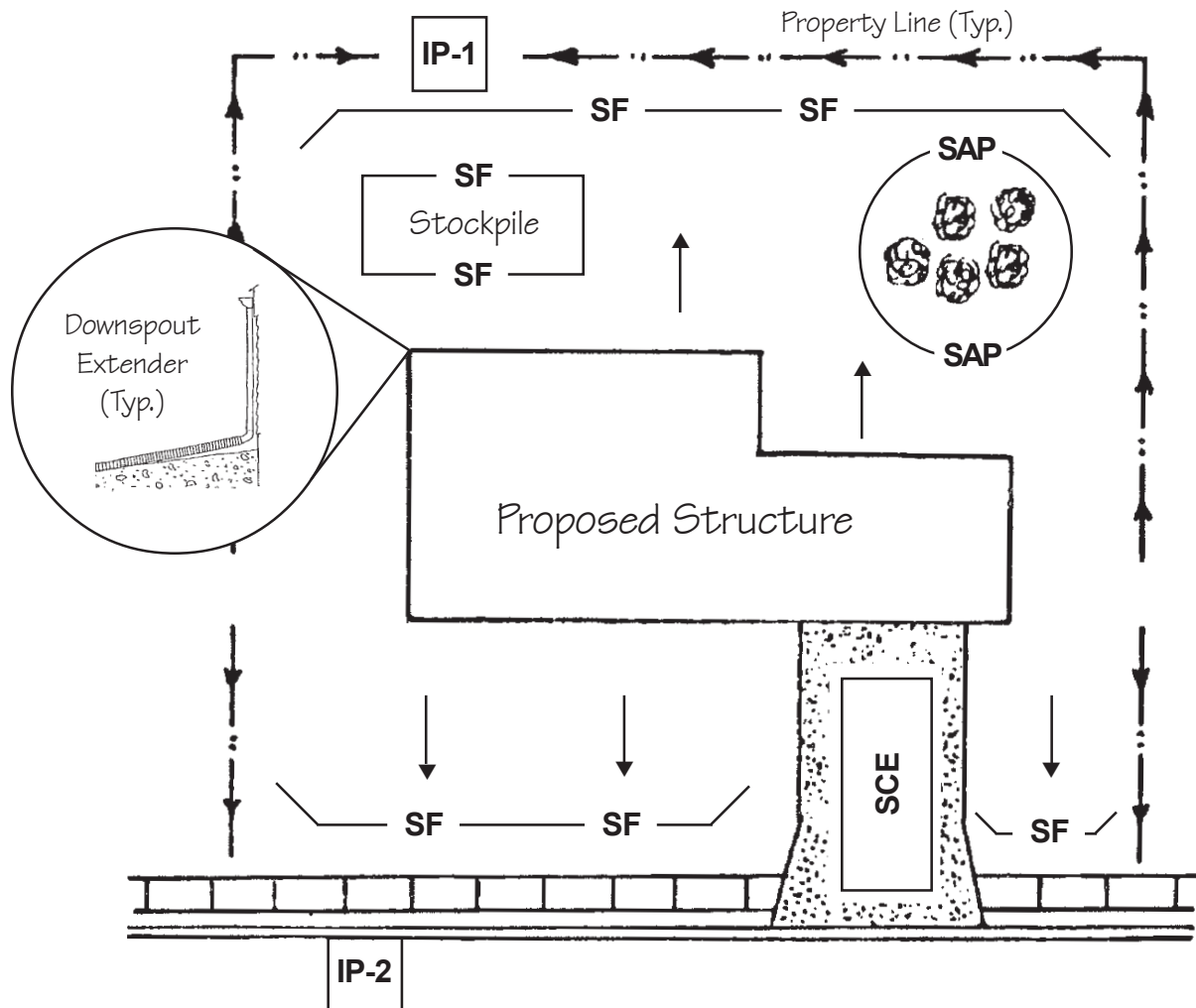
c. *Silt fence.*

Reference:

Indiana Dept. of Natural Resources, Division of Soil Conservation, "*Erosion Control for the Home Builder*" (1/96)

Standard Detail & Specifications

ESC for Minor Development



LEGEND

Flow

Silt Fence

Sensitive Area Protection

Stabilized Construction
Entrance



SF

SAP

SCE

Inlet protection - Type 1

IP-1

Inlet Protection - Type 2

IP-2

Source:

Adapted from IN DNR,
"Erosion Control for the
Home Builder"

Symbol:

Detail No.

DE-ESC-3.7.1

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

ESC for Minor Development

Construction Notes:

1. Evaluate the Site.
 - a. Identify Vegetation To Be Saved
 - b. Protect Trees and Sensitive Areas
2. Install Perimeter Erosion And Sediment Controls.
 - a. Protect down-slope areas with vegetative filter strips.
 - b. Protect down-slope areas with silt fence.
 - c. Restrict all lot access to stabilized construction entrance to prevent vehicles from tracking mud onto roadways.
 - d. Install inlet protection on nearby storm drain inlets.
3. Prepare the Site for Construction.
4. Salvage and Stockpile the Topsoil/Subsoil
5. Build the Structure(s) and Install the Utilities.
6. Install Downspout Extenders
7. Maintain the Control Practices.
 - a. Maintain all erosion and sediment control practices until construction is completed and the lot is stabilized.
 - b. Inspect the control practices a minimum of twice a week and after each storm event, making any needed repairs immediately.
8. Revegetate the Building Site.
 - a. Redistribute the stockpiled subsoil and topsoil.
 - b. Seed or sod bare areas.
 - c. Mulch newly seeded areas.
9. Remove Remaining Temporary Control Measures.

Source:

Adapted from IN DNR,
"Erosion Control for the
Home Builder"

Symbol:

Detail No.

DE-ESC-3.7.1

Sheet 2 of 2

Effective July 2023

STANDARD AND SPECIFICATIONS FOR SENSITIVE AREA PROTECTION

Definition: Protection of desirable trees, proposed infiltration areas, wellhead protection zones, and other sensitive areas while land is being developed.



Purpose: To provide necessary protective measures to ensure the survival of desirable trees, avoid compaction of infiltration areas, and denote wellhead protection zones and other sensitive areas as areas to be avoided with construction equipment.

Conditions Where Practice Applies: On developing sites that have desirable trees, infiltration areas, wellhead protection zones, or other sensitive areas.

Planning Considerations:

Trees may appear to be inanimate objects, but they are living organisms that are constantly involved in the process of respiration, food processing, and growth. Construction activities expose trees to a variety of stresses resulting in injury ranging from superficial wounds to death. An understanding of these stresses is helpful in planning for tree protection.

Design Criteria:

No formal design is required. The sensitive areas to be protected must be indicated on the construction plans with protection fencing, and the construction around the sensitive area must be minimized.

Specifications:

1. **Location:** Locate all sensitive areas on the plan, including individual or groups of trees, future infiltration stormwater management facilities, and other sensitive areas, with a “to be saved” or “do not disturb” sensitive area designation.
2. **Limits:** At a minimum, the limits of clearing or construction shall be located outside the dripline of any tree to be retained (edge of tree mature tree canopy), and in no case, closer than 5 feet to the trunk of any tree. A five foot minimum buffer from the edge of the proposed infiltration area or other sensitive area shall denote the limits of clearing or construction.

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3. **Marking:** Install orange safety fencing or equivalent along the length of the sensitive area. Silt fence may be substituted only if a “Sensitive Area Protection – Do Not Disturb Sign” is adhered to the silt fence, and the fencing is already required for that area. For heavily wooded sites, where the fencing cannot be installed until after clearing has occurred, the areas shall be marked with bright colored ribbon or a spray paint line 6 to 8 inches in length. After clearing, additional fencing should be installed prior to any excavation or grading.
 4. **Pre-construction Conference:** During any preconstruction conference, sensitive area preservation and protection measures should be reviewed with the contractor as they apply to that specific project.
 5. **Equipment Operation and Storage:** Heavy equipment, vehicular traffic, and construction stockpiles shall not be permitted within the designated sensitive areas. In addition, any toxic materials shall not be stored within 100 feet of the sensitive area, including paint, acid, nails, gypsum board, chemicals, fuels and lubricants.
 6. **Maintenance:** The sensitive area fencing shall be kept in good repair for the duration of the construction activities, and shall be the last items removed during the completion of the project. (Infiltration areas shall only be constructed when their contributing area has been stabilized. The sensitive area fencing can be removed with consent from the agency construction site reviewer. Excavation of the area shall be from the side of facility to avoid compaction of the underlying soils.)

Additional Tree Protection Guidelines:

1. **Surface Impacts:** Natural and man-related forces exerted on the tree above the ground can cause significant damage to trees.
 - a. *Wind damage* - Removal of some trees from groups will expose those remaining to greater wind velocities. Trees tend to develop anchorage where it is most needed. Isolated trees develop anchorage rather equally all around, with stronger root development on the side of the prevailing winds. The more a tree is protected from the wind, the less secure is its anchorage. The result of improper thinning is often wind-thrown trees. Selective removal in favor of a single tall tree may also create a lightning hazard.
 - b. *Excessive pruning* - Unprotected trees are often “topped” or carelessly pruned to prevent interference with utility wires or buildings. If too many branches are cut, the tree may not be able to sustain itself. If the pruning is done without considering the growth habit, the tree may lose all visual appeal. If the branches are not pruned correctly, decay may set in.
 - c. *Trunk damage* - Tree trunks are often nicked or scarred by trucks and construction equipment. Such superficial wounds provide access to insects and disease.
2. **Root Zone Impacts:** Disturbing and delicate relationship between soil, roots, and the rest of the tree can damage or kill a tree. The roots of an existing tree are established in an area where essential materials (water, oxygen, and nutrients) are present. The mass of the root system is the correct size to balance the intake of water from the soil with the transpiration of water from the leaves.
 - a. Raising the grade as little as 6 inches can retard the normal exchange of air and gases. Roots may suffocate due to lack of oxygen, or be damaged by toxic gases and chemicals released by soil bacteria.

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- b. Raising the grade may also elevate the water table. This can cause drowning of the deeper roots.
 - c. Lowering the grade is not usually as damaging as raising it. However, even shallow cuts of 6 to 8 inches will remove most of the topsoil, removing some feeder roots and exposing the rest to drying and freezing.
 - d. Deep cuts may sever a large portion of the root system, depriving the tree of water and increasing the chance of wind-throw.
 - e. Lowering the grade may lower the water table, inducing drought. This is a problem in large roadway cuts or underdrain installations.
 - f. Trenching or excavating through a tree's root zone can eliminate as much as 40 percent of the root system. Trees suffering such damage usually die within 2 to 5 years.
 - g. Compaction of the soil within the drip line (even a few feet beyond the drip line) of a tree by equipment operation, materials storage, or paving can block off air and water from roots.
 - h. Construction chemicals or refuse disposed of in the soil can change soil chemistry or be toxic to trees. Most damage to trees from construction activities is due to the invisible root zone stresses.

Design Criteria:

No formal design is required. However, in planning for the development of where some trees will be preserved, a number of criteria must be considered.

Selecting Trees to be Retained

The proper development of a wooded site requires completion of a plan for tree preservation before clearing and construction begins. Trees should be identified by species, and located on a topographical map, either as stands or as individuals, depending on the density and value of the trees. Base decisions on which trees to save on the following considerations:

1. **Life expectancy and present age:** Preference should be given to trees with a long life span, such as white oak, beech, and maple. Long-lived specimens that are past their prime may succumb to the stresses of construction, so smaller, younger trees of desirable species are preferred; they are more resilient and will last longer. However, if the cost of preservation is greater than the cost of replacement with a specimen of the same age and size, replacement may be preferred.
2. **Health and disease susceptibility:** Check for scarring caused by fire or lightning, insect or disease damage, and rotted or broken trunks or limbs. Pest and pollution-resistant trees are preferred.
3. **Structure:** Check for structural defects that indicate weakness or reduce the aesthetic value of a tree, trees growing from old stumps, large trees with overhanging limbs that endanger property, trees with brittle wood (such as silver maple), misshapen trunks or crowns, and small crowns at the top of tall trunks. Open grown trees often have better form than those grown in the woods. Trees with strong tap or fibrous root systems are preferred to trees with weak rooting habits.

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4. **Cleanliness:** Some trees such as elm and black locust are notoriously “dirty”, dropping twigs, bark, fruit, or plant exudates. A clean tree is worth more than a dirty one. Trees which seed prolifically or sucker profusely are generally less desirable in urban areas. Thornless varieties are preferred.
 5. **Aesthetic values:** Handsome bark and leaves, neat growth habit, fine fall color, and attractive flowers and fruit are desirable characteristics. Trees that provide interest during several seasons of the year enhance the value of the site.
 6. **Comfort:** Trees help relieve the heat of summer and buffer strong winds throughout the year. Summer temperatures may be 10 degrees cooler under hardwoods than under conifers. Deciduous trees drop their leaves in winter, allowing the sun to warm buildings and soil. Evergreens are more effective wind buffers.
 7. **Wildlife:** Preference should be given to trees that provide food, cover, and nesting sites for birds and game.
 8. **Adaptability to the proposed development:**
 - a. *Consider the mature height and spread of trees;* they may interfere with proposed structures and overhead utilities. Roots may interfere with walls, walks, driveways, patios, and other paved surfaces; or water lines, septic tanks, and underground drainage.
 - b. *Trees must be appropriate to the proposed use of the development;* select trees which are pollution-tolerant for high-traffic and industrial areas, screen and buffer trees for noise or objectionable views, salt tolerant species for areas exposed to deicing salts or ocean spray.
 - c. *Consider location of landfills.* Gases generated in them can travel long distances underground, to injure distant trees. Choose species tolerant of anaerobic soil conditions.
 - d. *Determine the effect of proposed grading on the water table.* Grading should not take place within the drip line of any tree to be saved.
 9. **Survival needs of the tree:** Chosen trees must have enough room to develop naturally. They will be subject to injury from increased exposure to sunlight, heat radiated from buildings and pavement, and wind. It is best to retain groups of trees rather than individuals. As trees mature, they can be thinned gradually.
 10. **Relationship to other trees:** Individual species should be evaluated in relation to other species on the site. A species with low value when growing among hardwoods will increase in value if it is the only species present. Trees standing alone generally have higher landscape value than those in a wooded situation. However, tree groups are much more effective in preventing erosion and excess stormwater runoff.

Site Planning for Tree Protection:

1. If lot size allows, select trees to be saved before siting the building. No tree should be destroyed or altered until the design of buildings and utility systems is final.
2. Critical areas, such as flood plains, steep slopes, and wetlands, should be left in their natural condition or only partially developed as open space.

-
3. Locate roadways to cause the least damage to valuable stands. Follow original contours, where feasible, to minimize cuts and fills.
 4. Minimize trenching by locating several utilities in the same trench. Excavations for basements and utilities should be kept away from the drip line of trees.
 5. Construction material storage areas and worker parking should be noted on the site plan, and located where they will not cause compaction over roots.
 6. When retaining existing trees in parking areas, leave enough ground ungraded beyond the drip line of the tree to allow for its survival.
 7. Locate erosion and sediment control measures at the limits of clearing and not in wooded areas, to prevent deposition of sediment within the drip line of trees being preserved. Sediment basins should be constructed in the natural terrain, if possible, rather than in locations where extensive grading and tree removal will be required.

Specifications:

1. **Location:** Groups of trees and individual trees selected for retention shall be accurately located on the plan and designated as “tree(s) to be saved.” Individual specimens that are not part of a tree group shall also have their species and diameter noted on the plan.
2. **Limits:** At a minimum, the limits of clearing shall be located outside the drip line of any tree to be retained and, in no case, closer than 5 feet to the trunk of any tree.
3. **Marking:** Prior to construction and before the preconstruction conference, individual trees and stands of trees to be retained within the limits of clearing shall be marked at a height visible to equipment operators. A diagonal slash of brightly colored paint approximately 8 to 10 inches in length is a common practice in areas where an accidental or purposeful alteration of the proper markings is a concern. In most situations, such as an area which is supposed to receive formal landscaping, a surveyor’s ribbon or a similar material applied at a reasonable height encircling the tree will suffice.
4. **Pre-construction Conference:** During any preconstruction conference, tree preservation and protection measures should be reviewed with the contractor as they apply to that specific project.
5. **Equipment Operation and Storage:** Heavy equipment, vehicular traffic, or stockpiles of any construction materials (including topsoil) shall not be permitted within the drip line of any tree to be retained. Trees being removed shall not be felled, pushed or pulled into trees being retained. Equipment operators shall not clean any part of their equipment by slamming it against the trunks of trees to be retained.
6. **Fires:** Fires shall not be permitted within 100 feet from the drip line of any trees to be retained. Fires shall be limited in size to prevent adverse effects on trees, and kept under surveillance.

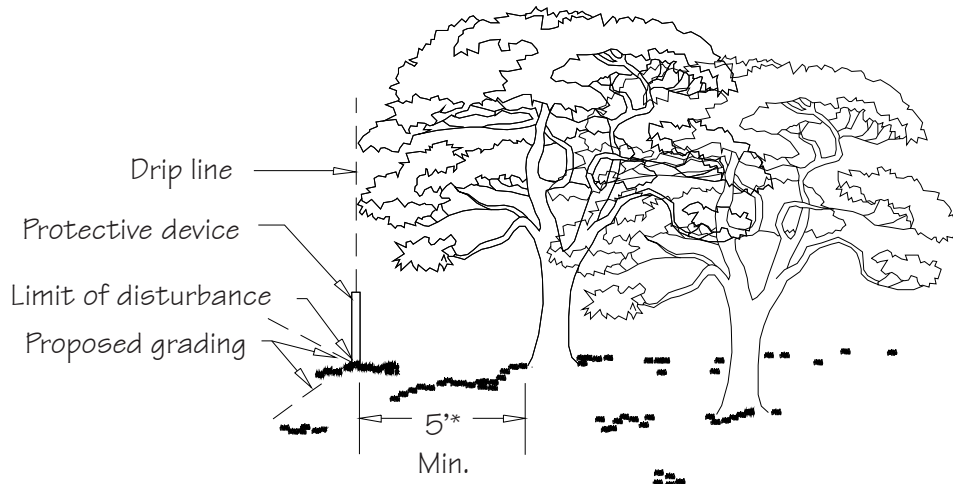
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7. **Storage and Disposal of Toxic Materials:** No toxic materials shall be stored closer than 100 feet to the drip line of any trees to be retained. Paint, acid, nails, gypsum board, wire, chemicals, fuels, and lubricants shall not be disposed of in such a way as to injure vegetation.
 8. **Fencing and Armoring:** Any device may be used which will effectively protect the roots, trunk and tops of trees retained on the site. However, trees to be retained within 40 feet of a proposed building or excavation shall be protected by fencing. Personnel must be instructed to honor protective devices. (See Standard Detail & Specifications for Tree Protection for suggested methods and materials.)

Maintenance:

Fencing and armoring devices shall be in place before any excavation or grading is begun, shall be kept in good repair for the duration of construction activities, and shall be the last items removed during the final cleanup after the completion of the project.

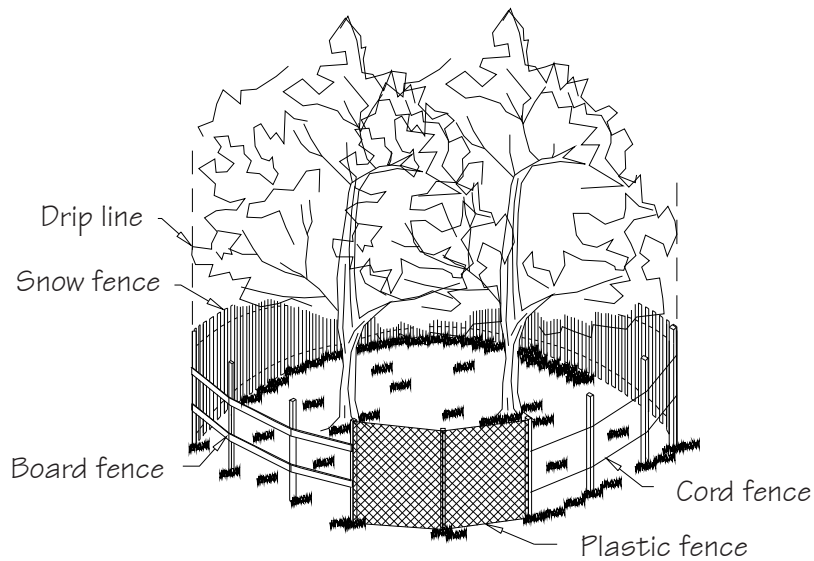
Standard Detail & Specifications

Sensitive Area Protection



*5' min. setback applies to all sensitive areas covered by this specification.

Location of Sensitive Area Protection



Methods of Sensitive Area Protection

Source:

Adapted from
VA ESC Handbook

Symbol:

—SAP—

Detail No.

DE-ESC-3.7.2

Sheet 1 of 3

Effective July 2023

Standard Detail & Specifications

Sensitive Area Protection

Construction Notes:

Fencing shall be installed at the extents of all sensitive areas. For trees, the fencing shall be installed outside the dripline (mature canopy) and at no time within 5 feet of the trunk. Personnel must be instructed to honor protective devices. The devices described are suggested only, and are not intended to exclude the use of other devices which will protect the trees to be retained. If silt fence is to be used for demarcation purposes, appropriate signage shall be provided a minimum of every 20 feet denoting the area as a sensitive area protection zone.

Materials:

1. Snow Fence - Standard 40-inch high snow fence shall be placed at the limits of clearing or construction on standard steel posts set 6 feet apart.
2. Board Fence - Board fencing consisting of 4-inch square posts set securely in the ground and protruding at least 4 feet above the ground shall be placed at the limits of clearing with a minimum of two horizontal boards between posts. For tree protection, if it is not practical to erect a fence at the drip line, construct a triangular fence nearer the trunk. The limits of clearing will still be located at the drip line, since the root zone within the drip line will still require protection.
3. Plastic Fencing - 40-inch high "international orange" plastic (polyethylene) web fencing secured to conventional metal "T" or "U" posts driven to a minimum depth of 18 inches on 6-foot minimum centers shall be installed at the limits of clearing. The fence should have the following minimum physical qualities:
 - a. Tensile yield: Average 2,000 lbs. per 4-foot width (ASTM D638)
 - b. Ultimate tensile yield: Average 2,900 lbs. per 4-foot width (ASTM D638)
 - c. Elongation at break (%): Greater than 1000% (ASTM D638)
 - d. Chemical resistance: Inert to most chemicals and acids

Source:

Adapted from
VA ESC Handbook

Symbol:

—SAP—

Detail No.

DE-ESC-3.7.2

Sheet 2 of 3

Effective July 2023

Standard Detail & Specifications

Sensitive Area Protection

4. Cord Fence - Posts with a minimum size of 2 inches square or 2 inches in diameter set securely in the ground and protruding at least 4 feet above the ground shall be placed at the limits of clearing with two rows of cord 1/4-inch or thicker at least 2 feet apart running between posts with strips of colored surveyor's flagging tied securely to the string at intervals no greater than 3 feet.
5. Earth Berms - Temporary earth berms shall be constructed according to specifications for a Temporary Earth Dike with the base of the berm on the sensitive area side located along the limits of clearing. Earth berms may not be used for this purpose if their presence will conflict with drainage patterns.
6. Trunk Armoring (Tree Protection Only) - As a last resort, a tree trunk can be armored with burlap wrapping and 2-inch studs wired vertically no more than 2 inches apart to a height of 5 feet encircling the trunk. If this alternative is used, the root zone within the drip line will still require protection. Nothing should ever be nailed to a tree.

Maintenance:

Fencing and armoring devices shall be in place before any excavation or grading is begun, shall be kept in good repair for the duration of construction activities, and shall be the last items removed during the final cleanup after the completion of the project.

Source:

Adapted from
VA ESC Handbook

Symbol:

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Detail No.

DE-ESC-3.7.2

Sheet 3 of 3

Effective July 2023

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STANDARD AND SPECIFICATIONS FOR SOIL STOCKPILE

Definition: A temporary deposit of excavated soil being reserved for future use.



Purpose: To provide a designated location for the temporary storage of soil on-site, and to protect it from potential erosion.

Conditions Where Practice Applies:

Stockpiles can be used on all sites where topsoil or subsoil is needed to be stored for later use. This detail does not apply to disposal sites for dredging or other activities disposing a liquid slurry.

Design Criteria:

Location

Stockpiles should not be located within wetlands or open channels. Stockpiles should be located a minimum of 50 feet away from wetlands, open channels and storm drain inlets. Any concentrated flow being directed towards the stockpile should be redirected using an approved erosion and sediment control practice.

The designated soil stockpile area should be clearly indicated on the Construction Site Stormwater Management Plan, and should not be relocated without prior approval from the Department or Delegated Agency construction reviewer. The footprint area reserved should be sized to accommodate the anticipated volume of material. The surface topsoil shall be stockpiled separately from any subsoil.

Design

The maximum slope of the stockpile should be 3:1 in order to promote vegetation cover. The maximum height of the stockpile is 20 feet or as governed by local restrictions. In a residential lot, the maximum height of the stockpile is 10 feet or as governed by local restrictions.

The stockpile must be protected with an approved perimeter control, such as silt fence, stabilized earthen berm, or compost log(s), following the slope versus length requirements of that control. The perimeter

control shall be a minimum of 3' from the toe of the stockpile, or as specified per the chosen perimeter control, whichever is greater. The access to the stockpile should only be from the upslope side of the pile.

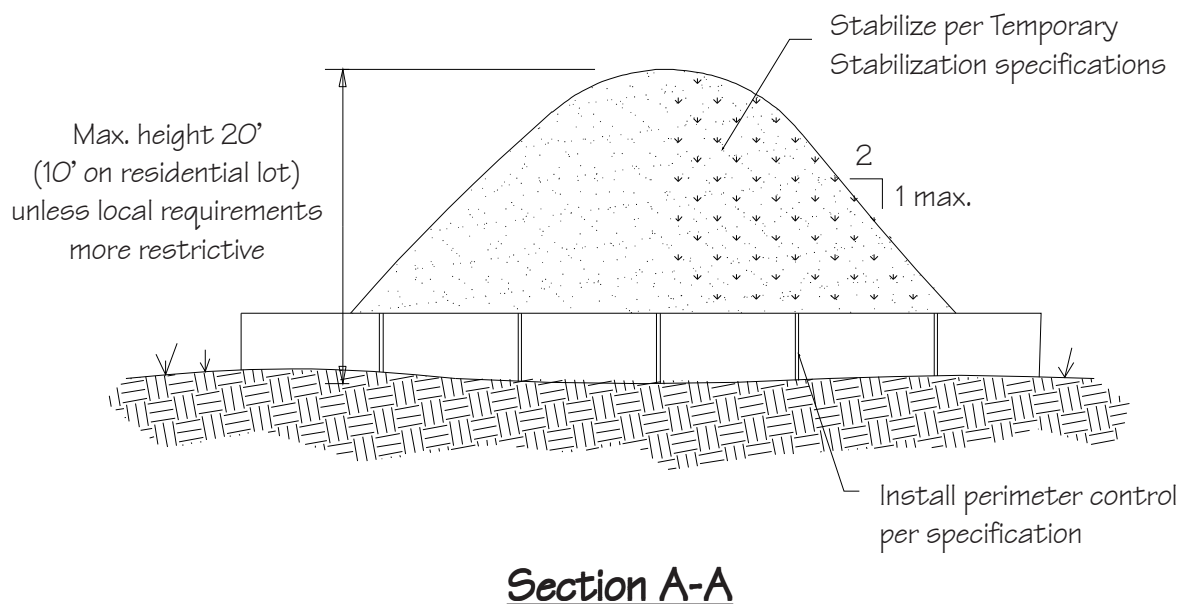
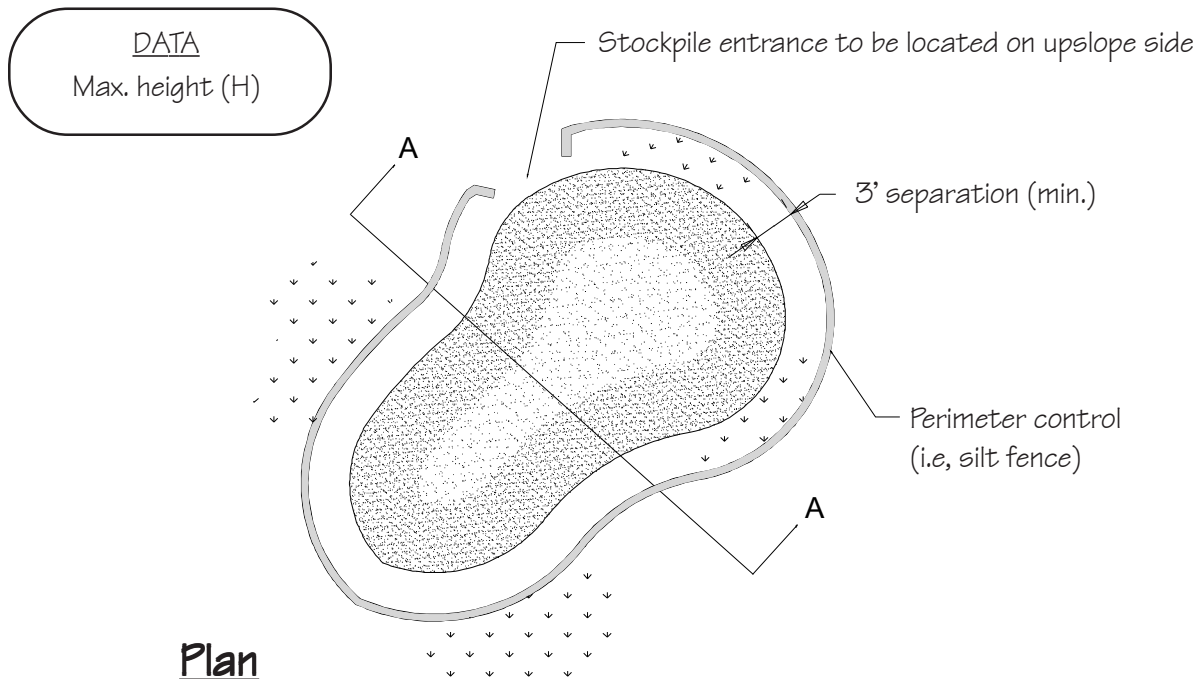
Maintenance and Disposal:

The perimeter controls around the stockpile should be checked regularly, and immediately following a rain event to ensure that they are still functioning properly. If the stockpiles are to remain inactive for more than 14 calendar days, they are to be temporarily vegetated within that time period, unless a more restrictive requirement applies.

Stockpiles shall be removed before the completion of site construction and the area formerly containing the stockpile must be restabilized once the soil has been incorporated in or removed from the site. Stockpile areas may only remain if they have been identified as permanent, graded feature in accordance with the approved Sediment and Stormwater Management Plan.

Standard Detail & Specifications

Soil Stockpile



Source:

Adapted from
Colorado Urban Storm Drain-
age Criteria Manual, Vol 3

Symbol:

—— **SP** ——

Detail No.

DE-ESC-3.7.3

Sheet 1 of 2

Effective July 2023

Standard Detail & Specifications

Soil Stockpile

Construction Notes:

1. Locate stockpiles so that they are 50 feet from any storm drain inlet, open channel, wetland or waterbody. Redirect any concentrated flow around the stockpile using an approved erosion and sediment control measure.
2. Secure the perimeter of the stockpile with an approved erosion and sediment control perimeter device.
3. If stockpile is to remain inactive for more than 14 calendar days, the stockpile must be vegetated. Follow the temporary vegetation specifications. The vegetation chosen shall last the duration of the stockpile; the stockpile shall be restabilized if the temporary vegetation dies or erosion results.

Source:

Adapted from
Colorado Urban Storm Drain-
age Criteria Manual, Vol 3

Symbol:

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Detail No.

DE-ESC-3.7.3

Sheet 2 of 2

Effective July 2023

Appendix A-1

Handbook Update Notices

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Delaware ESC Handbook Update Notices

Date	Description
12/03	Initial release.
6/05	Acknowledgements - updated Sediment & Stormwater Program phone number
"	3.1.2 Silt Fence - clarified min. stake dimensions
"	DE-ESC-3.1.2.1 Silt Fence - clarified min. stake dimensions
"	DE-ESC-3.1.2.2 Reinforced Silt Fence - clarified min. stake dimensions
"	3.1.3 Sediment Trap - clarified temp. storage requirements
"	DE-ESC-3.1.3.2 Stone Outlet Sediment Trap - clarified temporary storage requirements
"	DE-ESC-3.1.3.3 Riprap Outlet Sediment Trap - clarified temporary storage requirements
"	3.1.4 Temporary Sediment Basin - changed clean-out volume to 67 CY on Fig. 3.4.1c
"	3.1.4 Temporary Sediment Basin - clarified units to be used for surface area on Pg. 3.1.4-11
"	3.3.6 Check Dam - increased spacing for S<2%
"	DE-ESC-3.3.6 Stone Check Dam - increased spacing for S<2%
"	DE-ESC-3.3.10.1 ROP-1 - added note to depress centerline
"	3.4.2 Slope Treatment - clarified spacing requirements for benching
"	3.4.5 Mulching - revised
"	DE-ESC-3.4.5 Mulching - revised
"	DE-ESC-3.4.6.1 Stabilization Matting - Slope - corrected staple pattern "E"
"	DE-ESC-3.4.6.2 Stabilization Matting - Channel - corrected staple pattern "E"
"	DE-ESC-3.6.1 Site Pollution Prevention - updated contact phone numbers
"	A-3 Geotextile Application Guide - added example products to GD-I
"	A-3 Geotextile Application Guide - revised min. flow-through rate for GD-II to 110 gpm/sq.ft.
"	DG-2 Riprap Stilling Basin - added additional design charts
03/13	Contents - added new practices
"	Acknowledgements - updated Div. of Watershed Stewardship
"	Symbols - added symbols for new practices
"	3.1.3 Sediment Trap - additional Std. & Specs for Compost Log Sediment Trap
"	DE-ESC-3.1.3.4 - added new detail for Compost Log Sediment Trap
"	3.1.5 Inlet Protection - added Type 3 for curb opening inlets
"	DE-ESC-3.1.5.3 - added new detail for Type 3 Inlet Protection
"	DE-ESC-3.1.6 - replaced silt fence option with compost log on Culvert Inlet Protection detail
"	3.1.7 Compost Filter Log - added new Std & Specifications
"	DE-ESC-3.1.7 - added new detail for Compost Filter Log
"	3.1.8 Flocculation - added new Std & Specifications
"	DE-ESC-3.1.8 - added new detail for Flocculation
"	3.2.3 Dewatering Device - deleted Pipe Dewatering Device from Std & Specification
"	DE-ESC-3.2.3.2 - rescinded detail for Pipe Dewatering device
"	3.4.1 Topsoiling - added compost amendments to Std & Specifications
"	DE-ESC-3.4.1 - revised Topsoiling detail to include compost amendments
"	DE-ESC-3.4.2.4 Slope Treatment - Erosion Control Log - added new detail
"	3.4.5 Mulching - added compost blankets to Std & Specifications
"	DE-ESC-3.4.5 Mulching - added compost blankets to detail
"	3.4.6 Stabilization Matting - clarified netting must be biodegradable for mulch matting
"	3.6.1 Constuction Site Waste Management & Spill Control - expanded Std & Specifications
"	DE-ESC-3.6.1 - added spill control graphic & guidelines to detail
"	3.6.2 Concrete Washout - added new Std & Specifications

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Appendix A-2

Glossary

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GLOSSARY

The list of terms that follows is representative of those used by soil scientists, engineers, developers, conservationist planners, etc. The terms are not necessarily used in the text, nonetheless they are in common use in conservation matters. The aim of this Glossary is representativeness, not completeness.

AASHTO classification - the official classification of soil materials and soil aggregate mixtures for highway construction used by the American Association of State Highway and Transportation Officials.

Acid soil - A soil with a preponderance of hydrogen ions, and probably of aluminum in proportion to hydroxyl ions. Specifically, soil with a PH value less than 7.0. For most practical purposes, a soil with a PH value less than 6.6.

Acre-foot - The volume of water that will cover 1 acre to a depth of 1 foot.

Aggradation - The process of building up a surface by deposition. This is a long-term or geologic trend in sedimentation.

Alluvial - Pertaining to material that is transported and deposited by running water.

Alluvial land - Areas of unconsolidated alluvium, generally stratified and varying widely in texture, recently deposited by streams, and subject to flooding.

Alluvial soils - Soils developed from transported and relatively recently deposited material (alluvium) characterized by a weak modification (or none) of the original material by soil-forming processes.

Alluvium - A general term for all detrital material deposited or in transit by streams, including gravel, sand, silt, clay, and all variations and mixtures of these. Unless otherwise noted, alluvium is unconsolidated.

Anti-seep collar - A device constructed around a pipe or other conduit and placed through a dam, levee, or dike for the purpose of reducing seepage losses and piping failures.

Anti-vortex device - A facility placed at the entrance to a pipe conduit structure such as a drop inlet spillway or hood inlet spillway to prevent air from entering the structure when the pipe is flowing full.

Apron (soil engineering) - A floor or lining to protect a surface from erosion. An example is the pavement below chutes, spillways, or at the toes of dams.

Backfill - The material used to refill a ditch or other excavation, or the process of doing so.

Bearing capacity - The maximum load that a material can support before failing.

Bedrock - The more or less solid rock in place either on or beneath the surface of the earth. It may be soft, medium or hard and have a smooth or irregular surface.

Benthic region - The bottom of a body of water, supporting the benthos.

Benthos - The plant and animal life whose habitat is the bottom of a sea, lake, or river.

Bentonite - A highly plastic clay consisting of the minerals montmorillonite and beidellite that swells extensively when wet.

Berm - A narrow shelf or flat area that breaks the continuity of a slope.

Blind inlet - Inlet to a drain in which entrance of water is by percolation rather than open flow channel.

Borrow area - A source of earth fill material used in the construction of embankments or other earth fill structures.

Bottom lands - A term often used to define lowlands adjacent to streams.

Capillary action - In hydrology, the tendency of dry soil particles to attract moisture from wetter portions of soil.

Catch basin - A chamber or well, usually built at the curb line of a street, for the admission of surface water to a sewer or subdrain, having at its base a sediment sump designed to retain grit and detritus below the point of overflow.

Catchment - Surface drainage area.

Channel - A natural stream that conveys water. A ditch or channel excavated for the flow of water.

Channel improvement - The improvement of the flow characteristics of a channel by clearing, excavation, realignment, lining or other means in order to increase its capacity.

Channel stabilization - Erosion prevention and stabilization of velocity distribution in a channel using jetties, drops, revetments, vegetation, and other measures.

Channel storage - Water temporarily stored in channels while en route to an outlet.

Check dam - Small dam constructed in a gully or other small watercourse to decrease the streamflow velocity, minimize channel scour, and promote deposition of sediment.

Chute - A high-velocity, open channel for conveying water to a lower level without erosion.

Cohesion - The capacity of a soil to resist shearing stress, exclusive of functional resistance.

Cohesive soil - A soil that, when unconfined, has considerable strength when air-dried and significant cohesion when submerged.

Compaction - In soil engineering, the process by which the soil grains are rearranged to decrease void space and bring them into closer contact with one another, thereby increasing the weight of solid material per cubic foot.

Compost - Organic residue or a mixture of organic residues and soil, that has undergone biological decomposition until it has become relatively stable humus.

Conservation - The protection, improvement and use of natural resources according to principles that will assure their highest economic or social benefits.

Conservation District - A public organization created under state enabling law as a special-purpose district to develop and carry out a program of soil, water, and related resource conservation, use, and development within its boundaries, usually a subdivision of state government with a local government body and always with limited authorities. Often called a soil conservation district or a soil and water conservation district. In Delaware there is a conservation district covering each county.

Contour - (1) An imaginary line on the surface of the earth connecting points of the same elevation. (2) A line drawn on a map connecting points of the same elevation.

Cover crop - A close-growing crop grown primarily for the purpose of protecting and improving soil between periods of permanent vegetation.

Critical area or site - Sediment producing highly erodible or severely eroded areas.

Cut - Portion of land surface or area from which earth has been removed or will be removed by excavating; the depth below original ground surface of excavated surface.

Cut-and-fill - Process of earth moving by excavating part of an area and using the excavated material for adjacent embankments or fill areas.

Cutoff trench - A long, narrow excavation constructed along the center line of a dam, dike, levee or embankment and filled with relatively impervious material intended to reduce seepage of water through porous strata.

Dam - A barrier to confine or raise water for storage or diversion, to create a hydraulic head, to prevent gully erosion, or for retention of soil, rock, or other debris.

Debris dam - A barrier built across a stream channel to retain rock, sand, gravel, silt or other material.

Debris guard - Screen or grate at the intake of a channel or a drainage or pump structure for the purpose of stopping debris.

Design highwater - The elevation of the water surface as determined by the flow conditions of the design floods.

Design life - The period of time for which a facility is expected to perform its intended function.

Design storm - A selected rainfall pattern of specified amount, intensity, duration, and frequency that is used as a basis for design.

Desilting area - An area of grass, shrubs, or other vegetation used for inducing deposition of silt and other debris from flowing water; located above a stock tank, pond, field, or other area needed protection from sediment accumulation.

Detention - Managing stormwater runoff or sewer flows through temporary holding and controlled release.

Detention dam - A dam constructed for the purpose of temporary storage of streamflow or surface runoff and for releasing the stored water at controlled rates.

Detention time - The theoretical time required to displace the contents of a tank or unit at a given rate of discharge (volume divided by rate of discharge).

Dike - (Engineering) - An embankment to confine or control water, especially one built along the banks of a river to prevent overflow of lowlands; a levee.

Discharge - Outflow; the flow of a stream, canal, or aquifer. One may also speak of the discharge of a canal or stream into a lake, river, or ocean. (Hydraulics) Rate of flow, specifically fluid flow; a volume of fluid passing a point per unit time commonly expressed as cubic feet per second, cubic meters per second, gallons per minute, or millions of gallons per day.

Discharge coefficient (Hydraulics) - The ratio of actual rate of flow to the theoretical rate of flow through orifices, weirs, or other hydraulic structures.

Dispersion, Soil - The breaking down of soil aggregates into individual particles, resulting in single-grain structure. Ease of dispersion is an important factor influencing the erodibility of soils. Generally speaking, the more easily dispersed the soil, the more erodible it is.

Diversion - A channel with a supporting ridge on the lower side constructed across or at the bottom of a slope for the purpose of intercepting surface runoff. See **Terrace**.

Diversion dam - A barrier built to divert part or all of the water from a stream into a different course.

Diversion terrace - Diversions, which differ from terraces in that they consist of individually designed channels across a hillside, may be used to protect bottomland from hillside runoff or may be needed above a terrace system for protection against runoff from an untiered area. They may also divert water out of active gullies, protect buildings from runoff, or reduce the number of waterways, and are sometimes used in connection with strip cropping to shorten the length of slope so that the strips can effectively control erosion. See **Terrace**.

Divide, Drainage Divide - The boundary between one drainage basin and another.

Drain - A buried pipe or other conduit (closed drain). A ditch (open drain) for carrying off surplus surface water or groundwater.

Drainage - The removal of excess surface water or groundwater from land by means of surface or subsurface drains. Soil characteristics that affect natural drainage.

Drainage basin - A geographical area or region that is so sloped and contoured that surface runoff from streams and other natural watercourses is carried away by a single drainage system by gravity to a common outlet or outlets. Also referred to as a watershed or drainage area.

Drainage, Soil - As a natural condition of the soil, soil drainage refers to the frequency and duration of periods when the soil is free of saturation; for example, in well-drained soils the water is removed readily but not rapidly; in poorly drained soils the root zone is waterlogged for long periods unless artificially drained, and the roots of ordinary crop plants cannot get enough oxygen; in excessively drained soils the water is removed so completely that most crop plants suffer from lack of water. Strictly speaking, excessively drained soils are a result of excessive runoff due to steep slopes or low available water-holding capacity due to small amounts of silt and clay in the soil material. The following classes are used to express soil drainage:

Well drained - Excess water drains away rapidly and no mottling occurs within 36 inches of the surface.

Moderately well drained - Water is removed from the soil somewhat slowly, resulting in small but significant periods of wetness. Mottling occurs between 18 and 36 inches.

Somewhat poorly drained - Water is removed from the soil slowly enough to keep it wet for significant periods but not all of the time. Mottling occurs between 8 and 18 inches.

Poorly drained - Water is removed so slowly that the soil is wet for a large part of the time. Mottling occurs between 0 and 8 inches.

Very poorly drained - Water is removed so slowly that the water table remains at or near the surface for the greater part of the time. There may also be periods of surface ponding. The soil has a black to gray surface layer with mottles up to the surface.

Drawdown - Lowering of the water surface (in open channel flow), water table or piezometric surface (in ground-water flow) resulting from a withdrawal of water.

Drop-inlet spillway - Outlet structure in which the water drops through a vertical riser connected to a discharge conduit.

Drop spillway - Outlet structure in which the water drops over a vertical wall onto an apron at a lower elevation.

Drop structure - A structure for dropping water to a lower level and dissipating its surplus energy; a fall. The drop may be vertical or inclined.

Earth dam - Dam constructed of compacted soil materials.

Embankment - A man-made deposit of soil, rock, or other material used to form an impoundment.

Emergency spillway - A vegetated earth channel used to safely convey flood discharges in excess of the capacity of the principal spillway.

Energy dissipator - A device used to reduce the energy of flowing water.

Environment - The sum total of all the external conditions that may act upon an organism or community to influence its development or existence.

Erodible - Susceptible to erosion.

Erosion - The wearing away of the land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep. Detachment and movement of soil or rock fragments by water, wind, ice, or gravity. The following terms are used to describe different types of water erosion:

Accelerated erosion - Erosion much more rapid than normal or geologic erosion, primarily as a result of the influence of the activities of man or, in some cases, of animals or natural catastrophes that expose bare surfaces (e.g., fires).

Channel erosion - The erosion process whereby the volume and velocity of a concentrated flow wears away the bed and banks of a well-defined channel.

Geological erosion - The normal or natural erosion caused by geological processes acting over long geologic periods and resulting in the wearing away of mountains, the building up of floodplains, coastal plains, etc. Synonymous to natural erosion.

Gully erosion - The erosion process whereby water accumulates in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths, ranging from 1 to 2 feet to as much as 75 to 100 feet.

Natural erosion - Wearing away of the earth's surface by water, ice, or other natural agents under natural environmental conditions of climate, vegetation, etc., undisturbed by man. Synonymous to geological erosion.

Normal erosion - The gradual erosion of land used by man which does not greatly exceed natural erosion. See **Natural Erosion**.

Rill erosion - An erosion process in which numerous small channels only several inches deep are formed; occurs mainly on recently disturbed and exposed soils. See **Rill**.

Raindrop erosion - The spattering of small soil particles caused by the impact of raindrops on wet soils. The loosened and spattered particles may or may not be subsequently removed by surface runoff.

Sheet erosion - The removal of a fairly uniform layer of soil from the land surface by runoff water.

Erosion classes (soil survey) - a grouping of erosion conditions based on the degree of erosion or on characteristic patterns. Applied to accelerated erosion, not to normal, natural, or geological erosion. Four erosion classes are recognized for water erosion and three for wind erosion.

Erosive - Refers to wind or water having sufficient velocity to cause erosion. Not to be confused with erodible as a quality of soil.

Estuary - Area where fresh water meets salt water, where the tide meets the river current (e.g., bays, mouths of rivers, salt marshes and lagoons). Estuaries serve as nurseries and spawning and feeding grounds for large groups of marine life and provide shelter and food for birds and wildlife.

Existing grade - The vertical location of the existing ground surface prior to cutting or filling.

Filter blanket - A layer of sand and/or gravel designed to prevent the movement of fine-grained soils.

Filter fabric - A woven or non-woven, water-permeable material generally made of synthetic products such as polypropylene and used in stormwater management and erosion and sediment control applications to trap sediment or prevent the clogging of aggregates by fine soil particles.

Filter strip - A long, narrow vegetative planting used to retard or collect sediment for the protection of water-courses, diversions, drainage basins or adjacent properties.

Flood - An overflow or inundation that comes from a river or other body of water. Any relatively high stream flow overtopping the natural or artificial banks in any reach of a stream.

Flood control - Methods of facilities for reducing flood flows.

Floodgate - A gate placed in a channel or closed conduit to keep out floodwater or tidal backwater.

Frequency of storm (design storm frequency) - The anticipated period in years that will elapse, based on average probability of storms in the design region, before a storm of a given intensity and/or total volume will recur; thus a 10-year storm can be expected to occur on the average once every 10 years. Sewers designed to handle flows which occur under such storm conditions would be expected to be surcharged by any storms of greater amount of intensity.

Gabion - A rectangular or cylindrical wire mesh cage (a chicken wire basket) filled with rock and used as a protecting agent, revetment, etc., against erosion.

Gage or gauge - Device for registering precipitation, water level, discharge velocity, pressure, temperature, etc. A measure of the thickness of metal; e.g., diameter of wire, wall thickness of steel pipe.

Gaging station - A selected section of a stream channel equipped with a gage, recorder, or other facilities for determining stream discharge.

Gradation (geology) - The bringing of a surface or a stream bed to grade, by running water. As used in connection with sedimentation and fragmental products for engineering evaluation, the term gradation refers to the frequency distribution of the various sized grains that constitute a sediment, soil, or other material.

Grade - The slope of a road, channel, or natural ground. The finished surface of a canal bed, roadbed, top of embankment, or bottom of excavation; any surface prepared for the support of construction such as paving or the laying of a conduit.

(To) Grade - To finish the surface of a canal bed, roadbed, top of embankment or bottom of excavation.

Graded stream - A stream in which, over a period of years, the slope is delicately adjusted to provide, with available discharge and with prevailing channel characteristics, just the velocity required for transportation of the load (of sediment) supplied from the drainage basin.

Grade stabilization structure - A structure for the purpose of stabilizing the grade of a gully or other watercourse, thereby preventing further head-cutting or lowering of the channel grade.

Gradient - Change of elevation, velocity, pressure, or other characteristics per unit length; slope.

Grading - Any stripping, cutting, filling, stockpiling, or any combination thereof, including the land in its cut-and-filled condition.

Grass - A member of the botanical family Gramineae, characterized by blade-like leaves arranged on the culm or stem in two ranks.

Grassed waterway - A natural or constructed waterway, usually broad and shallow, covered with erosion-resistant grasses, used to conduct surface water from an area at reduced flow rate.

Gully - An incised channel or miniature valley cut by concentrated runoff but through which water commonly flows only during snow. A gully may be dendritic or branching or it may be linear, rather long, narrow, and of uniform width. The distinction between gully and rill is one of depth. A gully is sufficiently deep that it would not be obliterated by normal tillage operations, whereas a rill is of lesser depth and would be smoothed by use of ordinary tillage equipment. Syn. arroyo. See **Erosion**; **Rill**.

Gully erosion - See **Erosion**.

Gully control plantings - The planting of forage, legume, or woody plant seeds, seedlings, cuttings, or transplants in gullies to establish or re-establish a vegetative cover adequate to control runoff and erosion and incidentally produce useful products.

Habitat - The environment in which the life needs of a plant or animal are supplied.

Head (Hydraulics) - The height of water above any plane of reference. The energy, either kinetic or potential, possessed by each unit weight of a liquid, expressed as the vertical height through which a unit weight would have to fall to release the average energy possessed. Used in various compound terms such as pressure head, velocity head, and lost head.

Head gate - Water control structure; the gate at the entrance to a conduit.

Head loss - Energy loss due to friction, eddies, changes in velocity, or direction of flow.

Headwater - The source of a stream. The water upstream from a structure or point on a stream.

Hydrology - The science of the behavior of water in the atmosphere, on the surface of the earth, and underground.

Hydrologic cycle - The circuit of water movement from the atmosphere to the earth and back to the atmosphere through various stages or processes such as precipitation, interception, runoff, infiltration, percolation, storage, evaporation, and transpiration.

Impact basin - A device used to dissipate the energy of flowing water. Generally constructed of concrete in the form of a partially depressed or partially submerged vessel, and may utilize baffles to dissipate velocities.

Impervious - Not allowing infiltration.

Impoundment - Generally, an artificial collection or storage of water, as a reservoir, pit, dugout, sump, etc.

Indirect runoff - That portion of runoff that contributes to the runoff pollution that enters receiving water as point discharges from separate storm sewer systems and as general surface runoff.

Infiltration/inflow - A combination of infiltration and inflow waste water volumes in sewer lines that permits no distinction between the two basic sources which have the same effect of usurping the capacities of sewer systems and other sewerage system facilities.

Infiltration-percolation - An approach to land application in which large volumes of wastewater are applied to the land, infiltrate the surface and percolate through the soil pores

Infiltration rate - A soil characteristic determining or describing the maximum rate at which water can enter the soil under specified conditions, including the presence of an excess of water.

Inoculant - A peat carrier impregnated with bacteria which forms a symbiotic relationship enabling legumes to utilize atmospheric nitrogen. Most legumes require a specific bacteria.

Intercepted surface runoff - That portion of surface runoff that enters a sewer, either storm or combined, directly through catch basins, inlets, etc.

Interception (Hydraulics) - The process by which precipitation is caught and held by foliage, twigs, and branches of trees, shrubs, and other vegetation. Often used for "interception loss" or the amount of water evaporated from the precipitation intercepted.

Interception channel - A channel excavated at the top of earth cuts, at the foot of slopes or at other critical places to intercept surface flow; a catch drain. Synonymous to interception ditch.

Interflow - That portion of rainfall that infiltrates into the soil and moves laterally through the upper soil horizons until intercepted by a stream channel or until it returns to the surface at some point downslope from its point of infiltration.

Intermittent stream - A stream or portion of a stream that flows only in direct response to precipitation. It receives little or no water from springs and no long-continued supply from melting snow or other sources. It is dry for a large part of the year, ordinarily more than 3 months.

Internal soil drainage - The downward movement of water through the soil profile. The rate of movement is determined by the texture, structure, and other characteristics of the soil profile and underlying layers and by the height of the water table, either permanent or perched. Relative terms for expressing internal drainage are: none, very slow, slow, medium, rapid, and very rapid.

Invert - The lowest point on the inside of a sewer or other conduit.

Land capability - The suitability of land for use without permanent damage. Land capability, as ordinarily used in the United States, is an expression of the effect of physical land conditions, including climate, on the total suitability for use without damage for crops that require regular tillage, for grazing, for woodland, and for wildlife. Land capability involves consideration of (1) the risks of land damage from erosion and other causes and (2) the difficulties in land use owing to physical land characteristics, including climate.

Land capability classification - A grouping of kinds of soils into special units, classes, and subclasses according to their capability for intensive use and the treatments required for sustained use; prepared by the USDA, Soil Conservation Service.

Land capability map - A map showing land capability units, classes and subclasses, or a soil survey map colored to show land capability classes.

Land use controls - Methods for regulating the uses to which a given land area may be put, including such things as zoning, subdivision regulation, and floodplain regulation.

Legume - A member of the legume or pulse family, Leguminosae, one of the most important and widely distributed plant families. The fruit is a "legume" or pod that opens along two sutures when ripe. The flowers are usually papilionaceous (butterfly-like). Leaves are alternate, have stipules, and are usually compound. Includes many valuable food and forage species, such as the peas, beans, peanuts, clovers, alfalfas, sweet clovers, lespedezas, vetches, and kudzu. Practically all legumes are nitrogen-fixing plants.

Level spreader - A shallow channel excavation at the outlet end of a diversion with a level section for the purpose of diffusing the diversion outflow.

Lime - Lime, from the strictly chemical standpoint, refers to only one compound, calcium oxide (CaO); however, the term "lime" is commonly used in agriculture to include a great variety of materials which are usually composed of the oxide, hydroxide, or carbonate of calcium or of calcium and magnesium. The most commonly used forms of agricultural lime are ground limestone (carbonates), hydrated lime (Hydroxides), burnt lime (oxides), marl, and oyster shells.

Liquefaction, Spontaneous - The sudden large decrease of the shearing resistance of a cohesionless soil, caused by a collapse of the structure from shock or other type of strain and associated with a sudden but temporary increase in the pore-fluid pressure. It involves a temporary transformation of the material into a fluid mass.

Liquid limit - The moisture content at which the soil passes from a plastic to a liquid state. In engineering, a high liquid limit indicates that the soil has a high content of clay and low capacity for supporting loads.

Manning's equation (Hydraulics) - An equation used to predict the velocity of water flow in an open channel or pipe lines:

$$V = \frac{1.486r^{2/3}S^{1/2}}{n}$$

where:

V	is the mean velocity of flow in feet per second
r	is the hydraulic radius in feet
s	is the slope of the energy gradient or, for assumed uniform flow, the slope of the channel in feet per foot; and
n	is the roughness coefficient or retardance factor of the channel lining.

Mean depth (Hydraulics) - Average depth; cross-sectional area of a stream or channel divided by its surface or top width.

Mean velocity - The average velocity of a stream flowing in a channel or conduit at a given cross-section or in a given reach. It is equal to the discharge divided by the cross-sectional areas of the reach.

Mechanical practices - Soil and water conservation practices that primarily change the surface of the land and/or that store, convey, regulate, or dispose of runoff water without excessive erosion.

Mulch - A natural or artificial layer of plant residue or other materials covering the land surface which conserves moisture, holds soil in place, aids in establishing plant cover, and minimizes temperature fluctuations.

Natural drainage - The flow patterns of stormwater runoff over the land in its pre-development state. Elements of natural drainage include overland flow, swales, depressions, rills, gullies, natural watercourses, etc.

Nonpoint source pollution - Pollution that enters a water body from diffuse origins on the watershed and does not result from discernible, confined or discrete conveyances.

Normal depth - Depth of flow in an open conduit during uniform flow for the given conditions.

Nutrient(s) - A substance necessary for the growth and reproduction of organisms. In water, those substances that promote growth of algae and bacteria; chiefly nitrates and phosphates.

Open drain - Natural watercourse or constructed open channel that conveys drainage water.

Outfall - The point, location, or structure where wastewater or drainage discharges from a sewer to a receiving body of water.

Outlet - Point of water disposal from a stream, river, lake, tidewater, or artificial drain.

Outlet channel - A waterway constructed or altered primarily to carry water from man-made structures, such as terraces, tile lines, and diversions.

Overflow - A pipeline or conduit device, together with an outlet pipe, that provides for the discharge or portions of combined sewer flows into receiving waters or other points of disposal, after a regular device has allowed the portion of the flow which can be handled by interceptor sewer lines and pumping and treatment facilities to be carried by and to such water pollution control structures.

Parent material (soils) - The unconsolidated, more or less chemically weathered mineral or organic matter from which the solum of soils has developed by pedogenic processes. The C horizon may or may not consist of materials similar to those from which the A and B horizons developed.

Peak discharge - The maximum instantaneous flow from a given storm condition at a specific location.

Percolation - The movement of water through soil.

Percolation rate - The rate, usually expressed as a velocity, at which water moves through saturated granular material.

Percolation test - A determination of the rate of percolation or seepage of water through natural soils expressed as time in minutes for a 1-inch fall of water in a test hole.

Perennial stream - A stream that maintains water in its channel throughout the year.

Permeability coefficient - The volume of water, in cubic feet, under a head of one foot, that will pass through a square foot of porous surface in one day.

Permeability, Soil - The quality of soil horizon that enables water or air to move through it. The permeability of a soil may be limited by the presence of one nearly impermeable horizon even though the others are permeable.

Permeability rate - The rate at which water will move through a saturated soil. Permeability rates are classified as follows:

- (a) Very slow - less than 0.06 inches per hour.
- (b) Slow - 0.06 to 0.20 inches per hour.
- (c) Moderately slow - 0.20 to 0.63 inches per hour.
- (d) Moderate - 0.63 to 2.0 inches per hour.
- (e) Moderately rapid 2.0 to 6.3 inches per hour.
- (f) Rapid - 6.3 to 20.0 inches per hour.
- (g) Very rapid - More than 20.0 inches per hour.

Pervious - Allowing movement of water.

pH - A numerical measure of acidity or hydrogen ion activity, and of alkalinity. The neutral point is pH 7.0. All pH values below 7.0 are acid and all above 7.0 are alkaline.

Phosphorus, Available - Inorganic phosphorus that is readily available for plant growth.

Plasticity index - The numerical difference between the liquid limit and the plastic limit of soil; the range of moisture content within which the soil remains plastic.

Plastic limit - The moisture content at which a soil changes from a semi-solid to a plastic state.

Plunge pool - A device used to dissipate the energy of flowing water that may be constructed or made by the action of flowing. These facilities may be protected by various lining materials.

Pollution - The presence of a body of water (or soil or air) of substances of such character and in such quantities that the natural quality of the environment is impaired or rendered harmful to health and life or offensive to the senses.

Porosity - The volume of pore space in a rock.

Porous pavement - A pavement through which water can flow at significant rates.

Principal spillway - A dam spillway generally constructed of permanent material and designed to regulate the normal water level, provide flood protection and/or reduce the frequency of operation of the emergency spillway.

Rational method - A means of computing storm drainage flow rates (Q) by use of the formula $Q = CIA$, where C is a coefficient describing the physical drainage area, I is the rainfall intensity and A is the area.

Retention - The storage of stormwater to prevent it from entering the sewer system; may be temporary or permanent.

Retention structure - A natural or artificial basin that functions similar to a detention structure except that it maintains a permanent water supply.

Rill- A small intermittent watercourse with steep sides, usually only a few inches deep.

Riprap - Broken rock, cobbles, or boulders placed on earth surfaces, such as the face of a dam or the bank of a stream, for protection against the action of water (waves). Also applied to brush or pole mattresses, brush and stone, or other similar materials used for soil erosion control.

Riser - The inlet portions of a drop inlet spillway that extend vertically from the pipe conduit barrel to the water surface.

River basin - A major water resource region. The U.S. has been divided into 20 major water resource regions (river basins). See **Drainage Basin**.

Rock-fill dam - A dam composed of loose rock usually dumped in place, often with the upstream part constructed of hand-placed or derrick-placed rock and faced with rolled earth or with an impervious surface of concrete, timber, or steel.

Runoff - That portion of precipitation that flows from a drainage area on the land surface, in open channels or in stormwater conveyance systems.

Saturation point - In soils, the point at which a soil or an aquifer will no longer absorb any amount of water without losing an equal amount.

Scour - The clearing and digging action of flowing air or water, especially the downward erosion caused by stream water in sweeping away mud and silt from the outside bank of a curved channel or during a flood.

Sediment - Solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level.

Sediment basin - A depression formed from the construction of a barrier or dam built at a suitable location to retain sediment and debris.

Sediment delivery ratio - The fraction of the soil eroded from upland sources that actually reaches a continuous stream channel or storage reservoir.

Sediment discharge - The quantity of sediment, measured in dry weight or by volume, transported through a stream cross-section in a given time. Sediment discharge consists of both suspended load and bedload.

Sediment grade sizes - Measurements of sediment and soil particles that can be separated by screening. A committee on sedimentation of the National Research Council has established a classification of textural grade sizes for standard use.

Sediment pool - The reservoir space allotted to the accumulation of submerged sediment during the life of the structure.

Seedbed - The soil prepared by natural or artificial means to promote the germination of seed and the growth of seedlings.

Seedling - A young plant grown from seed.

Settling basin - An enlargement in the channel of a stream to permit the settling of debris carried in suspension.

Silt - A soil consisting of particles between 0.05 and 0.002 millimeter in equivalent diameter. A soil textural class. See **Soil Texture**.

Silt loam - A soil textural class containing a large amount of silt and small quantities of sand and clay. See **Soil Texture**.

Silty clay - A soil textural class containing a relatively large amount of silt and clay and a small amount of sand. See **Soil Texture**.

Silty clay loam - A soil textural class containing a relatively large amount of silt, a lesser quantity of clay, and a still smaller quantity of sand. See **Soil Texture**.

Slope - Degree of deviation of a surface from the horizontal; measured as a numerical ratio, percent, or in degrees. Expressed as a ratio, the first number is the horizontal distance (run) and the second is the vertical distance (rise), as 2:1. A 2:1 slope is a 50 percent slope. Expressed in degrees, the slope is the angle from the horizontal plane, with a 90° slope being vertical (maximum) and 45° being a 1:1 or 100 percent slope.

Soil - The unconsolidated mineral and organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants.

Soil conservation - Using the soil within the limits of its physical characteristics and protecting it from unalterable limitations of climate and topography.

Soil horizon - A layer of soil, approximately parallel to the surface, that has distinct characteristics produced by soil-forming factors.

Soil profile - A vertical section of the soil from the surface through all horizons, including C horizons.

Soil structure - The relation of particles or groups of particles which impart to the whole soil a characteristic manner of breaking; some types are crumb structure, block structure, platy structure, and columnar structure.

Soil texture - The physical structure or character of soil determined by the relative proportions of the soil separates (sand, silt and clay) of which it is composed.

Spillway - A passage such as a paved apron or channel for surplus water over or around a dam or similar obstruction. An open or closed channel, or both, used to convey excess water from a reservoir. It may contain gates, either manually or automatically controlled, to regulate the discharge of excess water.

Stabilized grade - The slope of a channel at which neither erosion or deposition occurs.

Storm frequency - The time interval between major storms of predetermined intensity and volumes of runoff e.g., a 5-year, 10-year or 20-year storm.

Storm sewer - A sewer that carries stormwater and surface water, street wash and other wash waters or drainage, but excludes sewage and industrial wastes. Also called a storm drain.

Streambanks - The usual boundaries, not the flood boundaries, of a stream channel. Right and left banks are named facing downstream.

Stream gaging - The quantitative determination of stream flow using gages, current meters, weirs, or other measuring instruments at selected locations. See **Gaging station**.

Sub-basin - A physical division of a larger basin, associated with one reach of the storm drainage system.

Subcatchment - A subdivision of a drainage basin (generally determined by topography and pipe network configuration).

Subdrain - A pervious backfilled trench containing stone or a pipe for intercepting groundwater or seepage.

Subsoil - The B horizons of soils with distinct profiles. In soils with weak profile development, the subsoil can be defined as the soil below the plowed soil (or its equivalent of surface soil), in which roots normally grow. Although a common term, it cannot be defined accurately. It has been carried over from early days when "soil" was conceived only as the plowed soil and that under it as the "subsoil".

Subwatershed - A watershed subdivision of unspecified size that forms a convenient natural unit.

Surface runoff - Precipitation that falls onto the surface of roofs, streets, ground, etc., and is not absorbed or retained by that surface, but collects and runs off.

Surface water - All water, the surface of which is exposed to the atmosphere.

Suspended solids - Solids either floating or suspended in water, sewage or other liquid wastes.

Swale - An elongated depression in land surface that is at least seasonally wet, it usually heavily vegetated, and is normally without flowing water. Swales conduct stormwater into primary drainage channels and provide some groundwater recharge.

Tailwater depth - The depth of flow immediately downstream from a discharge structure.

Terrace - An embankment or combination of an embankment and channel across a slope to control erosion by diverting or storing surface runoff instead of permitting it to flow uninterrupted down the slope.

Terrace outlet channel - Channel, usually having a vegetative cover, into which the flow from one or more terraces is discharged and conveyed from the terrace system.

Tile, Drain - Pipe made of burned clay, concrete, or similar material, in short lengths, usually laid with open joints to collect and carry excess water from the soil.

Tile drainage - Land drainage by means of a series of tile lines laid at a specified depth and grade.

Toe drain - A drainage system constructed in the downstream portion of an earth dam or levee to prevent excessive hydrostatic pressure.

Topography - General term to include characteristics of the ground surface such as plains, hills, mountains, degree of relief, steepness of slopes, and other physiographic features.

Trash rack - A structural device used to prevent debris from entering a spillway or other hydraulic structure.

Turbidity - Cloudiness of a liquid, caused by suspended solids; a measure of the suspended solids in a liquid.

Unified soil classification system (engineering) - A classification system based on the identification of soils according to their particle size, gradation, plasticity index, and liquid limit.

Uniform flow - A state of steady flow when the mean velocity and cross-sectional area remain constant in all sections of a reach.

Urban runoff - Surface runoff from an urban drainage area that reaches a stream or other body of water or a sewer.

Vegetative protection - Stabilization of erosive or sediment-producing areas by covering the soil with:

- (a) Permanent seeding, producing long-term vegetative cover.
- (b) Short-term seeding, producing temporary vegetative cover, or
- (c) Sodding, producing areas covered with a turf of perennial sod-forming grass.

Water classification - Separation of water of an area into classes according to usage, such as domestic consumption, fisheries, recreation, industrial, agricultural, navigation, waste disposal, etc.

Water control (soil and water conservation) - The physical control of water by such measures as conservation practices on the land, channel improvement, and installation of structures for water retardation and sediment detention (does not refer to legal control or water rights as defined).

Watercourse - A definite channel with bed and banks within which concentrated water flows, either continuously or intermittently.

Water quality - A term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

Water quality standards - Minimum requirements of purity of water for various uses; for example, water for agricultural use in irrigation systems should not exceed specific levels of sodium bicarbonates, pH, total dissolved salts, etc.

Water resources - The supply of groundwater and surface water in a given area.

Watershed - The region drained by or contributing water to a stream, lake, or other body of water. See **Drainage Basin**.

Watershed area - All land and water within the confines of a drainage divide or a water problem area consisting in whole or in part of land needing drainage or irrigation.

Watershed management - Use, regulation, and treatment of water and land resources of a watershed to accomplish stated objectives.

Watershed planning - Formulation of a plan to use and treat water and land resources.

Water table - The upper surface of the free groundwater in a zone of saturation; locus of points in soil water at which hydraulic pressure is equal to atmospheric pressure.

Weir - Device for measuring or regulating the flow of water.

Weir notch - The opening in a weir for the passage of water.

Zoning ordinance - An ordinance based on the police power of government to protect the public health, safety, and general welfare. It may regulate the type of use and intensity of development of land and structures to the extent necessary for a public purpose. Requirements may vary among various geographically defined areas called zones. Regulations generally cover such items as height and bulk of buildings, density of dwelling units, off-street parking, control of signs, and use of land for residential, commercial, industrial, or agricultural purposes. A zoning ordinance is one of the major methods for implementation of a comprehensive plan.

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Appendix A-3

Geotextile Application Guide

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STANDARD AND SPECIFICATIONS FOR GEOTEXTILE

Definition: Woven or non-woven fabric consisting of long chain polymeric filaments or yarns of polypropylene, polyethylene, polyester, polyamide, or polyvinylidene chloride. The geotextile shall be inert to commonly encountered chemicals and hydrocarbons, and be mildew and rot resistant.

Purpose: To function as a barrier to sediment while allowing water to flow through when used as silt fence, inlet protection, or in a dewatering practice. To provide a stabilized base for stone and riprap applications when used as an underlay.

Conditions Where Practice Applies

Standard, reinforced and super silt fence, storm drain inlet protection, culvert inlet protection, geotextile dewatering bag, pumping pit, dewatering device, dewatering basin, lined channel, subsurface drain, riprap and gabion mattress chutes, riprap outlet protection, riprap stilling basin, stabilized construction entrance, temporary crossing, stream diversion. Refer to **Figure A-3a, Geotextile Selection Table** for choosing the appropriate type of geotextile for a given situation.

Design Criteria

For the purposes of this Handbook, geotextiles have been classified into different categories, or "Types", dependent upon the geotextile application. There are two general types of geotextiles under this classification, the "Type GS" and the "Type GD". Type GS geotextiles are used to separate and/or support layers of different media, such as stone and earth. They tend to have high tensile strength and low permeability. Type GD geotextiles are used in applications that depend on the passage of water through the fabric, thus they can generally be considered "drainage type" geotextiles. This class is further broken down into subclasses depending on the permeability and strength requirements for the given application. See **Figure A-3b, Geotextile Properties Table** for the minimum acceptable property values for the various geotextile types and applications. The minimum acceptable values have been established using the ASTM Test Methods listed below:

Property	Test Method
Grab Tensile Strength	ASTM D 4632
Grab Tensile Elongation	ASTM D 4632
Trapezoidal Tear Strength	ASTM D 4533
Mullen Burst Strength	ASTM D 3786
Puncture Strength	ASTM D 4833
Apparent Opening Size	ASTM D 4751
Ultraviolet Stability (% Strength Retained)	ASTM D 4355
Flow-thru Rate	ASTM D 4491

The designer shall specify on the plan the “Type” of geotextile for the application, such as “Type GD-II geotextile” for use in a pumping pit. In addition, a specific product, “or approved equivalent” shall be included on the plan. To further this example, on the pumping pit detail, a note would be included that says, “Use Type GD-II geotextile, Mirafi FW402 or approved equivalent”. If the contractor wishes to substitute products, he/she should refer to **Figure A-3b, Geotextile Properties Table** for the minimum acceptable values for Type GD-II geotextile in selecting an alternate product. **All substitutions must have prior approval from the appropriate plan approval agency.**

Considerations

The information in this geotextile reference section is generally intended for use with respect to the standard erosion and sediment controls presented in this Handbook. Geotextile products may also be used in stormwater management facilities, such as infiltration trenches and bioretention facilities. The designer shall determine the appropriate geotextile to be used in stormwater management applications, and specify on the plan a manufacturer’s product, “or approved equal”, to be used for that application. The example products cited in this appendix do not represent a complete list of all products, and listing of a product is not an endorsement of its use. It is the responsibility of the designer to specify a product that meets all of the site criteria. If, during construction, the contractor wishes to substitute a product, it must be with the concurrence of the designer and plan approval agency.

Geotextile Selection Table		
Type	Application	Example Products
GS-I	Separation / Stabilization / Underlayment for: Dewatering Basin - Type 2 Gabion Chute Lined Channel Riprap Chute Riprap Outlet Protection Riprap Stilling Basin Stabilized Construction Entrance Stream Diversion Temporary Crossing	US Fabrics US315 ADS 315W Amoco ProPex 2006
GD-I	Culvert Inlet Protection Reinforced Silt Fence Silt Fence Super Silt Fence	Mirafi 500X Geotex 2005T Amoco ProPex 2130
GD-II	Dewatering Basin - Type 1 Dewatering Device Inlet Protection - Type 1 Pumping Pit	Thrace-LINQ GTF 400EO Skaps M404 WinFAB 2197
GD-III	Inlet Protection - Type 2	Silt Sack High Flow Dandy Bag II Ultra-Drain Grate Guard
GD-IV	Geotextile Dewatering Bag	Dirtbag 53/55 Dandy Dewatering Bag TerraTex N08/N10

Figure A-3a Geotextile selection table

Geotextile Properties Table					
Type	GS-I	GD-I	GD-II	GD-III	GD-IV
Minimum Grab Tensile Strength (ASTM D-4632)	300 lbs	100 lbs	200 lbs	265 lbs	200 lbs
Maximum Grab Tensile Elongation (ASTM D-4632)	15%	20%	40%	40%	50%
Minimum Trapezoidal Tear Strength (ASTM D-4533)	100 lbs	50 lbs	50 lbs	50 lbs	80 lbs
Minimum Mullen Burst Strength (ASTM D-3786)	N/A	N/A	N/A	N/A	350 psi
Minimum Puncture Strength (ASTM D-4833)	150 lbs	60 lbs	45 lbs	100 lbs	130 lbs
Apparent Opening Size (ASTM D-4751)	40-80 US Sieve	30-80 US Sieve	30-80 US Sieve	20-40 US Sieve	40-80 US Sieve
Minimum UV Resistance after 500 hours (ASTM D-4355)	70%	70%	70%	70%	70%
Flow-thru Rate (ASTM D-4491)	6 gpm/ft ² maximum	10 gpm/ft ² maximum	110 gpm/ft ² minimum	110 gpm/ft ² minimum	70 gpm/ft ² minimum

Figure A-3b Geotextile properties table

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Appendix A-4

Stabilization Matting Application Guide

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BACKGROUND

Section 3.4.6, Standard and Specifications for Stabilization Matting discusses the general composition, uses, and benefits of stabilization matting. Slopes of 3:1 or steeper and all areas of concentrated flow will require some form of stabilization matting, either a temporary soil stabilization mat or a permanent turf reinforcement mat. This appendix will aid the designer in specifying the appropriate matting on the sediment and stormwater plan. The matting type from this manual (i.e. SSM-I, TRM-II, etc.) should be noted on the plan along with a manufacturer's product (i.e., "North American Green S75BN").

The example products cited in this appendix do not represent a complete list of all products, and listing of a product is not an endorsement of its use. It is the responsibility of the designer to specify a product that meets all of the site criteria. If, during construction, the contractor wishes to substitute a product, it must be with the concurrence of the designer and plan approval agency.

Stabilization matting is divided into two categories: temporary matting referred to as soil stabilization matting, and permanent matting referred to as turf reinforcement matting. A brief description of each category and each type of matting follows.

Soil Stabilization Matting

Types I through IV (SSM-I through SSM-IV) are temporary to long-term degradable mattings, applied to the soil surface to prevent erosion prior to vegetative establishment. They can be used both in slope applications and as temporary channel liners.

SSM-I is a temporary mat that will degrade within 12 months. It is composed of 100% agricultural straw (min 0.5 lbs/SY) or 100% wood excelsior fiber (min 0.8 lbs/SY, min 80% six-inch or longer fiber length) with a single top netting of biodegradable material. An **SSM-I** is acceptable on slopes of 3:1 or flatter and in low flow swales with a maximum design shear stress of 1.55 psf, where natural vegetation will provide permanent stabilization. *Example Products: North American Green S75BN, East Coast Erosion Blankets ECS-1B.*

SSM-II is also a temporary mat that will degrade within 12 months. It is also composed of 100% agricultural straw (min 0.5 lbs/SY) or 100% wood excelsior fiber (min 0.8 lbs/SY, min 80% six-inch or longer fiber length), but it contains a double netting (top and bottom) of biodegradable material. An **SSM-II** is acceptable on slopes of 2:1 or flatter and in low flow swales with a maximum design shear stress of 1.65 psf, where natural vegetation will provide permanent stabilization. *Example Products: North American Green S150BN, East Coast Erosion Blankets ECS-2B.*

SSM-III is an extended term mat lasting 12 to 24 months. It is composed of 70% agricultural straw or wood excelsior fiber and 30% coconut (coir) fibers with two woven biodegradable nettings. An **SSM-III** is acceptable on slopes of 1.5:1 or flatter and in medium flow swales with a maximum design shear stress of 1.80 psf, where natural vegetation will provide permanent stabilization. *Example Products: North American Green SC150BN, North American Green C125BN, East Coast Erosion Blankets ECC-2B.*

SSM-IV is a long term mat lasting 18 to 36 months. It is composed of 100% coconut (coir) fibers or 100% polypropylene fibers with two plastic or woven biodegradable nettings with UV stabilization. An **SSM-IV** is acceptable on slopes of 1:1 or flatter and in high flow swales with a maximum design shear stress of 2.0 psf, where natural vegetation will provide permanent stabilization. *Example Products: North American Green C125, Synthetic Industries Landlok C2, East Coast Erosion Blankets ECC-2 Double Net Coconut.*

Turf Reinforcement Mats

Types I through IV (TRM-I through TRM-IV) are permanent, non-degradable three-dimensional mattings that provide a matrix for the roots of vegetation to penetrate and entangle. TRMs can be used both in slope applications and as permanent channel liners. Some TRMs offer the option of being soil-filled or non-soil-filled, depending upon the site conditions and desired results.

TRM-I provides permanent soil and turf reinforcement on slopes steeper than 1:1 and in channels where maximum design shear stress over a 50-hour flow duration is 2 psf or less and where natural vegetation alone will not provide long term stabilization. *Example Products: Landlok TRM 450, North American Green P300 and East Coast Erosion Blanket ECP-2 10 oz. (all non-vegetated).*

TRM-II provides permanent soil and turf reinforcement on slopes steeper than 1:1 and in channels where maximum design shear stress over a 50-hour flow duration ranges from 2.1 psf to 5.9 psf and where natural vegetation alone will not provide long term stabilization. *Example Products: North American Green P550 (non-vegetated), Landlok TRM 435 (vegetated), 1060 and 1061B (all vegetated), Mirafi Miramat TM8 (vegetated), Contech C-60 (vegetated) and East Coast Erosion Blanket ECP-2/ECSC-3/ECC-3/ECP-3 (all non-vegetated).*

TRM-III provides permanent soil and turf reinforcement on slopes steeper than 1:1 and in channels where maximum design shear stress over a 50-hour flow duration ranges from 6 psf to 8 psf and where natural vegetation alone will not provide long term stabilization. Products in the **TRM-III** category have a maximum tensile strength in the machine direction of less than 1,500 lbs. *Example Products: North American Green P300 and P550 (vegetated), East Coast Erosion Blanket ECP-2/ECSC-3/ECC-3/ECP-3 (all vegetated) and LandLok 450/1051 (all vegetated).*

TRM-IV provides permanent soil and turf reinforcement on slopes steeper than 1:1 and in channels where the maximum design shear stress over a 50-hour duration of flow ranges from 6 psf to 8 psf and where natural vegetation alone will not provide long term stabilization. Products in the **TRM-IV** category have a maximum tensile strength in the machine direction of 1,500 lbs or greater. **TRM-IV** may be specified for use in stormwater management pond emergency spillways in lieu of riprap (up to a riprap size of R4) where infrequent flow will occur and grass is preferred over riprap. **TRM-IV** is not applicable as a replacement for riprap in areas of outlet protection where concentrated flow is anticipated. *Example Products: Pyramat High Performance TRM and East Coast Erosion Blanket T-RECS (all vegetated).*

Use of Figure A-4a, Stabilization Matting Selection Table

The Stabilization Matting Selection Table is a quick reference to be used as a starting point when specifying stabilization matting for a site. To use the table, follow these steps:

1. Determine the proposed application of the mat, either to stabilize a slope or to line a channel.
2. Select the appropriate criteria classification depending upon the application.
 - a. For slope applications, the criteria are based upon the slope's steepness. Ranges for slope steepness (i.e. 3:1 – 2:1) capture all slopes between those values.
 - b. For channel lining applications, the criteria are based upon the calculated shear stress for the channel. Shear stress shall be calculated using **Design Guide DG-1, FHWA HEC-15 Design of Flexible Channel Linings**. If HEC-15 results show that the channel will be stable once vegetation is established, a temporary channel lining may be used. If HEC-15 results show that reinforcement beyond grass is necessary to produce a stable, non-erosive channel, a permanent channel lining will be necessary. Shear stress minimums and ranges are provided in the table.
3. The criteria ranges in **Figure A-4a** correspond directly with the matting type. Specify the matting type (i.e. SSM-II) for each separate application on the plan.
4. Choose a product that meets the criteria for that type of matting from the descriptions in this document above (i.e. 100% agricultural straw with double netting) then refer to the manufacturer's specifications for that product to verify its applicability to the proposed site conditions.
5. If the product fits the site, provide notation on the plan such as "apply SSM-II, North American Green S150BN, to the full length of the slope".

When more than one type stabilization matting will be used on the same site, the plan must clearly delineate the locations where each type will be applied. The stabilization matting type from the reference table is the most appropriate for the application, but is considered a minimum. A matting that is rated for more extreme conditions may be used for less intense applications, as long as it does not inhibit vegetative growth. The designer should consider this when specifying several matting types for a site. If a single matting type can be used, that may be preferable to avoid confusion during construction.

Stabilization Matting Selection Table			
Application	Criteria	Type	Example Products
Slope Stabilization	3:1 or flatter	SSM-I	North American Green S75BN American Excelsior Curlex I PPS Packaging Xcel Straw Regular SR1
	2:1 or flatter	SSM-II	North American Green S150BN East Coast Erosion Blanket ECS-2B
	1.5:1 or flatter	SSM-III	North American Green SC150BN East Coast Erosion Blanket ECC-2B
	1:1 or flatter	SSM-IV	North American Green C125 Synthetic Industries Landlok C2
	steeper than 1:1	TRM-I	Landlok TRM 450 (non-vegetated) North American Green P300 (non-vegetated) Contech C-45 (non-vegetated)
Channel Lining, Temporary	≤ 1.55 psf	SSM-I	North American Green S75BN
	≤ 1.65 psf	SSM-II	North American Green S150BN East Coast Erosion Blanket ECS-2B
	≤ 1.80 psf	SSM-III	North American Green SC150BN East Coast Erosion Blanket ECC-2B
	≤ 2.0 psf	SSM-IV	North American Green C125 Synthetic Industries Landlok C2 East Coast Erosion Blanket ECC-2 Dbl Net Coconut
Channel Lining, Permanent	≤ 2 psf	TRM-I	Landlok TRM 450 (non-vegetated) North American Green P300 (non-vegetated) Contech TRM C-45 (non-vegetated) East Coast Erosion Blanket ECP-2 10 oz. (non-vegetated)
	2.1 psf - 5.9 psf	TRM-II	Mirafi Miramat TM8 (vegetated) Landlok TRM 1060 & 1061B (vegetated) Contech C-60 (vegetated)
	6 psf - 8 psf and <1500 lbs min tensile strength (Machine Direction)	TRM-III	North American Green P550 (vegetated) LandLok 450 (vegetated) East Coast Erosion Blanket ECC-3/ ECP-3/ECSC-3/ECP-2 (all vegetated)
	6 psf - 8 psf and >1500 lbs min tensile strength (Machine Direction)	TRM-IV	Pyramat High Performance TRM (vegetated) East Coast Erosion Blanket T-RECS (vegetated)

Figure A-4a Stabilization matting selection table

Appendix A-5

Riprap & Stone Properties Tables

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RIPRAP PROPERTIES				
NSA* No.	Graded Rock Size (in)			Min. Blanket Thickness (in)
	Max.	d ₅₀ **	Min.	
R-1	1.5	0.75	No. 8	3
R-2	3	1.5	1	5
R-3	6	3	2	9
R-4	12	6	3	18
R-5	18	9	5	22
R-6	24	12	7	29
R-7	30	15	12	36
R-8	48	24	15	58
* National Stone Association				
** 50% of pieces, by weight, should be larger than this size				

Figure A-5a Riprap properties table

CRUSHED STONE PROPERTIES													
DE No.	d ₅₀ (in)	Sieve Size (square openings), inches (mm)											
		4" (100)	3-1/2" (90)	3" (75)	2-1/2" (63)	2" (50)	1-1/2" (37.5)	1" (25)	3/4" (19)	1/2" (12.5)	3/8" (9.5)	No. 4 (4.75)	No. 8 (2.36)
1	2.5	100	90 - 100	100	25 - 60	35 - 70	0 - 15	0 - 5	0 - 5				
2	2			100	90 - 100	90 - 100	0 - 15	0 - 15					
3	1.5				100	90 - 100	35 - 70	0 - 15		0 - 5			
57	0.5						100	95 - 100		25 - 60		0 - 10	0 - 5
67	0.375							100	90 - 100		20 - 55	0 - 10	0 - 5
8	0.375									100	85 - 100	10 - 30	0 - 5
10	0.1875										100	85 - 100	10 - 30
Source - DelDOT Standard Specifications - August 2001 - Section 813													

Figure A-5b Crushed stone properties table

Appendix A-6

Compost Material Properties

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COMPOST MATERIAL PROPERTIES

This specification shall apply for all applications where compost is used as or within a stormwater best management practice.

Parameter	Range	Testing Method
Particle Size	For Amendments: 100% pass through a ½” screen For Compost Logs: 99% pass through a 2” screen; max. 40% pass through a 3/8” screen	TMECC 2.02-B
pH	6.0-8.0	TMECC 4.11
Manufactured Inert Material	<1% dry weight basis	TMECC 3.08-A
Organic Matter	35-95% dry weight basis	TMECC 5.07-A
Soluble Salt Concentration	<= 6.0 mmhos/cm	TMECC 4.10-A
Carbon to Nitrogen Ratio (C:N)	<= 25:1	
Stability (Carbon Dioxide evolution rate)	<= 2 C / unit VS / day	TMECC 5.08-B
Maturity (seed emergence and seedling vigor)	>90% relative to positive control	TMECC 5.05-A
Trace Metals	“Pass”	
Dry Bulk Density	12.5-25 lb/cu.ft.	
Moisture content	40-50%	

Table A6.1 Compost Material Properties

Compost Specifications

Compost used to fulfill regulatory requirements shall meet the criteria set forth in the separate Specifications for Compost. In addition, it must be provided by a member of the U.S. Composting Seal of Testing Assurance (STA) program.

The compost shall be the result of the biological degradation and transformation of plant-derived materials under conditions that promote anaerobic decomposition. The material shall be well composted, free of viable weed seeds, and stable with regard to oxygen consumption and carbon dioxide generation. The compost shall have a moisture content that has no visible free water or dust produced when handling the material. It shall meet the following criteria, as reported by the U.S. Composting Council STA Program Compost Technical Data Sheet (See Table 14.3).

Soluble salt refers to the amount of soluble ions in a solution of compost and water. The concentration of soluble ions is typically estimated by determining the solution's ability to carry an electrical current, i.e., electrical conductivity. The units of measure for soluble salts are either mmhos/cm or dS/m (they are 1:1 equivalent). Plant essential nutrients are actually supplied to plants in a salt form. While some specific soluble salts, (e.g., sodium, chloride), may be more detrimental to plants, most composts do not contain sufficient levels of these salts to be a concern in landscape applications. Plant species have a salinity tolerance rating and maximum tolerable quantities are known. Excess soluble salts can cause phytotoxicity to plants. Compost may contribute to, or dilute, the cumulative soluble salts content of a growing media or soil. Reduction in soluble salts content can be achieved through thorough watering at the time of planting. Most composts have a soluble salt conductivity of 1.0 to 10.0 mmhos/cm, whereas typical conductivity values in soil range from 0 to 1.5 in most areas of the country. 6 mmhos/cm is moderately saline and will inhibit the growth of some plants. The final selection of plants should be made after a soil test identifies the limiting characteristics of the soil mix.

The **Carbon to Nitrogen Ratio** is the first step in evaluating the maturity and stability of a compost sample. A Carbon to Nitrogen (C:N) ratio of less than or equal to 25 is acceptable prior to the additional tests of maturity and stability. Currently there are a number of tests available to determine compost stability and maturity. Some have been published in Test Methods for the Examination of Composting and Compost (TMECC) by the U.S. Composting Council (USCC), while commercial laboratories have developed others.

Stability refers to a specific stage or state of organic matter decomposition during composting, which is related to the type of organic compounds remaining and the resultant biological activity in the material. The stability of a given compost is important in determining the potential impact of the material on nitrogen availability, volume, and porosity in soil or growth media. Compost as a soil amendment requires a stable to very stable product that will prevent nutrient tie up and maintain or enhance oxygen availability in soil or growth media.

Maturity is the degree or level of completeness of composting. Maturity is not described by a single property and therefore maturity is best assessed by measuring two or more compost characteristics. Some immature composts may contain high amounts of free ammonia, certain organic acids or other water-soluble compounds which can limit seed germination and root development, or cause odor. All uses of compost require a mature product free of these potentially phytotoxic components. The bioassay used in the STA Program uses a seed germination and growth test to measure the percent of seed emergence and relative seedling vigor.

Trace metals are elements whose concentrations are regulated due to the potential for toxicity to humans, animals, or plants. Regulations governing the heavy metal content of composts, fertilizers, and certain other horticultural and agricultural products have been promulgated on both the State and Federal levels. Specific trace elements, often referred to as heavy metals include arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc. The quantity of these elements are measured on a dry weight basis and expressed as mg/kg (milligram per kilogram) or ppm (parts per million). Many of these elements are actually needed by plants for normal growth, although in limited quantities. Therefore, measuring the concentration of these elements, as well as other plant nutrients, can provide valuable management data relevant to the fertilizer requirements of plants and subsequent fertilizer application rates. All composts that contain regulated feedstocks must meet national and/or state safety standards for metals in order to be marketed.

Moisture content (percent) is the measure of the quantity of water present in a compost product; expressed as a percentage of total weight. The moisture content of compost affects its **bulk density** (weight per unit volume) and, therefore, affects handling and transportation. Overly dry compost (35% moisture, or below) can be dusty and irritating to work with, while very wet compost (55 to 60%) can become heavy and clumpy, making its application more difficult and delivery more expensive. A preferred moisture percent for finished compost is 40 -50%.

Pathogens, such as bacteria and other infectious microorganisms, should be limited in compost derived from plant-based material, versus bio-solids, but may be present due to animal feces and other sources. Pathogen removal of the compost shall be in compliance with Title 40 of the Code of Federal Regulations Part 503 (or 40 CFR 503).

Design Guide DG-1

FHWA HEC-15

Design of Roadside Channels With Flexible Linings

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U.S. Department
of Transportation

**Federal Highway
Administration**

Hydraulic Engineering Circular No. 15

Publication No. FHWA-IP-87-7

April 1988

DESIGN OF ROADSIDE CHANNELS WITH FLEXIBLE LININGS

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

Effective July 2023

FOREWORD

This Implementation Package provides guidance for the design of stable conveyance channels using flexible linings. The information in the manual should be of interest to State and Federal Hydraulics engineers and others responsible for stabilizing roadside channels. The manual has been adopted as HEC-15 in the Hydraulics Engineering Circular Series.

Copies of the manual are being distributed to FHWA regional and division offices and to each State highway agency for their use. Additional copies of the report can be obtained from the National Technical Information Service, 5280 Port Royal Road, Springfield, Virginia 22161.



Stanley R. Byington, Director
Office of Implementation

NOTICE

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16. Abstract Flexible linings provide a means of stabilizing roadside channels. Flexible linings are able to conform to changes in channel shape while maintaining the overall lining integrity. Permanent flexible lining such as riprap, gravel, or vegetation reinforced with synthetic mat are suitable for hydraulic conditions similar to those requiring rigid linings. Vegetation or temporary linings are suited to hydraulic condition where uniform flow exists and shear stresses are moderate. Design procedures are given for rock riprap, wire-enclosed riprap, gravel riprap, woven paper net, jute net, fiberglass roving, curled wood mat, synthetic mat, and straw with net. Special design procedures are presented for composite channels and channels with steep gradients. The design procedures are based on the concept of maximum permissible tractive force. Methods for determination of hydraulic resistance and permissible shear stress for individual linings are presented. Nomographs are provided for solution of uniform flow conditions in trapezoidal channels. Nomographs are also provided for determination of resistance characteristics for vegetation and permissible shear stress for soils.			
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U.S. Department
of Transportation
**Federal Highway
Administration**

Memorandum

6300 Georgetown Pike
McLean, Virginia 22101-2296

Symbol

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Symbol

Subject: Implementation Package "Design
of Roadside Channels with Flexible
Linings" Report No. FHWA-IP-87-7

Date: **OCT 20 1988**

From: Director, Office of Implementation
Director, Office of Engineering

Reply to
Attn. of: **HRT-10**

To: Regional Federal Highway Administrators
Direct Federal Program Administrator

This manual addresses the design of stable conveyance channels using flexible linings. These linings are able to conform to changes in channel shape while maintaining the overall lining integrity. Permanent flexible linings such as riprap, gravel or vegetation reinforced with synthetic mat are suitable for hydraulic conditions similar to those requiring rigid linings. Vegetation or temporary linings are suited to hydraulic conditions where uniform flow exists and shear stresses are moderate.

Design procedures are given for rock riprap, wire-enclosed riprap, gravel riprap, woven paper net, jute net, fiberglass roving, curled wood mat, synthetic mat and straw. Special design procedures are presented for composite channels and channels with steep gradients. The design procedures are based on the concept of maximum permissible tractive force. Nomographs are provided.

Direct distribution of the report is being made to Region and Division Offices. If you have any questions concerning the report or require additional copies, please contact Mr. Thomas Krylowski at (FTS) 285-2359.

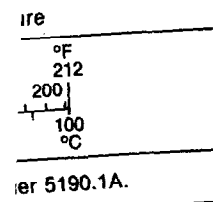
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* SI is the symbol for the International System of Measurements

Thomas Krylowski

Stanley Bymgh

TABLE OF CONTENTS

Page

I. INTRODUCTION	1
II. BACKGROUND	
Lining Types	3
Performance Characteristics	4
Information on Flexible Linings	5
III. DESIGN CONCEPTS	
Open-Channel Flow Concepts	10
Stable Channel Design Concepts	12
Design Parameters	15
IV. DESIGN PROCEDURE	
Flexible Lining Design	16
Permissible Shear Stress	17
Determination of Normal Flow Depth	17
Determination of Shear Stress on Channel	18
Side Slope Stability	18
Maximum Discharge Approach	19
Design Considerations for Riprap Lining	19
Design Procedures	20
Example Problems	22
V. STEEP GRADIENT CHANNEL DESIGN	
Steep Slope Design	52
Other Considerations for Steep Slope Design	52
Design Procedures	53
Example Problems	54
VI. COMPOSITE LINING DESIGN	
Special Considerations	69
Design Procedure	70
Example Problem	71

TABLE OF CONTENTS (continued)

	<u>Page</u>
APPENDIX A EQUATIONS FOR VARIOUS CHANNEL GEOMETRIES	77
APPENDIX B DEVELOPMENT OF DESIGN CHARTS AND PROCEDURES . . .	79
APPENDIX C DEVELOPMENT OF STEEP GRADIENT DESIGN CHARTS AND PROCEDURES	83
APPENDIX D SUGGESTED GUIDELINE SPECIFICATIONS	89
GLOSSARY	108
REFERENCES	111

LIST OF FIGURES

		<u>Page</u>
Figure 1.	Rigid Concrete Channel Lining	4
Figure 2.	Composite Channel Lining (Riprap and Jute Net)	5
Figure 3.	Vegetative Channel Lining	6
Figure 4.	Riprap Channel Lining	6
Figure 5.	Wire Enclosed Riprap	6
Figure 6.	Gravel Channel Lining	6
Figure 7.	Woven Paper Net Channel Lining	7
Figure 8.	Installed Woven Paper Net Lining	7
Figure 9.	Jute Net Lining	7
Figure 10.	Installed Jute Net Channel Lining	7
Figure 11.	Fiberglass Roving Lining	8
Figure 12.	Installation of Fiberglass Roving Along a Roadside	8
Figure 13.	Curled Wood Mat Lining	8
Figure 14.	Installed Curled Wood Mat Channel Lining	8
Figure 15.	Synthetic Mat Lining	9
Figure 16.	Installed Synthetic Mat Channel Lining	9
Figure 17.	Straw With Net Channel Lining	9
Figure 18.	Typical Distribution of Shear Stress	14
Figure 19.	Shear Stress Distribution in a Channel Bend	14
Figure 20.	Location Sketch of Flexible Linings for Example 5	28
Figure 21.	Worksheet for Example Problems 4 and 5	30
Figure 22.	Gradations of Granular Filter Blanket for Example 8	33
Figure 23.	Worksheet for Flexible Lining Design	34

LIST OF FIGURES (continued)

	<u>Page</u>
Figure 24. Worksheet for Example Problems 11 and 12	57
Figure 25. Worksheet for Steep Slope Channel Design	58
Figure 26. Compound Lining Example	71
Figure 27. Worksheet for Compound Lining Design	74
Figure 28. Worksheet for Example Problem 13	75
Figure 29. Equations for Various Channel Geometries	77
Figure 29. Equations for Various Channel Geometries (continued) .	78
Figure 30. Manning's n Versus Relative Roughness for Selected Lining Types	81
Figure 31. Hydraulic Forces Acting on a Riprap Element	86
Figure 32. Steep Slope Design Procedure	88

LIST OF CHARTS

	<u>Page</u>
Chart 1. Permissible shear stress for noncohesive soils	38
Chart 2. Permissible shear stress for cohesive soils	39
Chart 3. Solution for Manning's equation for channels of various side slopes	40
Chart 4. Geometric design chart for trapezoidal channels	41
Chart 5. Manning's n versus hydraulic radius, R , for class A vegetation	42
Chart 6. Manning's n versus hydraulic radius, R , for class B vegetation	43
Chart 7. Manning's n versus hydraulic radius, R , for class C vegetation	44
Chart 8. Manning's n versus hydraulic radius, R , for class D vegetation	45
Chart 9. Manning's n versus hydraulic radius, R , for class E vegetation	46
Chart 10. K_b factor for maximum shear stress on channel bends . . .	47
Chart 11. Protection length, L_p , downstream of channel bend . . .	48
Chart 12. Angle of repose of riprap in terms of mean size and shape of stone	49
Chart 13. Channel side shear stress to bottom shear stress ratio, K_1	50
Chart 14. Tractive force ratio, K_2	51
Chart 15. Steep slope riprap design, trapezoidal channel $Z = 3$. .	60
Chart 16. Steep slope riprap design - $B = 2$, $Z = 3$	61
Chart 17. Steep slope riprap design - $B = 4$, $Z = 3$	62
Chart 18. Steep slope riprap design - $B = 6$, $Z = 3$	63
Chart 19. Steep slope gabion mattress, triangular channel, $Z = 3$. .	64

LIST OF CHARTS (continued)

	<u>Page</u>
Chart 20. Steep slope gabion mattress, $B = 2$, $Z = 3$	65
Chart 21. Steep slope gabion mattress, $B = 4$, $Z = 3$	66
Chart 22. Steep slope gabion mattress, $B = 6$, $Z = 3$	67
Chart 23. Permissible shear stress for gabion mattress versus rock fill size	68
Chart 24. Permissible shear stress for gabion mattress versus mattress thickness	68
Chart 25. Roughness factor for compound channel linings	76

LIST OF TABLES

	<u>Page</u>
Table 1. Classification of Vegetal Covers as to Degree of Retardance	35
Table 2. Permissible Shear Stresses for Lining Materials	36
Table 3. Manning's Roughness Coefficients	37
Table 4. Values of A_3/A_z for Selected Side Slopes and Depth to Bottom Width Ratios	59
Table 5. Empirical Coefficients for Resistance Equation	80
Table 6. Relative Roughness Parameters for Vegetation	80

LIST OF SYMBOLS

- A = Cross-sectional area of flow prism, ft^2 , m^2 .
- AOS = Measure of the largest effective opening in a geotextile; represents opening size for which 95 percent of fabric pores are smaller than that diameter.
- B = Bottom width of trapezoidal channel, ft, m.
- CG = Channel geometry.
- D_{50} , D_{85} = Particle size of gradation, of which 50 percent, 85 percent, etc, of the mixture is finer by weight, ft, m.
- d = Depth of flow in channel, ft, m.
- d = Change in depth due to superelevation of flow in a bend, ft, m.
- d_n = Depth of normal or uniform flow, ft, m.
- F_d = Drag force in direction of flow.
- F_l = Lift force.
- Fr = Froude number, ratio of inertial forces to gravitational force in a system.
- g = Gravitational acceleration, ft/sec^2 , m/sec^2 .
- h = Average height of vegetation, ft, cm.
- K_b = Ratio of maximum shear stress in bend to maximum shear stress upstream from bend.
- K_c = Compound channel lining factor.
- K_1 = Ratio of channel side shear to bottom shear stress.
- K_2 = Tractive force ratio.
- L_p = Protected length downstream from bend, ft, m.
- k_s = Roughness height, ft, cm.
- K_s = Tractive force ratio at bottom of channel.
- MEI = Stiffness factor, $\text{lb} \cdot \text{ft}^2$, $\text{Newton} \cdot \text{m}^2$.
- n = Manning's flow resistance coefficient.
- P = Wetted perimeter of flow prism, ft, m.
- P_ℓ = Wetted perimeter of low-flow channel, ft, m.

P.C. = Point on curve.

P.T. = Point on tangent.

Q = Discharge, flow rate, ft^3/sec , m^3/sec .

R = Hydraulic radius, A/P, ft, m.

R_c = Mean radius of channel center line, ft, m.

REG = Roughness element geometry.

S = Average channel gradient.

S_f = Energy gradient.

S_{50} = Mean of the short axis lengths of the distribution of roughness element.

SF = Safety factor.

SSF = Side slope factor.

T = Channel top width, ft, m.

V = Mean channel velocity, ft/sec, m/sec.

V_* = Shear velocity, ft/sec, m/sec.

W_s = Weight of riprap element, lb, Kg.

Y_{50} = Mean value of the distribution of the average of the long and median axes of a roughness element.

Z = Side slope; cotangent of angle measured from horizontal.
 $Z = \cot \phi$.

ℓ = Moment arms of riprap channel.

α = Angle of channel bed slope.

β = Angles between weight vector and the resultant in the plane of the side slope.

γ = Unit weight of water, lb/ft^3 , Kg/m^3 .

δ = Angle between the drag vector and resultant in the plane of the side slope.

θ = Angle of repose of coarse, noncohesive material, degrees.

η = Stability number.

η' = Stability number for side slopes.

σ = Bed material gradation.

τ = Average shear stress, lb/ft², Kg/m².

τ_b = Shear stress in a bend, lb/ft², Kg/m².

τ_d = Shear stress in channel at maximum depth, lb/ft², Kg/m².

τ_p = Permissible shear stress, lb/ft², Kg/m².

τ_s = Shear stress on sides of channel, lb/ft², Kg/m².

ϕ = Angle of side slope (bank) measured from horizontal.

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

DESIGN OF ROADSIDE CHANNELS WITH FLEXIBLE LININGS

I. INTRODUCTION

This manual addresses the design of stable conveyance channels using flexible linings. Because the roadside channel is included within the highway right-of-way, the gradient of the channel typically parallels the grade of the highway. Hydraulic conditions in the conveyance channel can become severe even at fairly mild highway grades. As a result, these channels often require stabilization against erosion. The channel stabilization measures included in this manual are deemed flexible linings.

The primary difference between rigid and flexible channel linings from an erosion-control standpoint is their response to changing channel shape. Flexible linings are able to conform to change in channel shape while rigid linings can not. The result is that flexible linings can sustain some change in channel shape while maintaining the overall integrity of the channel lining. Rigid linings tend to fail when a portion of the lining is damaged. Damage to a lining is often from secondary forces such as frost heave or slumping. Rigid linings can be disrupted by these forces whereas flexible linings, if properly designed, will retain erosion-control capabilities.

Flexible linings also have several other advantages compared to rigid linings. They are generally less expensive, permit infiltration and exfiltration, and have a natural appearance. Hydraulically, flow conditions in channels with flexible linings generally conform to those found in natural channels, and thus provide better habitat opportunities for local flora and fauna. In some cases, flexible linings may provide only temporary protection against erosion while allowing vegetation to be established. The vegetation will then provide permanent erosion control in the channel. The presence of vegetation in a channel can also provide a buffering effect for runoff contaminants.

Flexible linings have the disadvantage of being limited in the magnitude of erosive force they can sustain without damage to either the channel or the lining. Because of this limitation, the channel geometry (both in cross section and profile) required for channel stability may not fit within the acquired right-of-way. A rigid channel can provide a much higher capacity and in some cases may be the only alternative.

Design procedures covered in this manual relate to flexible channel linings. Rigid linings are discussed only briefly so that the reader remains familiar with the full range of channel lining alternatives. The primary reference for the design of rigid channels is Hydraulic Design Series No. 3, "Design of Roadside Drainage Channels". (1) For channels which require other protection measures, the design of energy dissipators and grade-control structures can be found in Hydraulic Engineering Circular (HEC) No. 14.(2)

Riprap design procedures covered in this manual are for channels having a design discharge of 50 cfs or less. The use of the procedures in Hydraulic Engineering Circular (HEC) No. 11 is recommended for the design of riprap revetments or linings on channels and streams with design flows in excess of 50 cfs. (3)

The permissible tractive force and Manning n values provided in this manual for grass lined channels cannot be compared to values found in earlier manuals. The current values are based on research conducted at Colorado State University which takes into account the stiffness of the vegetation.

The riprap procedure for steep channels is based on an analysis of forces acting on the riprap. While this procedure is theoretically sound, the results should be used with caution and be taken as guidance. Whenever possible, the procedure should be checked against the performance of installed channels in the field. The steep slope design procedure is limited to channels having a design discharge of 50 cfs or less.

II. BACKGROUND

Considerable development and research have been done on rigid and flexible channel linings. Prior to the late 1960's, natural materials were predominantly used to stabilize channels. Typical materials included rock riprap, stone masonry, concrete, and vegetation. Since that time a wide variety of manufactured and synthetic channel linings applicable to both permanent and temporary channel stabilization have been introduced. Relatively little data on hydraulic performances of these materials are available compared to the variety of materials produced. Work is continuing on comparing hydraulic performances, material improvement, and new material development.

Lining Types

Because of the large number of channel stabilization materials currently available, it is useful to classify these materials based on their performance characteristics. Lining types are classified as rigid, such as concrete, or flexible, such as vegetation or rock riprap. Flexible linings are further classified as temporary or permanent. Lining materials are classified as follows:

Rigid Linings

- Cast-in-place concrete
- Cast-in-place asphaltic concrete
- Stone masonry
- Soil cement
- Fabric formwork systems for concrete
- Grouted riprap

Flexible Linings

Permanent

- Riprap
- Wire-enclosed riprap
- Vegetation lining
- Gravel

Temporary

- Bare soil
- Straw with net
- Curled wood mat
- Jute, paper, or synthetic net
- Synthetic mat
- Fiberglass roving

Performance Characteristics

Rigid Linings. Rigid linings (figure 1) are useful in flow zones where high shear stress or nonuniform flow conditions exist, such as at transitions in channel shape or at an energy dissipation structure. In areas where loss of water or seepage from the channel is undesirable, they provide an impermeable lining. Since rigid linings are nonerodible, the designer can use any channel shape that adequately conveys the flow and provides adequate freeboard. This may be necessary if right-of-way limitations restrict the channel size.

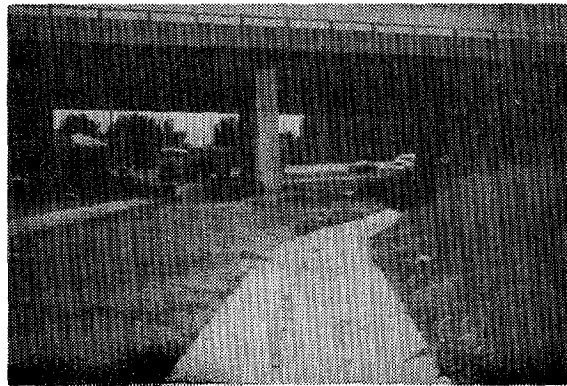


Figure 1. Rigid Concrete Channel Lining.

Despite the non-erodible nature of rigid linings, they are highly susceptible to failure from structural instability. For example, cast-in-place or masonry linings often break up and deteriorate if foundation conditions are poor. Once a rigid lining deteriorates, it is very susceptible to erosion because the large, flat, broken slabs are easily moved by channel flow.

The major causes of structural instability and failure of rigid linings are freeze-thaw, swelling, and excessive soil pore water pressures. Freeze-thaw and swelling soils exert upward forces against the lining and the cyclic nature of these conditions can eventually cause failure. Excessive soil pore pressure occurs when the flow levels in the channel drop quickly. Side slope instability can develop from excessively high pore pressures and high hydraulic gradients along the slope surface.

Construction of rigid linings requires specialized equipment and costly materials. As a result, the cost of rigid channel linings is high. Prefabricated linings can be a less expensive alternative if shipping distances are not excessive.

Flexible Linings. Riprap and vegetation are suitable linings for hydraulic conditions similar to those requiring rigid linings. Because flexible linings are permeable, they may require protection of underlying soil to prevent washout. For example, filter cloth is often used with riprap to inhibit soil piping.

Vegetative and temporary linings are suited to hydraulic conditions where uniform flow exist and shear stresses are moderate. Vegetative channel linings are not suited to sustained flow conditions or long periods of submergence. Vegetative channels with sustained low flow and intermittent high flows are often designed with a composite lining of a riprap or concrete low-flow section, (figure 2).

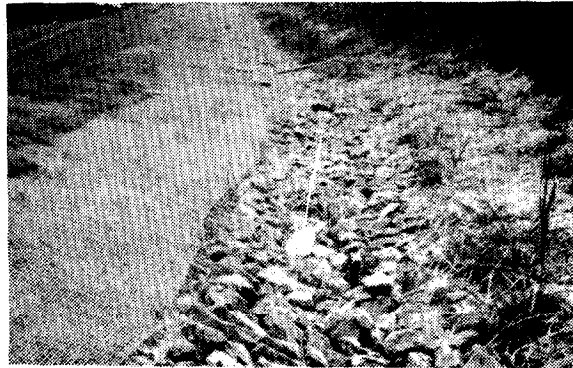


Figure 2. Composite Channel Lining
(Riprap and Jute Net).

Temporary linings provide erosion protection until vegetation is established. In most cases the lining will deteriorate over the period of one growing season, which means that successful revegetation is essential to the overall channel stabilization effort. Temporary channel linings may be used without vegetation to temporarily control erosion on construction sites.

Information on Flexible Linings

The following is a summary of materials currently available for use as flexible channel linings.

Permanent Flexible Linings

Vegetation: Vegetative linings consist of planted or sodded grasses placed in and along the drainage (figure 3). If planted, grasses are seeded and fertilized according to the requirements of that particular variety or mixture. Sod is laid parallel to the flow direction and may be secured with pins or staples.

Rock Riprap: Rock riprap is dumped in place on a filter blanket or prepared slope to form a well-graded mass with a minimum of voids (figure 4). Rocks should be hard, durable, preferably angular in shape, and free from overburden, shale, and organic material. Resistance to disintegration from channel erosion should be determined from service records or from specified field and laboratory tests.

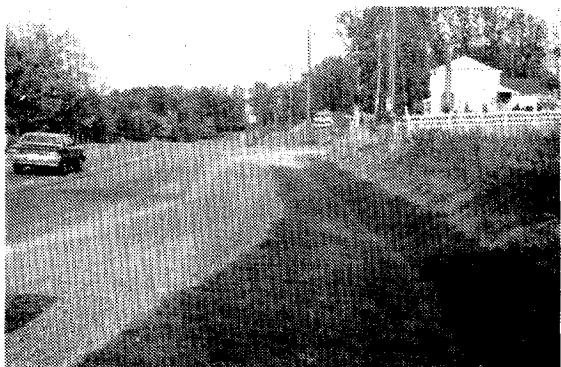


Figure 3. Vegetative Channel Lining
(Class D Retardance).



Figure 4. Riprap Channel Lining.

Wire-Enclosed Riprap: Wire-enclosed riprap is manufactured from a rectangular container made of steel wire woven in a uniform pattern, and reinforced on corners and edges with heavier wire (figure 5). The containers are filled with stone, connected together, and anchored to the channel side slope. Stones must be well graded and durable. The forms of wire-enclosed riprap vary from thin mattresses to boxlike gabions. Wire-enclosed riprap is typically used when rock riprap is either not available or not large enough to be stable.

Gravel Riprap: Gravel riprap consists of coarse gravel or crushed rock placed on filter blankets or prepared slope to form a well-graded mass with a minimum of voids (figure 6). The material is composed of tough, durable, gravel-sized particles and should be free from organic matter.

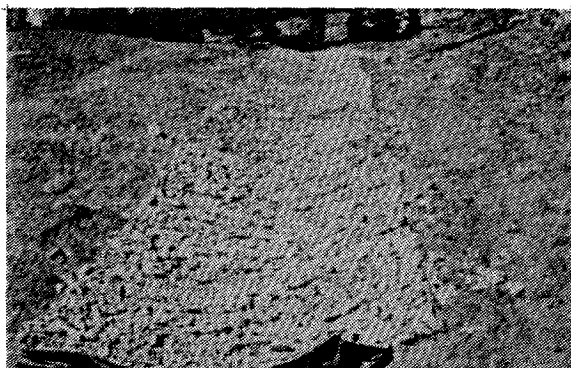


Figure 5. Wire-Enclosed Riprap.



Figure 6. Gravel Channel Lining.

Temporary Flexible Linings

Woven Paper Net: Woven paper net consists of knitted plastic netting, interwoven with paper strips (figures 7 and 8). The net is applied evenly on the channel slopes with the fabric running parallel to the flow direction of the channel. The net is secured with staples and by placement of fabric into cutoff trenches at intervals along the channel. Placement of woven paper net is usually done immediately after seeding operations.

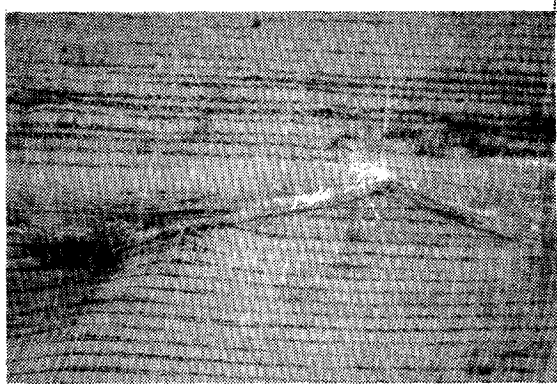


Figure 7. Woven Paper Net Channel Lining.



Figure 8. Installed Woven Paper Net Lining.

Jute Net: Jute net consists of jute yarn, approximately 1/4 inch (0.6 cm) in diameter, woven into a net with openings that are about 3/8 by 3/4 inch (1.0 by 2.0 cm). The jute net (figures 9 and 10) is loosely laid in the channel parallel to the direction of flow. The net is secured with staples and by placement of the fabric into cutoff trenches at intervals along the channel. Placement of jute net is usually done immediately after seeding operations.

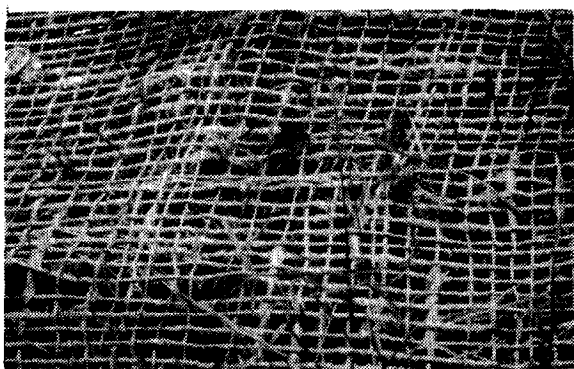


Figure 9. Jute Net Lining.

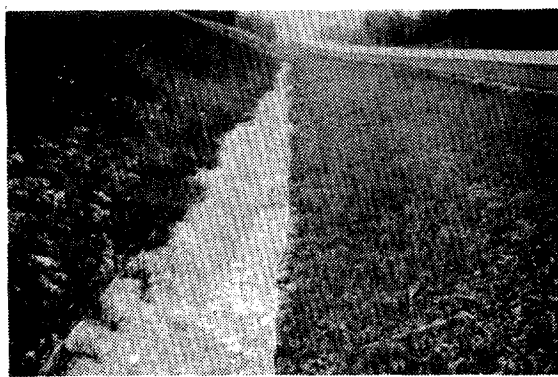


Figure 10. Installed Jute Net Channel Lining.

Fiberglass Roving: Fiberglass roving consists of continuous fibers drawn from molten glass, coated, and lightly bound together into roving. The roving is ejected by compressed air forming a random mat of continuous glass fibers. The material is spread uniformly over the channel and anchored with asphaltic materials (figures 11 and 12).

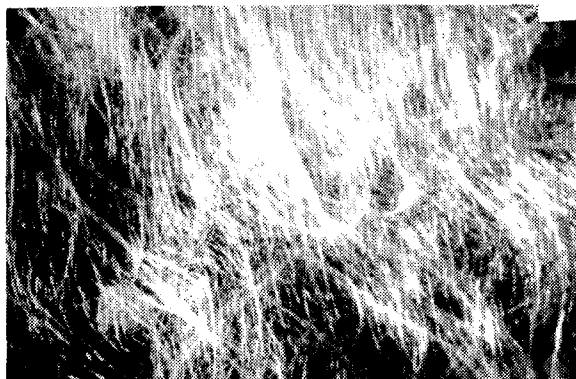


Figure 11. Fiberglass Roving Lining.



Figure 12. Installation of Fiberglass Roving Along a Roadside.

Curled Wood Mat: Curled wood mat consists of curled wood with wood fibers, 80 percent of which are 6 inches (15 cm) or longer, with a consistent thickness and an even distribution of fiber over the entire mat (figures 13 and 14). The top side of the mat is covered with a biodegradable plastic mesh. The mat is placed in the channel parallel to the direction of the flow and secured with staples and cutoff trenches.

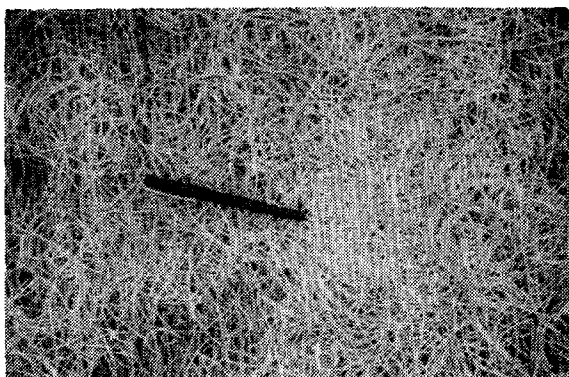


Figure 13. Curled Wood Mat Lining.

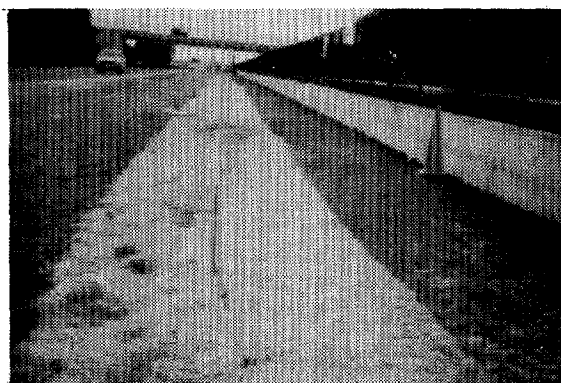


Figure 14. Installed Curled Wood Mat Channel Lining.

Synthetic Mat: Synthetic mat consists of heavy synthetic monofilaments which are fused at their intersections to form a blanket ranging in thickness from 1/4 to 3/4 inch (0.6 to 2.0 cm). The mat, shown in figures 15 and 16, is laid parallel to the direction flow. The mat is secured with staples or wooden stakes, and anchored into cutoff trenches at intervals along the channel. After the mat is in place the area is seeded through the openings in the mat and the cutoff trenches backfilled.

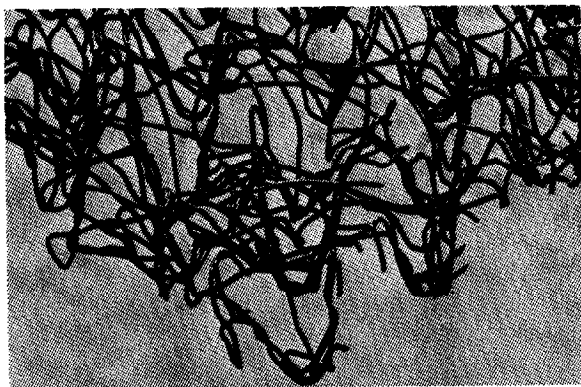


Figure 15. Synthetic Mat Lining.

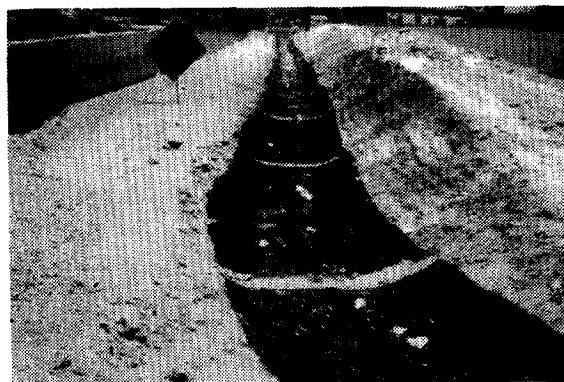


Figure 16. Installed Synthetic Mat Channel Lining.

Straw with Net: Straw with net consists of plastic material forming a net of 3/4-inch (2.0-cm) minimum square openings overlying straw mulch (figure 17). Straw is spread uniformly over the area at a rate of approximately 2.0 tons per acre (4.5 tonnes/hectare) and may be incorporated into the soil according to specifications. Plastic net is placed after mulching with straw to secure the mulch to the finished channel.

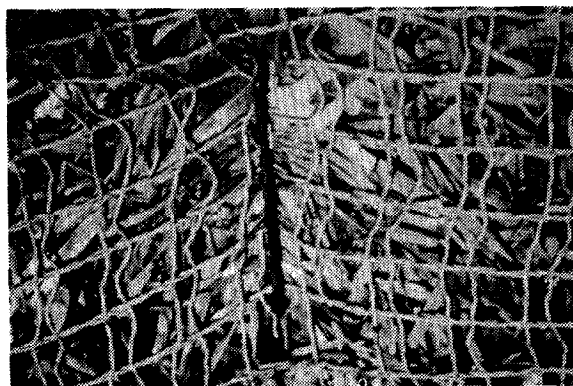


Figure 17. Straw With Net Channel Lining.

III. DESIGN CONCEPTS

The design method presented in this circular is based on the concept of maximum permissible tractive force, coupled with the hydraulic resistance of the particular lining material. The method includes two parts, computation of the flow conditions for a given design discharge and determination of the degree of erosion protection required. The flow conditions are a function of the channel geometry, design discharge, channel roughness, and channel slope. The erosion protection required can be determined by computing the shear stress on the channel at the design discharge and comparing the calculated shear stress to the permissible value for the type of channel lining used.

Open-Channel Flow Concepts

Type of Flow. Open-channel flow can be classified according to three general conditions: (1) uniform or nonuniform flow, (2) steady or unsteady flow, and (3) subcritical or supercritical flow. In uniform flow, the depth and discharge remain constant along the channel. In steady flow, no change in discharge occurs over time. Most natural flows are unsteady and are described by runoff hydrographs. It can be assumed in most cases that the flow will vary gradually and can be described as steady, uniform flow for short periods of time. Subcritical flow is distinguished from supercritical flow by a dimensionless number called the Froude number (Fr), which is defined as the ratio of inertial forces to gravitational forces in the system. Subcritical flow ($Fr < 1.0$) is characterized as tranquil and has deep, slower velocity flow. Supercritical flow ($Fr > 1.0$) is characterized as rapid and has shallow, high velocity flow.

For design purposes, uniform flow conditions are usually assumed with the energy slope approximately equal to average bed slope. This allows the flow conditions to be defined by a uniform flow equation such as Manning's equation. Supercritical flow creates surface waves that are approaching the depth of flow. For very steep channel gradients, the flow may splash and surge in a violent manner and special considerations for freeboard are required.

Resistance to Flow. Depth of uniform flow in a channel depends on the roughness of a particular lining. For practical purposes in highway drainage engineering, Manning's equation provides a reliable estimate of uniform flow conditions. With a given depth of flow, d , the mean velocity may be computed as:

$$V = \frac{1.49}{n} R^{2/3} S_f^{1/2} \quad (1)$$

where V = average velocity in the cross section;

n = Manning's roughness coefficient;

R = hydraulic radius, equal to the cross-sectional area, A , divided by the wetted perimeter, P ; and

S_f = friction slope of the channel, approximated by the average bed slope for uniform flow conditions.

The discharge in the channel is given by the continuity equation as:

$$Q = AV \quad (2)$$

where A = flow area in the channel.

For most types of channel linings Manning's roughness coefficient, n , is approximately constant. The roughness coefficient will increase for very shallow flows where the height of the roughness features on the lining approaches the flow depth (see figure 29). For a riprap lining, the flow depth in small channels may be only a few times greater than the diameter of the mean riprap size. In this case, use of a constant n value is acceptable, but consideration of the shallow flow depth should be made by using a higher n value.

A channel lined with a good stand of vegetation cannot be described by a single n value. The resistance to flow in vegetated channels is further complicated by the fact that vegetation will bend in the flow, changing the height of the vegetation. The Soil Conservation Service (SCS) (4) developed a classification of vegetation depending on the degree of retardance. Grasses are classified into five broad categories, as shown in table 1 in chapter IV. Retardance Class A presents the highest resistance to flow and Class E presents the lowest resistance to flow. In general, taller and stiffer grass species have a higher resistance to flow, while short flexible grasses have a low-flow resistance.

Recent studies by Kouwen et al. (5,6), examined the biomechanics of vegetation and provided a more general approach for determining the Manning's n value for vegetated channels. The resulting resistance equation (see appendix B, equation 19) uses the same vegetative classification as the SCS but is more accurate for very stiff vegetation and mild channel gradients. Design charts 5 to 9 were developed from the Kouwen resistance equation.

Channel Bends. Flow around a bend in an open channel induces centrifugal forces because of the change in flow direction. (7) This results in a superelevation of the water surface. The water surface is higher at the outside of the bend than at the inside of the bend. This superelevation can be estimated by the equation:

$$\Delta d = \frac{V^2 T}{g R_c} = \text{superelevation of water surface} \quad (3)$$

where V = mean velocity;
 T = surface width of the channel;
 g = gravitational acceleration; and
 R_c = mean radius of the bend.

Flow around a channel bend imposes higher shear stress on the channel bottom and banks. The nature of the shear stress induced by a bend is discussed in more detail in the tractive force section on page 13. The increase stress requires additional design considerations within and downstream of the bend.

Freeboard. The freeboard of a channel is the vertical distance from the water surface to the top of the channel at design condition. The importance

of this factor depends on the consequence of overflow of the channel bank. At a minimum the freeboard should be sufficient to prevent waves or fluctuations in water surface from overflowing the sides. In a permanent roadway channel, about one-half foot of freeboard should be adequate, and for temporary channels, no freeboard is necessary. Steep gradient channels should have a freeboard height equal to the flow depth. This allows for large variations to occur in flow depth for steep channels caused by waves, splashing and surging. Lining materials should extend to the freeboard elevation.

Stable Channel Design Concepts

Equilibrium Concepts. Stable channel design concepts focus on evaluating and defining a channel configuration that will perform within acceptable limits of stability. Methods for evaluation and definition of a stable configuration depend on whether the channel boundaries can be viewed as (1) essentially rigid (static) or (2) moveable (dynamic). In the first case, stability is achieved when the material forming the channel boundary effectively resists the erosive forces of the flow. Under such conditions the channel bed and banks are in static equilibrium, remaining basically unchanged during all stages of flow. Principles of rigid boundary hydraulics can be applied to evaluate this type of system.

In a dynamic system, some change in the channel bed and/or banks is to be expected if erosive forces of the flow are sufficient to detach and transport the materials comprising the channel boundary. Stability in a dynamic system is generally attained when the sediment supply rate equals the sediment-transport rate. This condition, where sediment supply equals sediment transport, is often referred to as dynamic equilibrium. Although some detachment and transport of bed and/or bank materials may occur, this does not preclude attainment of a channel configuration that is basically stable. A dynamic system can be considered stable so long as the net change does not exceed acceptable levels. For most highway drainage channels, bank instability and possible lateral migration cannot be tolerated. Consequently, development of static equilibrium conditions or utilization of linings to achieve a stable condition is usually preferable to using dynamic equilibrium concepts.

Two methods have been developed and are commonly applied to determine if a channel is stable in the sense that the boundaries are basically immobile (static equilibrium). These methods are defined as the permissible velocity approach and the permissible tractive force (shear stress) approach. Under the permissible velocity approach the channel is assumed stable if the adopted mean velocity is lower than the maximum permissible velocity. The tractive force (boundary shear stress) approach focuses on stresses developed at the interface between flowing water and materials forming the channel boundary. By Chow's definition, permissible tractive force is the maximum unit tractive force that will not cause serious erosion of channel bed material from a level channel bed.(7)

Permissible velocity procedures were first developed around the 1920's. In the 1950's, permissible tractive force procedures became recognized, based on research investigations conducted by the U.S. Bureau of Reclamation. Procedures for design of vegetated channels using the permissible velocity approach were developed by the SCS and have remained in common use.

In spite of the empirical nature of permissible velocity approaches, the methodology has been employed to design numerous stable channels in the United States and throughout the world. However, considering actual physical processes occurring in open-channel flow, a more realistic model of detachment and erosion processes is based on permissible tractive force.

Tractive Force Theory. The hydrodynamic force of water flowing in a channel is known as the tractive force. The basis for stable channel design with flexible lining materials is that flow-induced tractive force should not exceed the permissible or critical shear stress of the lining materials. In a uniform flow, the tractive force is equal to the effective component of the gravitational force acting on the body of water, parallel to the channel bottom.(7) The average tractive force on the channel, or shear stress is equal to:

$$\tau = \gamma R S \quad (4)$$

where γ = unit weight of water;
 R = hydraulic radius; and
 S = average bed slope or energy slope.

The maximum shear stress, τ_d , for a straight channel occurs on the channel bed (7, 8) and is less than or equal to the shear stress at maximum depth.

$$\tau_d = \gamma d S \quad (5)$$

where d = maximum depth of flow.

Shear stress in channels is not uniformly distributed along the wetted perimeter. (9,10) A typical distribution of shear stress in a trapezoidal channel tends toward zero at the corners with a maximum on the center line of the bed, and the maximum for the side slopes occurring about the lower third of the side as shown in figure 18. Flow around a bend creates secondary currents, which impose higher shear stresses on the channel sides and bottom compared to a straight reach (11) as shown in figure 19. At the beginning of the bend, the maximum shear stress is near the inside and moves toward the outside as the flow leaves the bend. The increased shear stress caused by a bend persists downstream of the bend, a distance, L_p . The maximum shear stress in a bend is a function of the ratio of channel curvature to bottom width, R_c/B .(12) As R_c/B decreases, that is as the bend becomes sharper, the maximum shear stress in the bend tends to increase (see chart 10). The bend shear stress, τ_b , is expressed by a dimensionless factor, K_b , multiplied by the shear stress in an equivalent straight section of channel where

$$\tau_b = K_b \tau_d \quad (6)$$

The relationship between permissible shear stress and permissible velocity for a lining can be found by substituting equation 4 into equation 1 giving:

$$V_p = \frac{0.189}{n} R^{1/6} \tau_p^{1/2} \quad (7)$$

where τ_p = permissible shear stress.

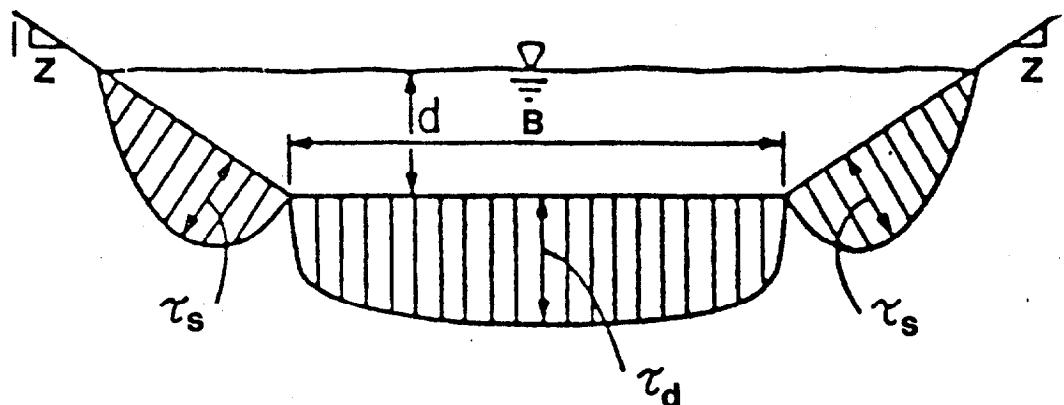


Figure 18. Typical Distribution of Shear Stress.

It can be seen from this equation that permissible velocity varies due to the hydraulic radius. However, permissible velocity is not extremely sensitive to hydraulic radius since the exponent is only $1/6$. Equation 7 is useful in judging the field performance of a channel lining, because depth and velocity may be easier to measure in the field than water surface or channel gradient.

The tractive force method is a more compact approach than the permissible velocity method, because the failure criteria for a particular lining is represented by a single critical shear stress value. This critical shear stress value is applicable over a wide range of channel slopes and channel shapes. Permissible velocities, on the other hand, are a function of lining roughness, channel slope, and channel shape, and are only approximately constant over a range of these parameters. An accurate solution of the permissible velocity method therefore requires design nomographs. The simpler representation of failure for the tractive force method is a definite advantage for users who prefer to use programmable calculators and microcomputers.

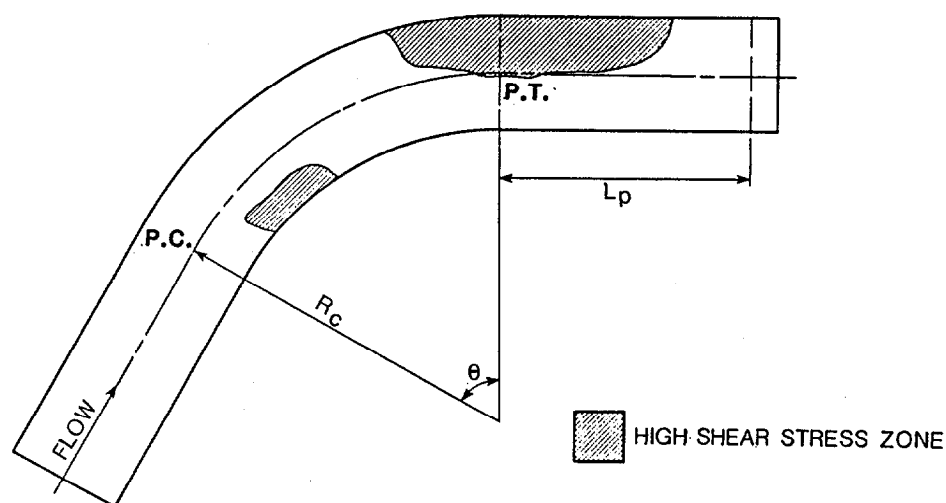


Figure 19. Shear Stress Distribution in a Channel Bend (after 11).

Design Parameters

Design Discharge Frequency. Design flow rates for permanent roadside and median drainage channel linings usually have a 5- or 10-year return period. A lower return period flow is allowable if a temporary lining is to be used, typically the mean annual storm (approximately a 2-year return period, i.e., 50 percent probability of occurrence in a year). Temporary channel linings are often used during the establishment of vegetation. The probability of damage during this relatively short time is low, and if the lining is damaged, repairs are easily made. Design procedures for determining the maximum permissible discharge in a roadway channel are given in chapter IV.

Channel Cross Section Geometry. Most highway drainage channels are trapezoidal or triangular in shape with rounded corners. For design purposes a trapezoidal or triangular representation is sufficient. Design of roadside channels should be integrated with the highway geometric and pavement design to insure proper consideration of safety and pavement drainage needs. If available channel linings are found to be inadequate for the selected channel geometry, it may be feasible to widen the channel. This can be accomplished by either increasing the bottom width or flattening the side slopes. Widening the channel will reduce the flow depth and lower the shear stress on the channel perimeter.

It has been demonstrated that if a riprap-lined channel has 3:1 or flatter side slopes, there is no need to check the banks for erosion. (8) With steeper side slopes, a combination of shear stress against the bank and the weight of the lining may cause erosion on the banks before the channel bottom is disturbed. The design method in this manual includes procedures for checking the adequacy of channels with steep side slopes.

Equations for determining cross-sectional area, wetted perimeter, and top width of channel geometries commonly used for highway drainage channels are given in appendix A.

Channel Slope. The channel bottom slope is generally dictated by the roadway profile, and therefore is usually fixed. If channel stability conditions warrant and available linings are not sufficient, it may be feasible to reduce the channel gradient slightly relative to the roadway profile. For channels outside the roadway right-of-way, the slope may be adjusted slightly.

Channel slope is one of the major parameters in determining shear stress. For a given design discharge, the shear stress in the channel with a mild or subcritical slope is smaller than a channel with supercritical slope. Roadside channels with gradients in excess of about two percent will flow in a supercritical state. Most flexible lining materials are suitable for protecting channel gradients of up to 10 percent. Riprap and wire-enclosed riprap are more suitable for protecting very steep channels with gradients in excess of 10 percent.

IV. DESIGN PROCEDURE

This section outlines the design procedure for flexible channel linings. Channels with steep gradients (slopes greater than 10%) will usually produce a tractive force in excess of the permissible shear stress for most linings presented in this chapter at relatively small discharges. Also, when riprap is used on steeper gradients, the design procedure must take into consideration the additional forces acting on the riprap. Designs involving riprap should be checked and compared to results obtained from design procedures presented in chapter V, Steep Gradient Design. The more conservative results, i.e., largest riprap size, should be used for design. Other linings presented in this chapter are applicable over a wide range of channel gradients, provided the permissible shear for the lining is not exceeded.

The basic design procedure is supplemented for riprap lined channels with side slopes steeper than 3:1. Use of side slopes steeper than 3:1 is not encouraged for flexible linings other than riprap or gabions because of the potential for erosion of the side slopes. If a combination of linings is used, the composite channel lining procedure outlined in chapter VI should be used. In cases where flexible linings discussed in this circular do not provide adequate protection, other alternatives, including rigid linings should be considered. Because of the substantial increased cost of rigid linings, and their vulnerability to failure, other alternatives such as use of additional inlets, a modified channel geometry or a flatter channel gradient are preferred.

Flexible Lining Design

The basic design procedure for flexible channel linings is quite simple. It involves only two computations and several straight forward comparisons of lining performance. The computations include a determination of the uniform flow depth in the channel, known as the normal depth, and determination of the shear stress at maximum flow depth. Designers familiar with methods for determining normal depth may use any convenient method and the Manning's roughness coefficients provided in this manual. A nomograph is also provided in this chapter for determining the normal depth in trapezoidal channels. The computation for shear stress is much simpler and can be carried out without the need of any design aids.

The basic comparison required in the design procedure is that of permissible to computed shear stress for a lining. A table and two figures are provided that give permissible shear stress values for a variety of lining types. If the permissible shear stress is greater than the computed shear, the lining is considered acceptable. If a lining is unacceptable, a lining with a higher permissible shear stress is selected and the calculations for normal depth and shear stress is repeated. A worksheet is provided at the end of this chapter (figure 23) for carrying out the design procedures presented in this chapter.

Channels lined with gravel or riprap on side slopes steeper than 3:1 must be designed using the steep side slope design procedure. Steep side slopes are allowable within a channel if cohesive soil conditions exist. Channels with steep slopes should not be allowed if the channel is constructed in non-cohesive soils.

Permissible Shear Stress

The permissible shear stress, τ_p , indicates the force required to initiate movement of the lining material. Prior to movement of the lining, the underlying soil is relatively protected. Therefore permissible shear stress is not significantly affected by the erodibility of the underlying soil. However, if the lining is eroded and moved, the bed material is exposed to the erosive force of the flow. The consequence of lining failure on highly erodible soils is great, since the erosion rate after failure is high compared to soils of low erodibility.

Values for permissible shear stress for linings are based on research conducted at laboratory facilities and in the field. The values presented here are judged to be conservative and appropriate for design use. Table 2 presents permissible shear stress values for manufactured, vegetative, and riprap lining types. The permissible shear stress for non-cohesive soils is a function of mean diameter of the channel material as shown in chart 1. For larger stone sizes not shown in chart 1 and rock riprap, the permissible shear stress is given by the following equation:

$$\tau_p = 4.0 D_{50} \quad (8)$$

where D_{50} is the mean riprap size in feet. For cohesive materials the variation in permissible shear stress is governed by many soil properties. The plasticity index of the cohesive soil provides a good guide to the permissible shear stress as shown in chart 2.

Determination of Normal Flow Depth

The condition of uniform flow in a channel at a known discharge is computed using the Manning's equation combined with the continuity equation:

$$Q = \frac{1.49}{n} AR^{2/3} S_f^{1/2} \quad (9)$$

where Q = discharge;
 n = Manning's roughness coefficient;
 A = cross-sectional area;
 R = hydraulic radius; and
 S_f = friction gradient which, for uniform flow conditions, equals the channel bed gradient, S .

Chart 3 provides a solution to Manning's equation for trapezoidal channels. The geometric properties of a trapezoidal channel can be found using chart 4 or the equations provided in appendix A.

Manning's Roughness Coefficients for Nonvegetative Linings. Table 3 gives recommended values of the Manning's roughness coefficient for flexible channel lining materials, including riprap-type lining materials. The n values will vary with flow depth. The channel roughness will be higher for shallow flow depths and lower for large flow depths. The range of flow depths from 0.5 ft (15 cm) to 2.0 ft (60 cm) is typical of highway drainage channels and should be used in most cases.

Manning's Roughness Coefficients for Vegetative Linings. Manning's roughness coefficient for vegetative linings varies significantly depending on the amount of submergence of the vegetation and the flow force exerted on the channel bed. As a result, the Manning's n value must be determined by trial and error taking into consideration both the depth of flow and the flow force. Charts 5 to 9 show the variation in Manning's n for five classes of vegetation. These charts can be used to determine Manning's n for a wide range of flow conditions.

Determination of Shear Stress on Channel

As presented in chapter III, Tractive Force Theory (page 13), the shear stress on the channel lining at maximum depth, τ_d , is computed using the following equation:

$$\tau_d = \gamma d S \quad (5)$$

where γ = unit weight of water (62.4 lb/ft³);
 d = flow depth, ft; and
 S = channel gradient, ft/ft.

Flow around a channel bend imposes higher shear stress on the channel bottom and banks. For bends, the maximum shear stress is given by the following equation:

$$\tau_b = K_b \tau_d \quad (6)$$

where the value of K_b can be found using chart 10. In chart 10, the radius of curvature of the channel center line, R_c , and the bottom width of the channel, B , determine the magnitude of factor K_b . The length of protection, L_p , required downstream of a bend is found using chart 11. The length of protection is a function of the roughness of the lining material in the bend (n_b) and the depth of flow.

Side Slope Stability

Channels lined with gravel or riprap on side slopes steeper than 3:1 may become unstable. As the angle of the side slopes approaches the angle of repose of the channel lining, the lining material becomes less stable. However, the shear stress on the channel side is less than the maximum shear stress occurring on the channel bed. The stability of a side slope is a function of the channel side slope and the angle of repose of the rock lining material.

When the tractive force ratio is compared to the ratio of the shear stress on the sides to the shear stress on the bottom of the channel, the rock size for the channel side slope can be determined. The angle of repose, θ , for different rock shapes and sizes is provided in chart 12. The ratio of shear stress on the sides and bottom of a trapezoidal channel, K_1 , is given in chart 13 and the tractive force ratio, K_2 , is given in chart 14. The required rock size (mean diameter of the gradation D_{50}) for the side slopes is found using the following equation:

$$(D_{50})_{\text{sides}} = \frac{K_1}{K_2} (D_{50})_{\text{bottom}} \quad (10)$$

Maximum Discharge Approach

In many cases, the designer simply needs to know the maximum discharge a channel can convey given the permissible shear stress and the corresponding allowable depth. By knowing the maximum discharge that a lining can sustain, the designer can determine the maximum length of lining for a channel, based on the hydrology of the site. This information can assist the designer in an economic evaluation of lining types and can determine inlet spacing.

The procedure presented is for both vegetative linings and non-vegetative linings. Applying the procedure for vegetative linings is particularly useful, since it does not involve a trial and error solution.

Design Considerations for Riprap Lining

Two additional design considerations are required for riprap channel linings: (1) riprap gradation and thickness, and (2) use of filter material under rock riprap.

Riprap Gradation and Thickness. Riprap gradation should follow a smooth size distribution curve. Most riprap gradations will fall in the range of D₁₀₀/D₅₀ and D₅₀/D₂₀ between 3.0 to 1.5, which is acceptable. The most important criterion is a proper distribution of sizes in the gradation so that interstices formed by larger stones are filled with smaller sizes in an interlocking fashion, preventing the formation of open pockets. These gradation requirements apply regardless of the type of filter design used.

In general, riprap constructed with angular stones has the best performance. Round stones are acceptable as riprap provided they are not placed on side slopes steeper than 3:1. Flat slab-like stones should be avoided since they are easily dislodged by the flow. An approximate guide to stone shape is that neither the breadth nor thickness of a single stone is less than one-third its length.

The thickness of a riprap lining should equal the diameter of the largest rock size in the gradation. For most gradations, this will mean a thickness of from 1.5 to 3.0 times the mean riprap diameter.

Filter Design. When rock riprap is used the need for an underlying filter material must be evaluated. The filter material may be either a granular filter blanket or a engineering fabric.

For a granular filter blanket, the following criteria must be met:

$$\frac{D_{15 \text{ filter}}}{D_{85 \text{ base}}} < 5 < \frac{D_{15 \text{ filter}}}{D_{15 \text{ base}}} < 40 \quad (11)$$

$$\frac{D_{50 \text{ filter}}}{D_{50 \text{ base}}} < 40 \quad (12)$$

In the above relationships, "filter" refers to the overlying material and "base" refers to the underlying material. The relationships must hold between the filter blanket and base material and between the riprap and filter blanket.

The thickness of the granular filter blanket should approximate the maximum size in the filter gradation. The minimum thickness for a filter blanket should not be less than 6 inches.

In selecting an engineering filter fabric, the fabric should be able to transmit water from the soil and also have a pore structure that will hold back soil. The following properties of an engineering filter fabric are required to assure that their performance is adequate as a filter under riprap. (18)

1. The fabric must be able to transmit water faster than the soil.
2. The following criteria for the apparent opening size (AOS) must be met:
 - a. For soil with less than 50 percent of the particles by weight passing a U.S. No. 200 sieve, $AOS < 0.6 \text{ mm}$ (0.024 in) (greater than #30 U.S. Std. Sieve).
 - b. For soil with more than 50 percent of the particles by weight passing a U.S. No. 200 sieve, $AOS < 0.297 \text{ mm}$ (0.012 in) (greater than #50 U.S. Std. Sieve).

The above criteria only applies to non-severe or non-critical installations. Severe or critical installations should be designed based on permeability tests.

Design Procedures

The design procedure is summarized below. The procedure for flexible linings is a basic stepwise solution approach.

FLEXIBLE LINING DESIGN PROCEDURE (see computation sheet, figure 23)

1. Select a flexible lining and determine the permissible shear stress, τ_p . (see Table 2)
2. Estimate flow depth for vegetation or flow depth range for non-vegetative linings, the channel shape, slope and design discharge(s).
3. Determine Manning's n value for estimated flow depth.
 - a. For non-vegetive linings, use Table 3.
 - b. For vegetation:
 - (1) Calculate the hydraulic radius, R . (Use chart 4 for trapezoidal channels and Appendix A for other shapes.)
 - (2) Determine n from Chart 5, 6, 7, 8, or 9.

4. Calculate the flow depth, d , in the channel. (Chart 3 for trapezoidal channels.)
5. Compare computed flow depth, d , with estimated flow depth, d_i . If d is outside the assumed range for non-vegetative linings or differs by more than 0.1 ft from d_i for vegetation, repeat steps 2 through 4.
6. Calculate the shear stress, τ_d . If $\tau_d > \tau_p$, the lining is not acceptable, repeat steps 1 through 5.

$$\tau_d = \gamma d S$$

7. For channel bends:

- a. Determine the factor for maximum shear stress on channel bends, K_b , from chart 10. This is a function of the ratio of channel curvature to bottom width, R_c/B .

- b. Calculate the shear stress in the bend, τ_b .

$$\tau_b = K_b \tau_d \quad (6)$$

If $\tau_b > \tau_p$, the lining is not acceptable, repeat steps 1 through 7.

- c. Calculate length of protection, L_p , downstream of the bend from chart 11.

- d. Calculate superelevation.

$$\Delta d = \frac{V^2 T}{g R_c} \quad (3)$$

8. For riprap or gravel linings on steep side slopes (steeper than 3:1):

- a. Determine the angle of repose for the rock size and shape from chart 12.

- b. Determine K_1 , the ratio of maximum side shear to maximum bottom shear for a trapezoidal channel from chart 13.

- c. Determine K_2 , the tractive force ratio from chart 14.

- d. Calculate the required D_{50} for the side slopes.

$$(D_{50})_{sides} = \frac{K_1}{K_2} (D_{50})_{bottom} \quad (10)$$

9. For riprap on slopes greater than 10%, check design procedure in chapter V. Use whichever procedure results in the larger riprap size.

MAXIMUM DISCHARGE DESIGN PROCEUDRE

1. Determine the allowable depth of flow in the channel using the permissible shear stress (table 2 or charts 1 or 2). Check that this depth does not exceed the depth (including freeboard) provided in the typical roadway section.

$$d = \frac{\tau_p}{\gamma S} \quad (13)$$

2. Determine the area and hydraulic radius corresponding to the allowable depth using chart 4.
3. For non-vegetative linings, find the correct Manning's n from table 3. For vegetative linings, enter into charts 5 to 9 for the correct vegetation class and determine the Manning's n value.
4. Solve Manning's equation (equation 9) to determine the maximum discharge for the channel.

Example Problems

Example 1:

Determine whether it is feasible to use jute net as a temporary lining.

Given: $Q = 20 \text{ ft}^3/\text{sec}$
 $S = 0.005 \text{ ft/ft}$
Trapezoidal channel with a bottom width of 4.0 ft and 3:1 side slopes.

Find: Depth of flow in the channel and the adequacy of the jute net lining.

Solution: (1) From table 2, the permissible shear stress is 0.45 lb/ft^2 and from table 3, the Manning's n value is 0.022 (assuming a flow depth between 0.5 to 2.0).

(2) Entering chart 3 for $S = 0.005$, $Qn = 0.44$, and $B = 4$,
 $d/B = 0.22$
 $d = 0.88 \text{ ft}$

The flow depth has remained within the range of 0.5 to 2.0 ft so that the assumed Manning's n value is correct.

(3) Using equation 5, the shear stress on the channel bed at maximum depth is,

$$\begin{aligned} \tau_d &= \gamma d S = 62.4 \times 0.88 \times 0.005 \\ &= 0.27 \text{ lb/ft}^2 \end{aligned}$$

- (4) Comparing the shear stress, 0.27 lb/ft^2 , to the permissible shear stress, 0.45 lb/ft^2 , shows that jute net is an acceptable channel lining.

Example 2:

Determine if a single application of fiberglass roving lining is an adequate lining for a median ditch.

Given: $B = 2 \text{ ft}$
 $Z = 4$
 $S = 0.05 \text{ ft/ft}$
 $Q = 10 \text{ ft}^3/\text{sec}$

Find: Depth of flow.

Solution: (1) From table 3, Manning's n is 0.021 assuming a flow depth in the range of 0.5 to 2.0 ft

- (2) Entering chart 3 for $S = 0.05$, given
 $Qn = 0.21$ and $B = 2$
 $d/B = 0.21$
 $d = 0.42 \text{ ft}$

Checking the flow depth against the initial assumed range shows that the computed depth is below that range. The Manning's n for flow depth range of 0.0 to 0.5 ft is 0.028.

Enter chart 3 for $S = 0.05$,
 $Qn = 0.28$ and $B = 2$
 $d/B = 0.24$
 $d = 0.48 \text{ ft}$

The computed flow depth is within the assumed range.

- (3) The maximum shear stress from equation 5 is,

$$\tau_d = \gamma d S = 62.4 \times 0.48 \times 0.05 \\ = 1.5 \text{ lb/ft}^2$$

- (4) The permissible shear stress for fiberglass is 0.6 lb/ft^2 . Since this is less than the maximum shear stress, the lining is not adequate.

Example 3:

A roadside ditch is lined with a good stand of uncut buffalo grass. Determine the flow depth and Manning's n for the depth at design discharge.

Given: $Q = 20 \text{ ft}^3/\text{sec}$
 $S = 0.005 \text{ ft/ft}$
 $B = 4.0 \text{ ft}$
 $Z = 4$

- Find: (1) Manning's n value.
(2) Flow depth in the channel.

Solution: The vegetative retardance classification is found in table 1. A good stand of uncut buffalo grass is classified as retardance D.

The determination of Manning's n and flow depth for a vegetative lining may require several trials.

Trial 1

- (1) Initial depth is estimated at 1.0 ft.
- (2) From chart 4 for $Z = 4$ and $d/B = 0.25$,
 $R/d = 0.65$ ft
 $R = 0.65$
- (3) Entering chart 8 given $R = 0.65$ and $S = 0.005$,
 $n = 0.088$
- (4) Entering chart 3 given $S = 0.005$, $Qn = 1.76$, $B = 4$, and $Z = 4$,
 $d/B = 0.40$
 $d = 1.60$ ft
- (5) Since the difference between the initial and calculated depth is greater than 0.1 ft, the procedure is repeated.

Trial 2

- (1) Use the calculated depth of 1.60 ft from trial 1.
- (2) From chart 4 for $Z = 4$ and $d/B = 0.40$,
 $R/d = 0.61$
 $R = 0.98$
- (3) Entering chart 8 given $R = 0.98$ and $S = 0.005$,
 $n = 0.066$
- (4) Entering chart 3 given $S = 0.005$, $Qn = 1.32$, and $B = 4$,
 $d/B = 0.36$
 $d = 1.44$
- (5) Since the difference between the initial and calculated depths is 0.16 ft, which is greater than 0.1 ft, the procedure is repeated.

Trial 3

- (1) Use the calculated depth of 1.44 ft from trial 2.
- (2) From chart 4 for $Z = 4$ and $d/B = 0.36$,
 $R/d = 0.61$
 $R = 0.88$
- (3) Entering chart 8 given $R = 0.88$ and $S = 0.005$,
 $n = 0.070$
- (4) Entering chart 3 given $S = 0.005$, $Qn = 1.40$, and $B = 4$,
 $d/B = 0.37$
 $d = 1.48$ ft
- (5) The initial depth and the calculated depth are in agreement.
The procedure is completed with the following results,
 $n = 0.070$
 $d = 1.5$ ft

Example 4:

Determine a temporary channel lining for a trapezoidal channel.

Given: $Q = 16 \text{ ft}^3/\text{sec}$
 $S = 0.03 \text{ ft/ft}$
 $B = 4.0 \text{ ft}$
 $Z = 3$

Find: Adequate temporary channel lining.

Solution:

Trial 1

- (1) Jute net is selected as an initial channel lining alternative. The permissible shear stress (table 2) and Manning's n value (table 3) are,
 $\tau_p = 0.45 \text{ lb/ft}^2$
 $n = 0.022$ (assuming a depth range of 0.5 to 2.0 ft)
- (2) The flow depth is determined from chart 3, given $S = 0.03$,
 $Qn = 0.35$, and $B = 4$,
 $d/B = 0.12$
 $d = 0.48$ ft

The flow depth is slightly below the specified range for Manning's n .

Effective July 2023

- (3) The shear stress at maximum depth is found using equation 5,

$$\begin{aligned}\tau_d &= 62.4 \times 0.48 \times 0.03 \\ &= 0.90 \text{ lb/ft}^2\end{aligned}$$

- (4) The computed shear stress of 0.90 lb/ft² is greater than the permissible shear stress of 0.45 lb/ft², so jute net would not be an acceptable lining.

Trial 2

- (1) The next lining chosen is curled wood mat because the permissible shear stress for this lining exceeds the calculated shear stress from the first trial. Fiberglass roving was not chosen since its permissible shear stress was less than the calculated shear stress from the first trial. The permissible shear from table 2 and the Manning's n from table 3 for curled wood mat are,

$$\begin{aligned}\tau_p &= 1.55 \text{ lb/ft}^2 \\ n &= 0.035 \text{ (assuming a depth range of 0.5 to 2.0 ft)}\end{aligned}$$

- (2) The flow depth is determined from chart 3, given $S = 0.030$, $Qn = 0.56$, $B = 4$, and $Z = 3$,

$$\begin{aligned}d/B &= 0.15 \\ d &= 0.60 \text{ ft}\end{aligned}$$

The flow depth is within the specified range for the Manning's n value used.

- (3) The shear stress at maximum depth is found using equation 5,

$$\begin{aligned}\tau_d &= 62.4 \times 0.60 \times 0.03 \\ &= 1.12 \text{ lb/ft}^2\end{aligned}$$

- (4) The computed shear stress of 1.12 lb/ft² is less than the permissible shear stress of 1.55 lb/ft², so curled wood mat is an acceptable channel lining.

Use of the worksheets for this problem is illustrated in figure 21.

Example 5:

Determine an acceptable channel lining for the roadside channel in example 4 if a bend is included in the channel alignment.

Given: 45° channel bend
 $R_c = 20 \text{ ft}$

Find: (1) The channel lining required for the bend and the location of the lining.

(2) The superelevation of the water surface in the bend.

Effective July 2023

Solution:

Trial 1

- (1) From the results of example 4, the shear stress of the straight reach upstream of the bend is,

$$\tau_d = 1.12 \text{ lb/ft}^2$$

A curled wood mat lining was used to stabilize the channel.

- (2) The shear stress in the bend is given by equation 6. The value of K_b in equation 6 is found from chart 10 given $R_c/B = 5$,

$$K_b = 1.6$$

The bend shear stress is,

$$\begin{aligned}\tau_b &= 1.6 \times 1.12 \\ &= 1.79 \text{ lb/ft}^2\end{aligned}$$

- (3) The computed shear stress in the bend is greater than the permissible shear stress for a curled wood mat channel lining (1.55 lb/ft^2). A new lining is required for the channel bend.

Trial 2

- (1) Synthetic mat is chosen as a bend lining material, because it is permissible shear stress from table 2 (2.0 lb/ft^2) is greater than the computed shear stress from trial 1. The Manning's n value is 0.025 for a flow depth range from 0.5 to 2.0 ft.

- (2) Entering chart 3 given $S = 0.03$, $Qn = 0.40$, and $B = 4$,

$$\begin{aligned}d/B &= 0.13 \\ d &= 0.52 \text{ ft}\end{aligned}$$

This depth falls within the range originally assumed for Manning's n .

- (3) The shear stress from equation 5,

$$\begin{aligned}\tau_d &= 62.4 \times 0.52 \times 0.03 \\ &= 0.97 \text{ lb/ft}^2\end{aligned}$$

The bend shear stress from equation 6 is,

$$\begin{aligned}\tau_b &= 1.6 \times 0.97 \\ &= 1.55 \text{ lb/ft}^2\end{aligned}$$

- (4) The calculated bend shear stress is less than the permissible shear stress for synthetic mat of 2.0 lb/ft^2 . Synthetic mat therefore provides an acceptable channel bend lining.

- (5) The synthetic mat will extend through the bend and a distance downstream. The downstream distance is found using chart 11, given $n_b = 0.025$, $R = 0.40$ (from chart 4 for $d/B = 0.13$ and $Z = 3$),

$$L_p/R = 15.9$$

$$L_p = 6.4 \text{ ft}$$

The total length of synthetic mat lining is the sum of the length in the bend plus the length required for downstream protection. The following figure shows the required location of lining materials.

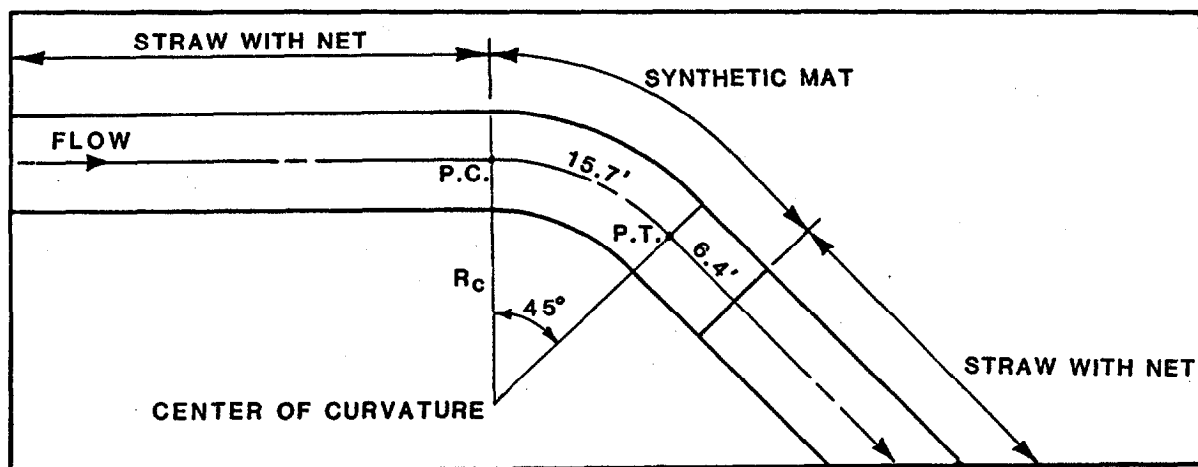


Figure 20. Location Sketch of Flexible Linings for Example 5.

- (6) The superelevation of the water surface is computed from equation 3. To execute equation 3, top width and cross-sectional area must be computed, where,

$$T = B + 2Zd$$

$$= 4 + 2 \times 3 \times 0.52$$

$$= 7.1 \text{ ft}$$

and

$$A = Bd + Zd^2$$

$$= 4 \times 0.52 + 3 \times 0.52^2$$

$$= 2.89 \text{ ft}^2$$

The velocity in the channel found using the continuity equation (equation 2),

$$V = Q/A$$

$$= 16.0/2.89$$

$$= 5.5 \text{ ft/sec}$$

Solving equation 3 given $V = 5.5$ ft/s, $T = 7.1$ ft, and $R_C = 20$ ft,

$$\Delta d = \frac{V^2 T}{g R_C}$$

$$\begin{aligned}\Delta d &= \frac{5.5^2 \times 7.1}{32.2 \times 20} \\ &= 0.33 \text{ ft}\end{aligned}$$

The freeboard in the channel bend should be at least 0.33 ft to accommodate the superelevation of the water surface.

Use of the worksheets for this problem is illustrated in figure 21.

Example 6:

Because of a width constraint on available right-of-way, the side slopes of a roadside ditch must be steepened to 2:1. The 2-inch gravel lining has been determined to be adequate to protect the ditch bed. Determine the gravel size, D_{50} , necessary to protect the ditch banks.

Given: Very rounded gravel
A trapezoidal channel

$$\begin{aligned}Z &= 2 \\ B &= 3.5 \text{ ft}\end{aligned}$$

Flow depth, $d = 0.7$ ft

Find: D_{50} for side slope.

Solution: (1) From chart 12 given a $D_{50} = 0.167$ ft, the angle of repose $\theta = 36^\circ$

(2) From chart 13 given $B/d = 5.0$, the ratio of side shear to bottom shear, $K_1 = 0.79$

(3) From chart 14 given $Z = 2$ and $\theta = 36^\circ$, the tractive force ratio, $K_2 = 0.65$

(4) The required side slope D_{50} from equation 10 is,

$$\begin{aligned}D_{50} &= \frac{0.79}{0.65} (2.0) \\ &= 2.4 \text{ inches}\end{aligned}$$

Example 7:

Determine the maximum allowable discharge for a median ditch lined with a good stand of Kentucky bluegrass (approximately 8 inches in height). The ditch has a depth of 3 feet from the roadway shoulder.

Given: $S = 0.010$ ft/ft
 $B = 4.0$ ft
 $Z = 4$

Worksheet for Flexible Lining Design

DESIGNER: _____ DATE: _____

PROJECT: Example Problems 4 & 5

STATION: _____ TO STATION: _____

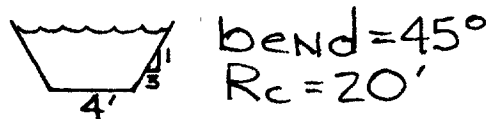
DRAINAGE AREA: _____ ACRES

DESIGN FLOW: Q _____ = _____ ft^3/sec

DESIGN FLOW FOR TEMPORARY LINING: Q 2 = 16 ft^3/sec

CHANNEL SLOPE (S) : .03 ft/ft

CHANNEL DESCRIPTION:



LINING	Q	τ_p (1)	d_i (2)	R (3)	n (4)	d (5)	$\tau_d = \gamma d S$ (6)	REMARKS
Example 4								
Jute Net	16	.45	0.5-2	—	.022	.48	0.9	not acceptable
Curled Wood	16	1.55	"	—	.035	.60	1.12	OK
Example 5								
Synthetic Mat	16	2	0.5-2	—	.025	.52	.97	check bend
								$K_b = 1.6$
								$\gamma_b = 1.79 < \gamma_p$

OK

- (1) Table 2
- (2) For vegetation, estimate initial depth
For other liners, select range from table 3
- (3) Vegetation only, chart 4 for trapezoidal channels
- (4) For vegetation, charts 5-9
For other liners, table 3
- (5) Normal depth, chart 3 (d must be in d_i range)
- (6) τ_d must be $\leq \tau_p$
- (7) Check for steep side slopes and channel bends

Figure 21. Worksheet for Example Problems 4 and 5

Find: Maximum allowable discharge.

Solution: (1) From table 1, a good stand of Kentucky bluegrass is classified as retardance C. From table 2 the permissible shear stress,

$$\tau_p = 1.00 \text{ lb/ft}^2$$

Determine the allowable depth from equation 5, given $\tau_d = \tau_p$,

$$\begin{aligned} d &= \tau_p / \gamma S \\ &= \frac{1.00}{62.4 \times 0.010} \\ &= 1.6 \text{ ft} \end{aligned}$$

Note that the allowable depth is less than the depth of the ditch.

(2) Determine the flow area and hydraulic radius from chart 4, given $d/B = 0.40$,

$$\begin{aligned} A/Bd &= 2.6 \\ A &= 16.6 \\ R/D &= 0.61 \\ R &= 0.98 \end{aligned}$$

(3) From chart 7: $n = 0.072$.

(4) Solving the Manning's equation with continuity (equation 9),

$$\begin{aligned} Q &= \frac{1.49}{n} AR^{2/3} S^{1/2} \\ &= \frac{1.49}{0.072} \times 16.6 \times 0.98^{2/3} \times 0.01^{1/2} \\ &= 33.9 \text{ cfs} \end{aligned}$$

Example 8:

Determine the need for a granular filter blanket.

Given: Riprap Gradation

$$\begin{aligned} D_{85} &= 1.3 \text{ ft} \\ D_{50} &= 0.66 \text{ ft} \\ D_{15} &= 0.33 \text{ ft} \end{aligned}$$

Base Soil Gradation

$$\begin{aligned} D_{85} &= 1.5 \text{ mm} = 0.0049 \text{ ft} \\ D_{50} &= 0.5 \text{ mm} = 0.0016 \text{ ft} \\ D_{15} &= 0.167 \text{ mm} = 0.00055 \text{ ft} \end{aligned}$$

Find: Granular filter blanket requirement.

Solution: $\frac{D_{15 \text{ riprap}}}{D_{85 \text{ base}}} = \frac{0.33}{0.0049} = 67.4$ not less than 5

$$\frac{D_{15 \text{ riprap}}}{D_{15 \text{ base}}} = \frac{0.33}{0.00055} = 600 \text{ not less than } 40$$

$$\frac{D_{50 \text{ riprap}}}{D_{50 \text{ base}}} = \frac{0.66}{0.0016} = 412 \text{ not less than } 40$$

Since the relationships between riprap and base do not meet the recommended dimensional criteria, a filter blanket is required. First, determine the required dimensions of the filter with respect to the base material,

$$\frac{D_{50 \text{ filter}}}{D_{50 \text{ base}}} < 40, \text{ so } D_{50 \text{ filter}} < 40 \times 0.0016 = 0.064 \text{ ft (20 mm)}$$

$$\frac{D_{15 \text{ filter}}}{D_{15 \text{ base}}} < 40, \text{ so } D_{15 \text{ filter}} < 40 \times 0.00055 = 0.022 \text{ ft (6.7 mm)}$$

$$\frac{D_{15 \text{ filter}}}{D_{85 \text{ base}}} < 5, \text{ so } D_{15 \text{ filter}} < 5 \times 0.0049 = 0.024 \text{ ft (7.3 mm)}$$

$$\frac{D_{15 \text{ filter}}}{D_{15 \text{ base}}} > 5, \text{ so } D_{15 \text{ filter}} > 5 \times 0.00055 = 0.0028 \text{ ft (0.83 mm)}$$

Therefore, with respect to the base material, the filter must satisfy:

$$D_{50 \text{ filter}} < 0.064 \text{ ft}$$

$$0.0028 \text{ ft} < D_{15 \text{ filter}} < 0.22 \text{ ft}$$

Second, determine the required filter dimensions with respect to the riprap,

$$\frac{D_{50 \text{ riprap}}}{D_{50 \text{ filter}}} < 40, \text{ so } D_{50 \text{ filter}} > \frac{0.66}{40} = 0.016 \text{ ft (4.9 mm)}$$

$$\frac{D_{15 \text{ riprap}}}{D_{15 \text{ filter}}} < 40, \text{ so } D_{15 \text{ filter}} > \frac{0.33}{40} = 0.0082 \text{ ft (2.5 mm)}$$

$$\frac{D_{15} \text{ riprap}}{D_{85} \text{ filter}} < 5, \text{ so } D_{85} \text{ filter} > \frac{0.33}{5} = 0.066 \text{ ft (20 mm)}$$

$$\frac{D_{15} \text{ riprap}}{D_{15} \text{ filter}} > 5, \text{ so } D_{15} \text{ filter} < \frac{0.33}{5} = 0.066 \text{ ft (20 mm)}$$

With respect to the riprap:

$$0.0082 \text{ ft} < \begin{matrix} D_{50} \text{ filter} > 0.016 \text{ ft} \\ D_{15} \text{ filter} < 0.066 \text{ ft} \\ D_{85} \text{ filter} > 0.066 \text{ ft} \end{matrix}$$

Combining:

$$\begin{aligned} 0.0082 \text{ ft} < D_{15} \text{ filter} < 0.022 \text{ ft} & (2.5 \text{ mm} < D_{15} \text{ filter} < 6.7 \text{ mm}) \\ 0.016 \text{ ft} < D_{50} \text{ filter} < 0.064 \text{ ft} & (4.9 \text{ mm} < D_{50} \text{ filter} < 19.5 \text{ mm}) \\ D_{85} \text{ filter} > 0.066 \text{ ft} & (D_{85} \text{ filter} > 20.0 \text{ mm}) \end{aligned}$$

The gradation requirements for the resulting granular filter blanket specifications are illustrated in figure 22.

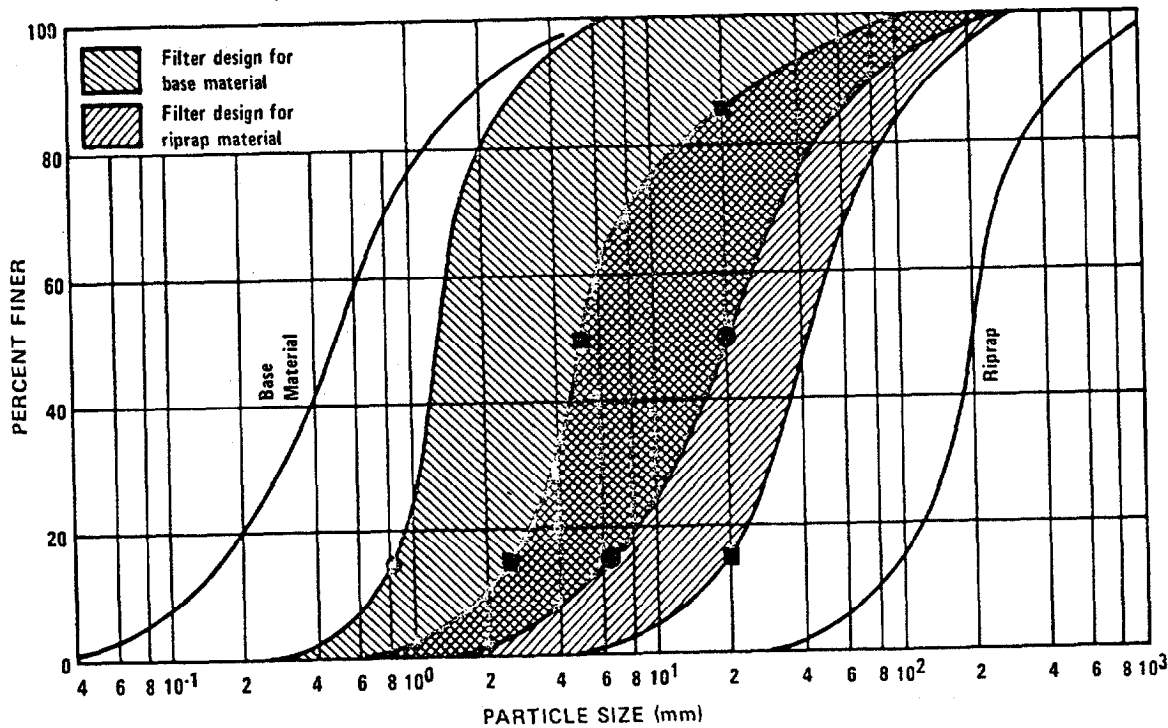


Figure 22. Gradations of Granular Filter Blanket for Example 8.

Worksheet for Flexible Lining Design

DESIGNER: _____ DATE: _____

PROJECT: _____

STATION: _____ TO STATION: _____

DRAINAGE AREA: _____ ACRES

DESIGN FLOW: Q _____ = _____ ft^3/sec

DESIGN FLOW FOR TEMPORARY LINING: Q _____ = _____ ft^3/sec

CHANNEL SLOPE (S) : _____ ft/ft

CHANNEL DESCRIPTION:

LINING	Q	τ_p (1)	d_i (2)	R (3)	n (4)	d (5)	$\tau_d = \gamma d S$ (6)	REMARKS

- (1) Table 2
- (2) For vegetation, estimate initial depth
For other liners, select range from table 3
- (3) Vegetation only, chart 4 for trapezoidal channels
- (4) For vegetation, charts 5-9
For other liners, table 3
- (5) Normal depth, chart 3 (d must be in d_i range)
- (6) τ_d must be $\leq \tau_p$
- (7) Check for steep side slopes and channel bends

Figure 23. Worksheet for Flexible Lining Design

Table 1. Classification of Vegetal Covers as to Degree of Retardance. (4)

Retardance Class	Cover	Condition
A	Weeping lovegrass	Excellent stand, tall (average 30") (76 cm)
	Yellow bluestem	
	Ischaemum	Excellent stand, tall (average 36") (91 cm)
B	Kudzu	Very dense growth, uncut
	Bermuda grass	Good stand, tall (average 12") (30 cm)
	Native grass mixture (little bluestem, blue-stem, blue gamma, and other long and short midwest grasses).....	Good stand, unmowed
	Weeping lovegrass	Good stand, tall (average 24") (61 cm)
	Lespedeza sericea	Good stand, not woody, tall (average 19") (48 cm)
	Alfalfa	Good stand, uncut (average 11") (28 cm)
	Weeping lovegrass	Good stand, unmowed (average 13") (33 cm)
	Kudzu	Dense growth, uncut
	Blue gamma	Good stand, uncut (average 13") (28 cm)
C	Crabgrass	Fair stand, uncut (10 to 48") (25 to 120 cm)
	Bermuda grass	Good stand, mowed (average 6") (15 cm)
	Common lespedeza	Good stand, uncut (average 11") (28 cm)
	Grass-legume mixture--summer (orchard grass, redtop, Italian ryegrass, and common lespedeza)....	Good stand, uncut (6 to 8 inches) (15 to 20 cm)
	Centipedegrass.....	Very dense cover (average 6 inches) (15 cm)
	Kentucky bluegrass.....	Good stand, headed (6 to 12 inches (15 to 30 cm)
D	Bermuda grass.....	Good stand, cut to 2.5-inch height (6 cm)
	Common lespedeza	Excellent stand, uncut (average 4.5") (11 cm)
	Buffalo grass	Good stand, uncut (3 to 6 inches (8 to 15 cm)
	Grass-legume mixture--fall, spring (orchard grass, redtop, Italian ryegrass, and common lespedeza).....	Good stand, uncut (4 to 5 inches) (10 to 13 cm)
	Lespedeza sericea	After cutting to 2-inch height (5 cm)
		Very good stand before cutting
E	Bermuda grass	Good stand, cut to 1.5 inch height (4 cm)
	Bermuda grass	Burned stubble

NOTE: Covers classified have been tested in experimental channels. Covers were green and generally uniform.

Table 2. Permissible Shear Stresses for Lining Materials.

Lining Category	Lining Type	Permissible Unit Shear Stress ¹	
		(lb/ft ²)	(Kg/m ²)
Temporary*	Woven Paper Net	0.15	0.73
	Jute Net	0.45	2.20
	Fiberglass Roving:		
	Single	0.60	2.93
	Double	0.85	4.15
	Straw with Net	1.45	7.08
	Curled Wood Mat	1.55	7.57
	Synthetic Mat	2.00	9.76
Vegetative	Class A	3.70	18.06
	Class B	2.10	10.25
	Class C	1.00	4.88
	Class D	0.60	2.93
	Class E	0.35	1.71
Gravel Riprap	1-inch	0.33	1.61
	2-inch	0.67	3.22
Rock Riprap	6-inch	2.00	9.76
	12-inch	4.00	19.52
Bare Soil	Non-cohesive	See Chart 1	
	Cohesive	See Chart 2	

¹Based on data in (5, 8, 13, 14, 15).

*Some "temporary" linings become permanent when buried.

Table 3. Manning's Roughness Coefficients.

Lining Category	Lining Type	n - value ¹		
		Depth Ranges		
		0-0.5 ft (0-15 cm)	0.5-2.0 ft (15-60 cm)	>2.0 ft (> 60 cm)
Rigid	Concrete	0.015	0.013	0.013
	Grouted Riprap	0.040	0.030	0.028
	Stone Masonry	0.042	0.032	0.030
	Soil Cement	0.025	0.022	0.020
	Asphalt	0.018	0.016	0.016
Unlined	Bare Soil	0.023	0.020	0.020
	Rock Cut	0.045	0.035	0.025
Temporary*	Woven Paper Net	0.016	0.015	0.015
	Jute Net	0.028	0.022	0.019
	Fiberglass Roving	0.028	0.021	0.019
	Straw with Net	0.065	0.033	0.025
	Curled Wood Mat	0.066	0.035	0.028
	Synthetic Mat	0.036	0.025	0.021
Gravel Riprap	1-inch (2.5-cm) D ₅₀	0.044	0.033	0.030
	2-inch (5-cm) D ₅₀	0.066	0.041	0.034
Rock Riprap	6-inch (15-cm) D ₅₀	0.104	0.069	0.035
	12-inch (30-cm) D ₅₀	--	0.078	0.040

¹Based on data in (5, 8, 13, 14, and 15).

Note: Values listed are representative values for the respective depth ranges. Manning's roughness coefficients, n, vary with the flow depth. See Appendix B.

*Some "temporary" linings become permanent when buried.

Chart 1

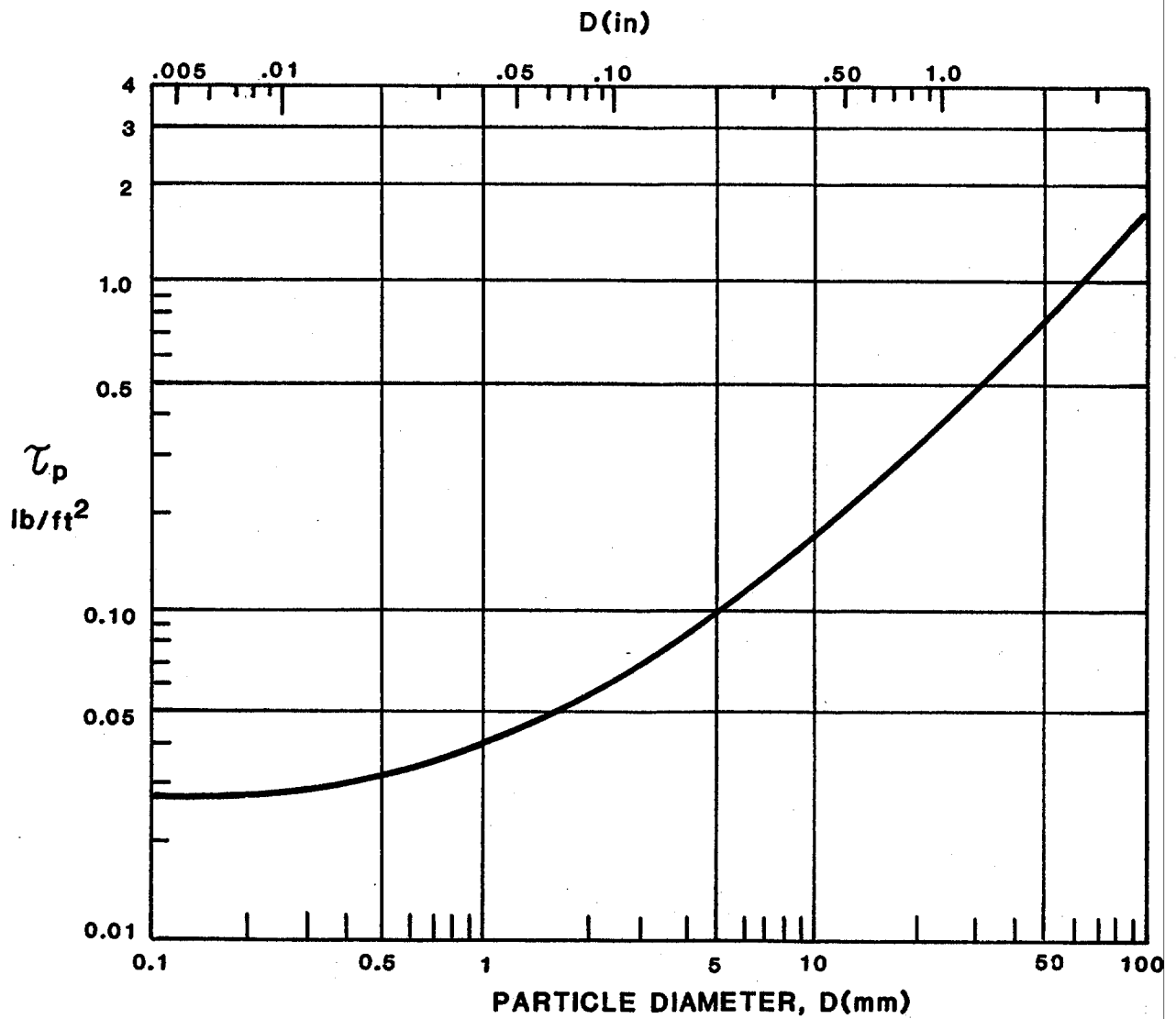


Chart 1. Permissible shear stress for non-cohesive soils.(after 15)

Chart 2

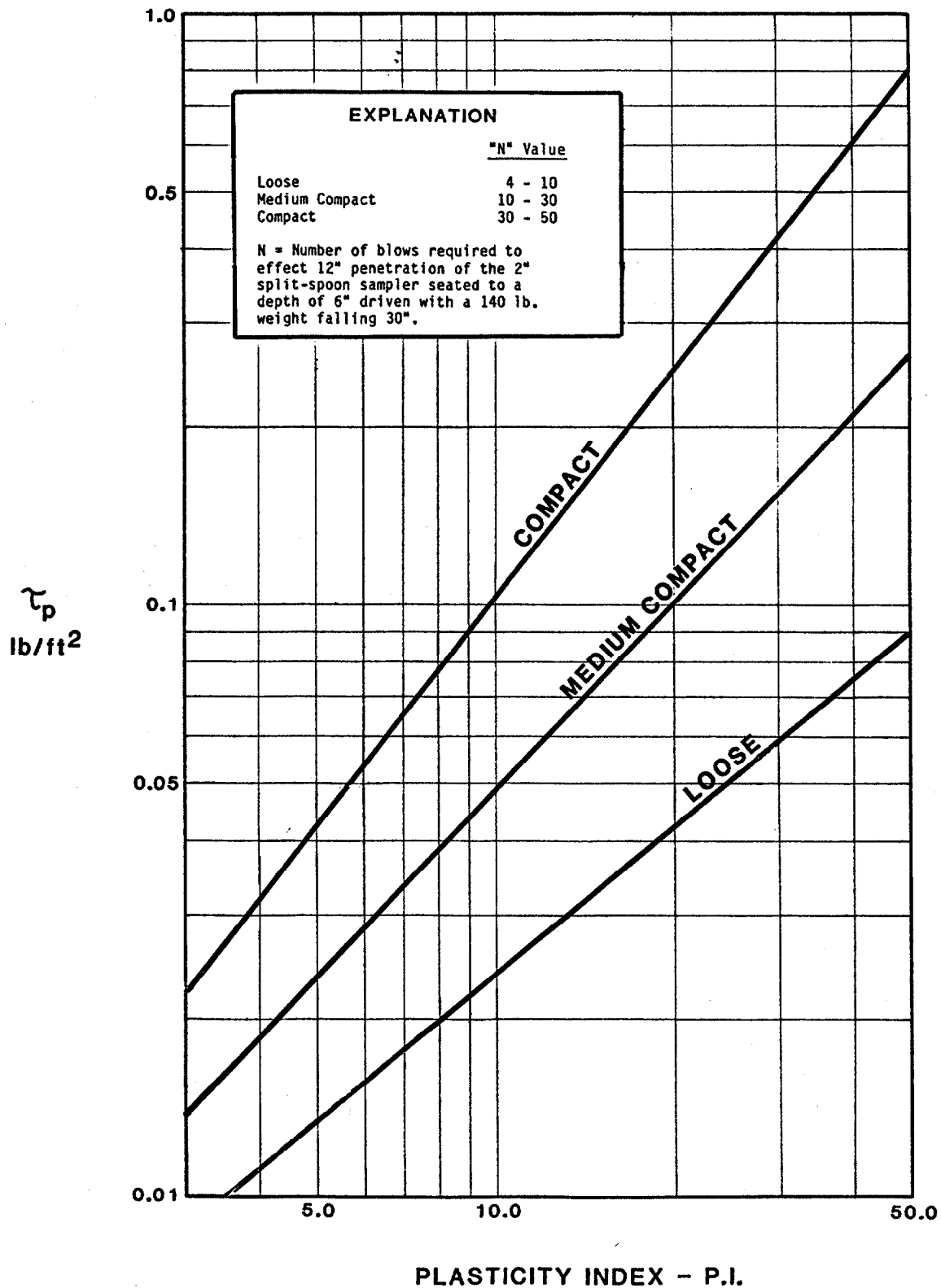
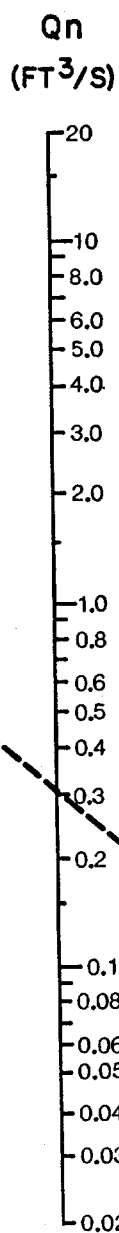
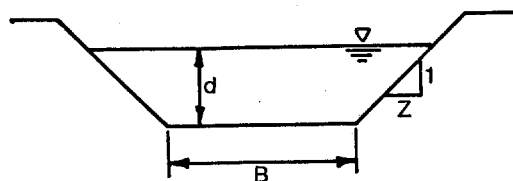


Chart 2. Permissible shear stress for cohesive soils.
(after 16)

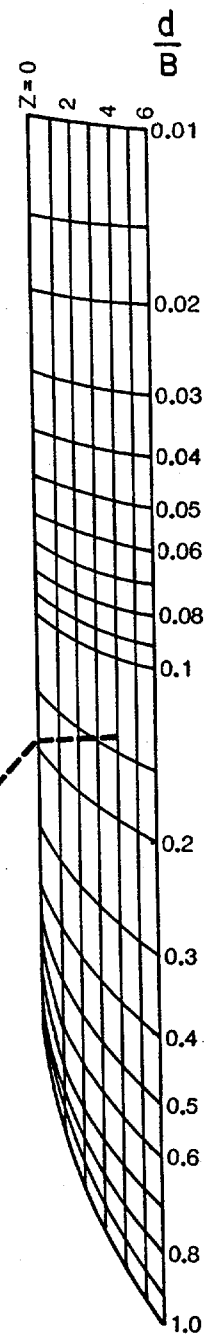
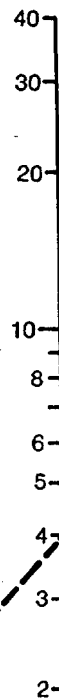
Chart 3

NOTE: Project horizontally from $Z=0$ scale to obtain values for $Z=1$ to 6



TURNING LINE

**B
(FT)**



EXAMPLE:

GIVEN:
 $S = 0.01$
 $Q = 10 \text{ FT}^3/\text{S}$
 $n = 0.03$
 $B = 4 \text{ FT}$
 $Z = 4$

FIND:
 d

SOLUTION:
 $Qn = 0.3$
 $d/B = 0.14$
 $d = 0.14(4) = 0.56 \text{ FT}$

Chart 3. Solution of Manning's equation for channels of various side slopes. (after 17)

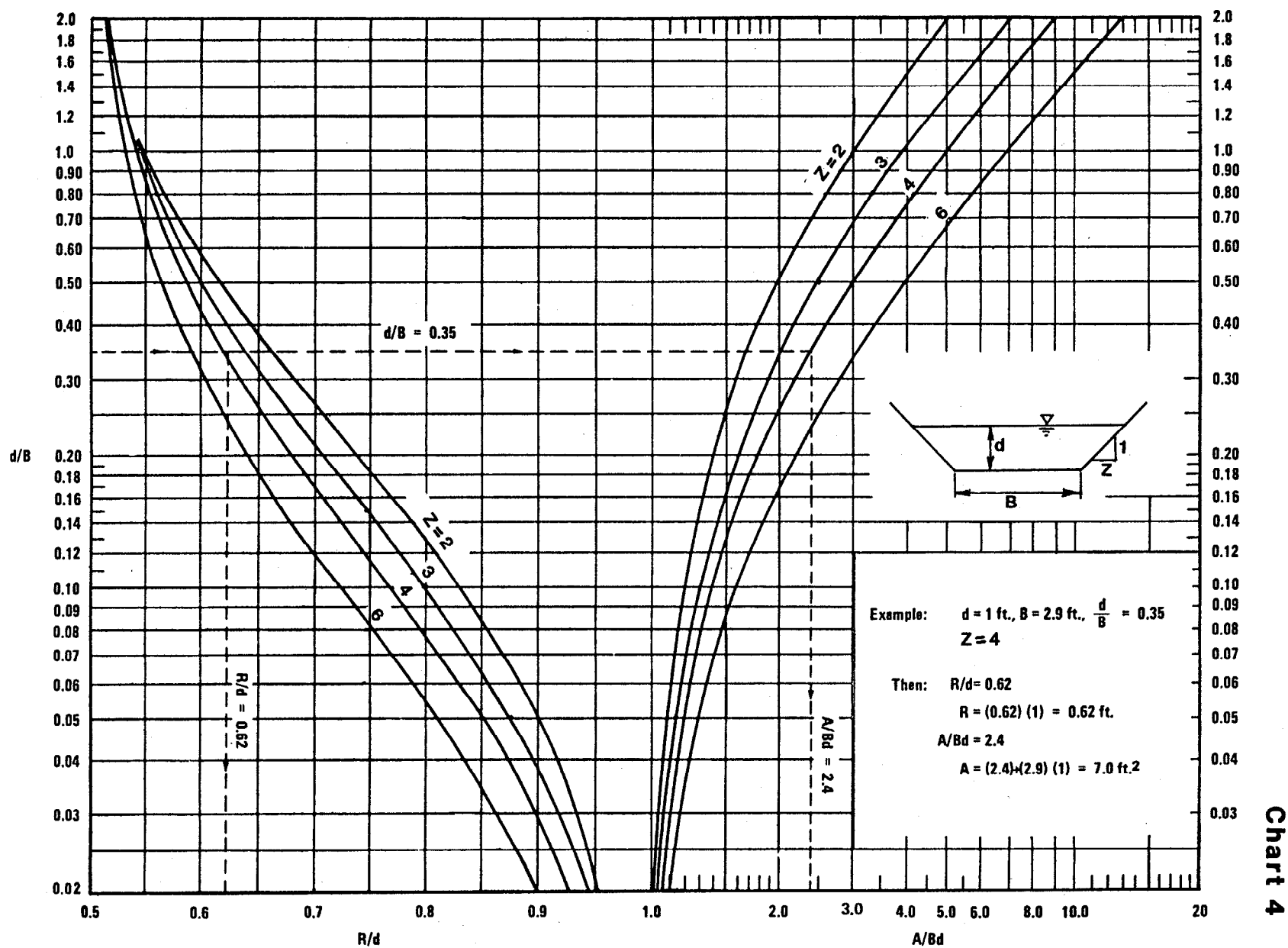
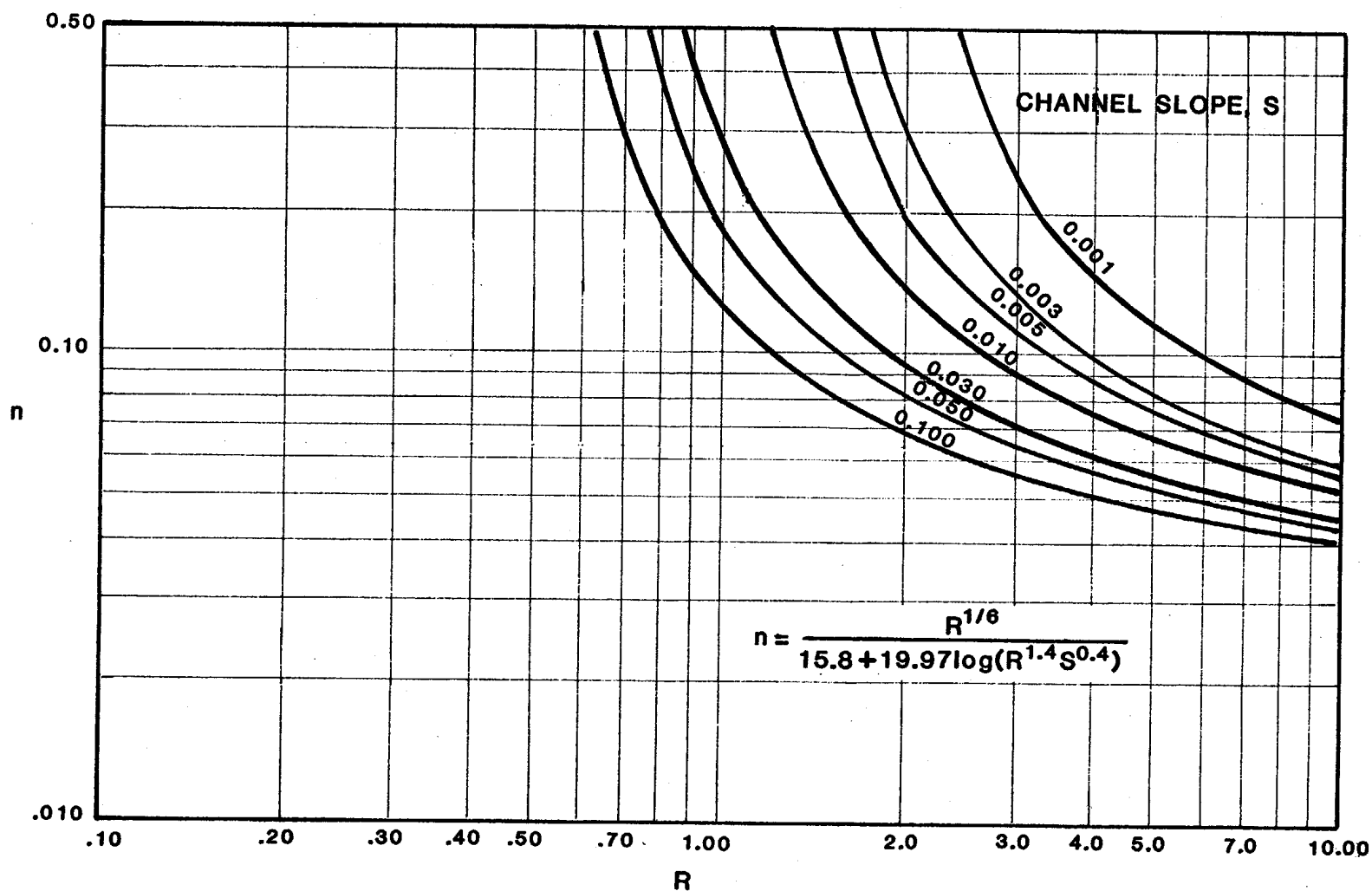
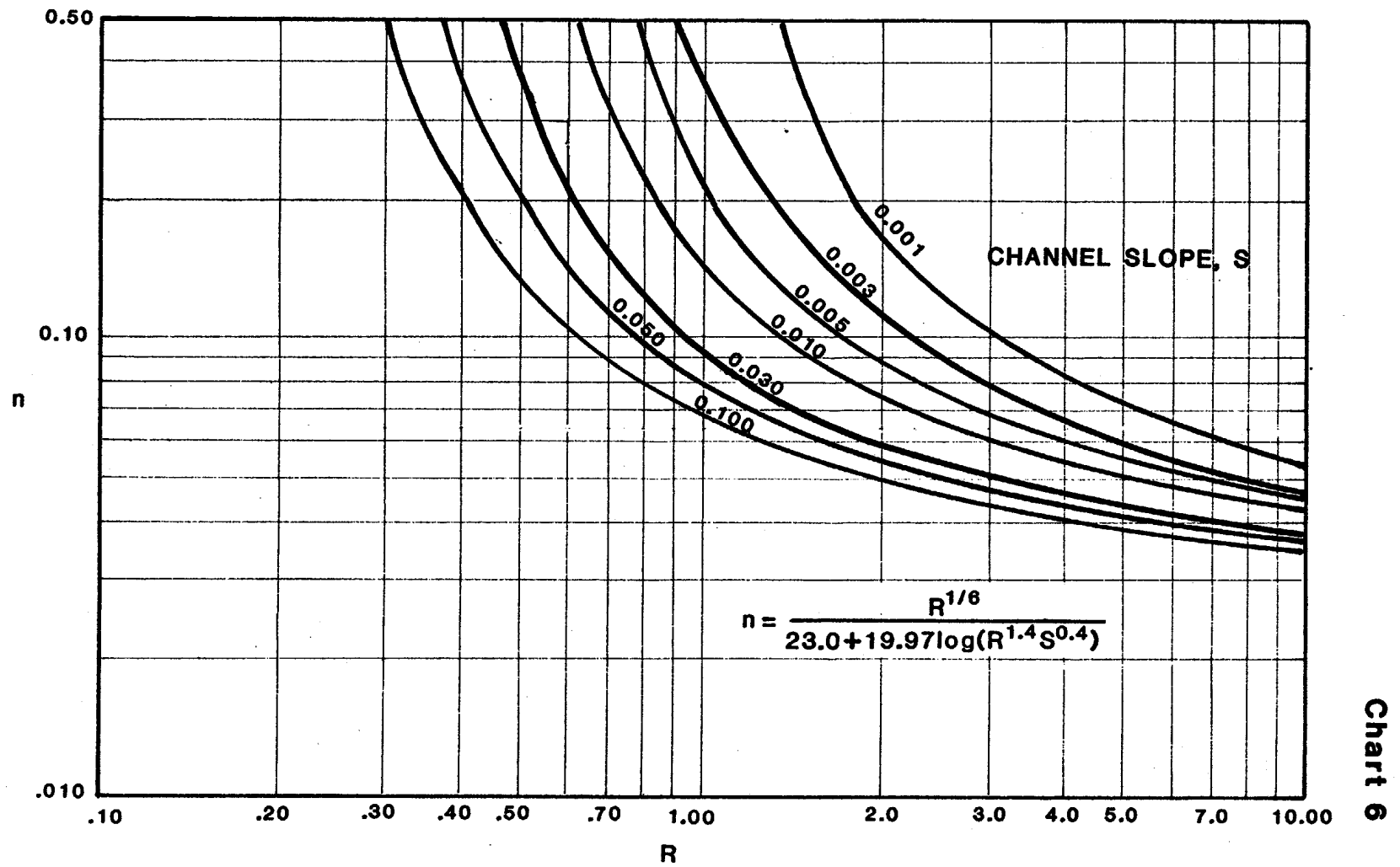


Chart 4. Geometric design chart for trapezoidal channels.



**Chart 5. Manning's n versus hydraulic radius, R , for class A vegetation.
(after 5)**



**Chart 6. Manning's n versus hydraulic radius, R , for class B vegetation.
(after 5)**

Chart 7

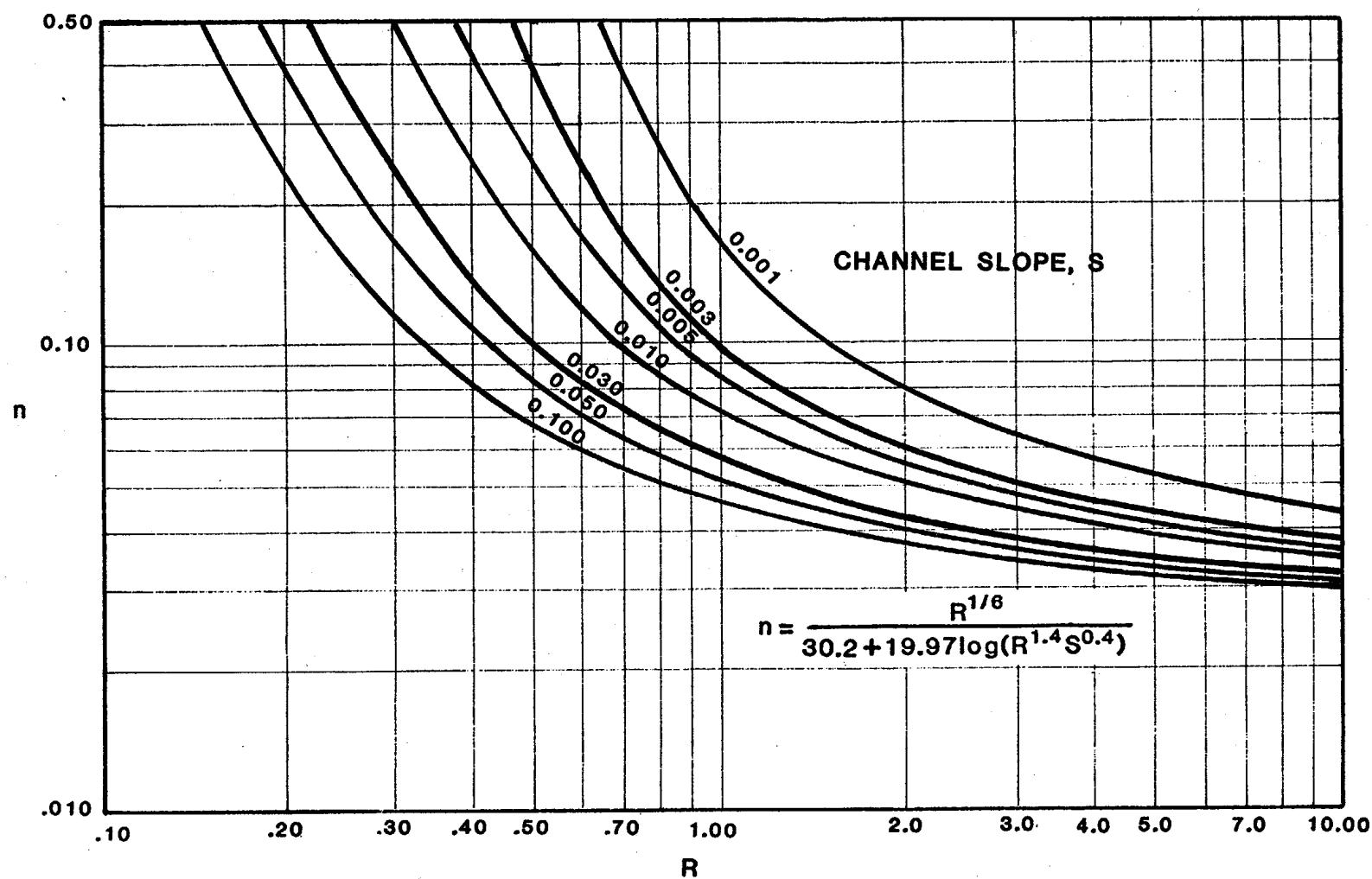


Chart 7. Manning's n versus hydraulic radius, R , for class C vegetation.
(after 5)

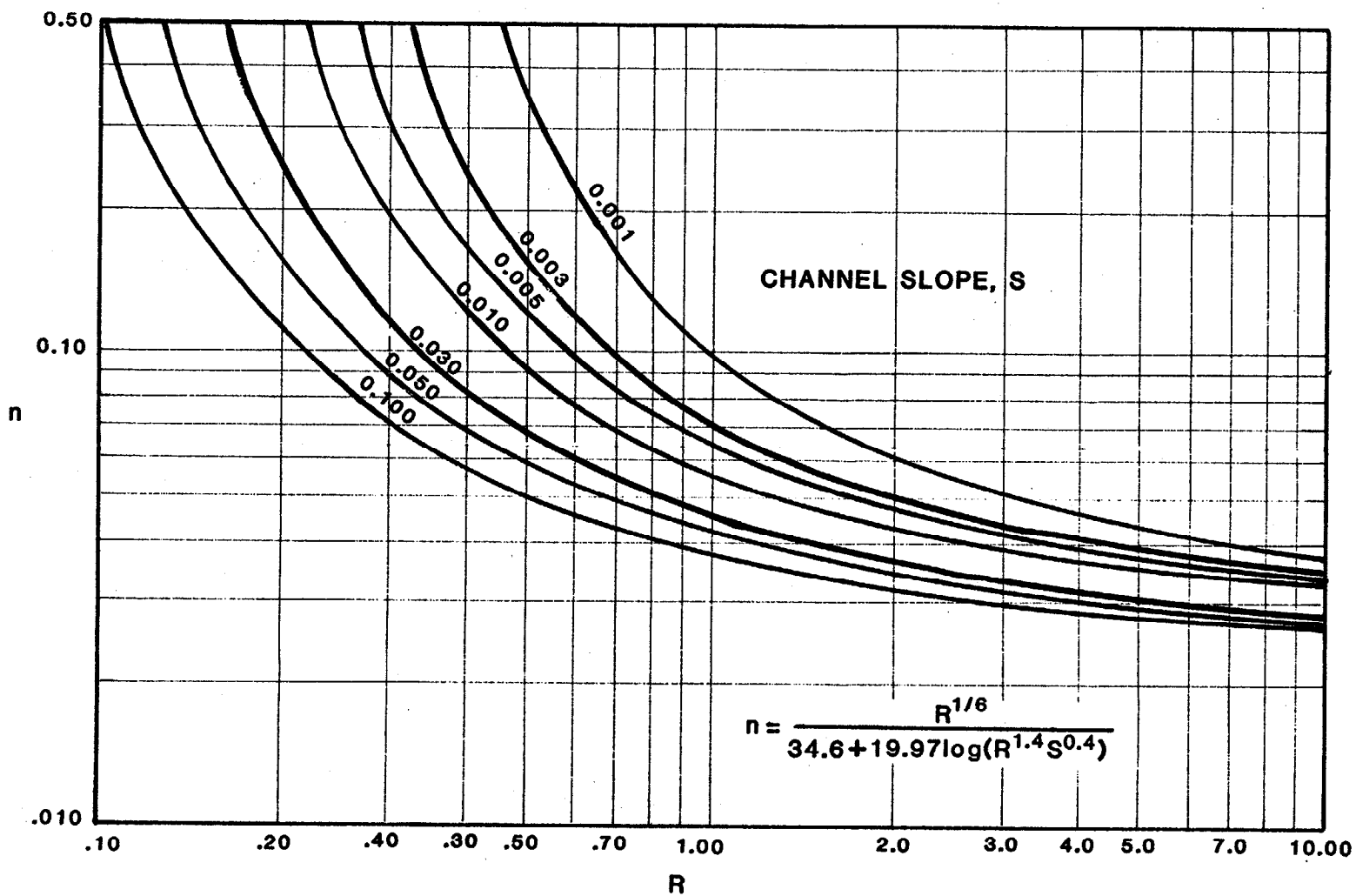


Chart 8

**Chart 8. Manning's n versus hydraulic radius, R , for class D vegetation.
(after 5)**

Chart 9

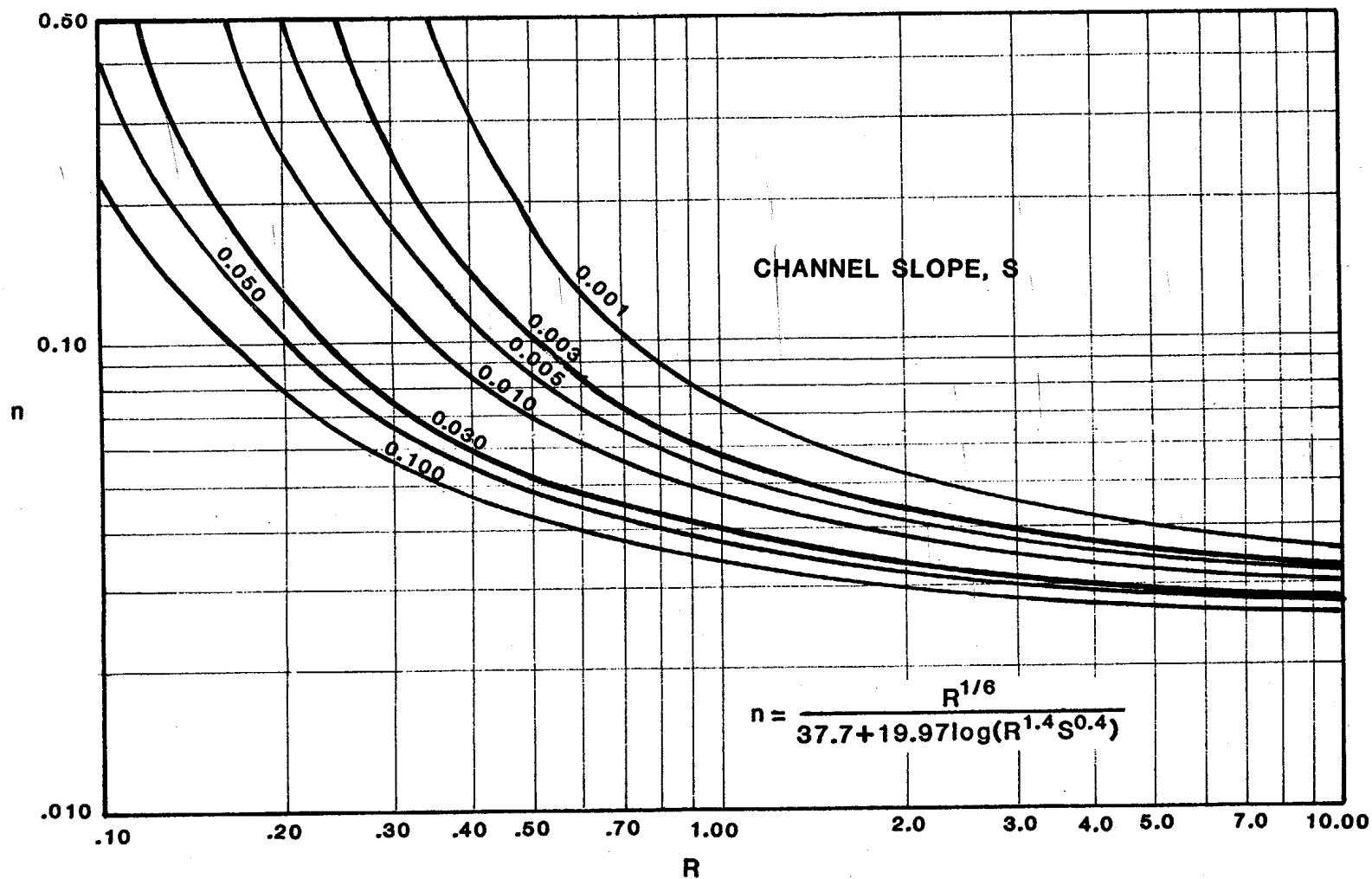


Chart 9. Manning's n versus hydraulic radius, R , for class E vegetation.
(after 5)

Chart 10

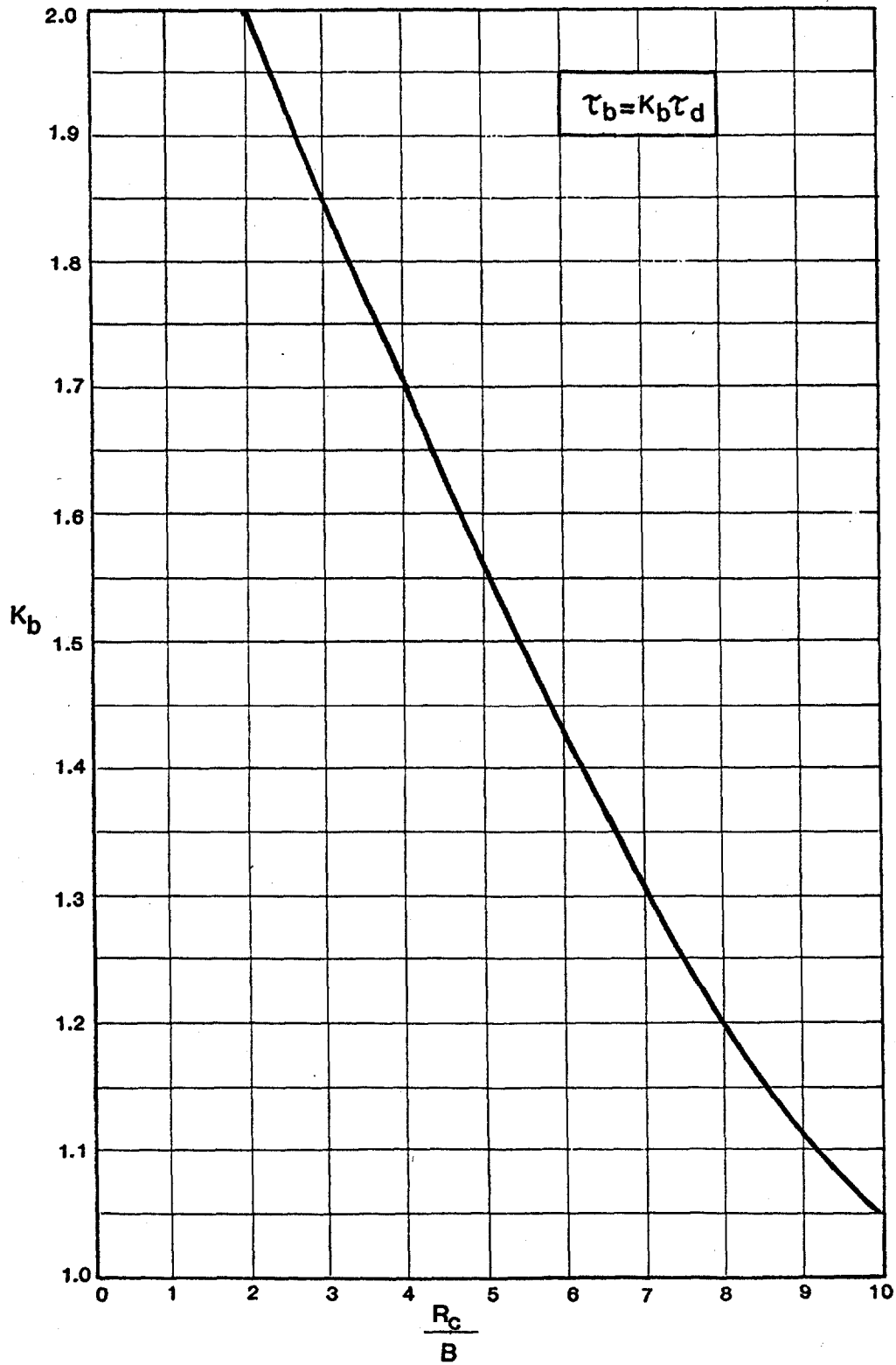
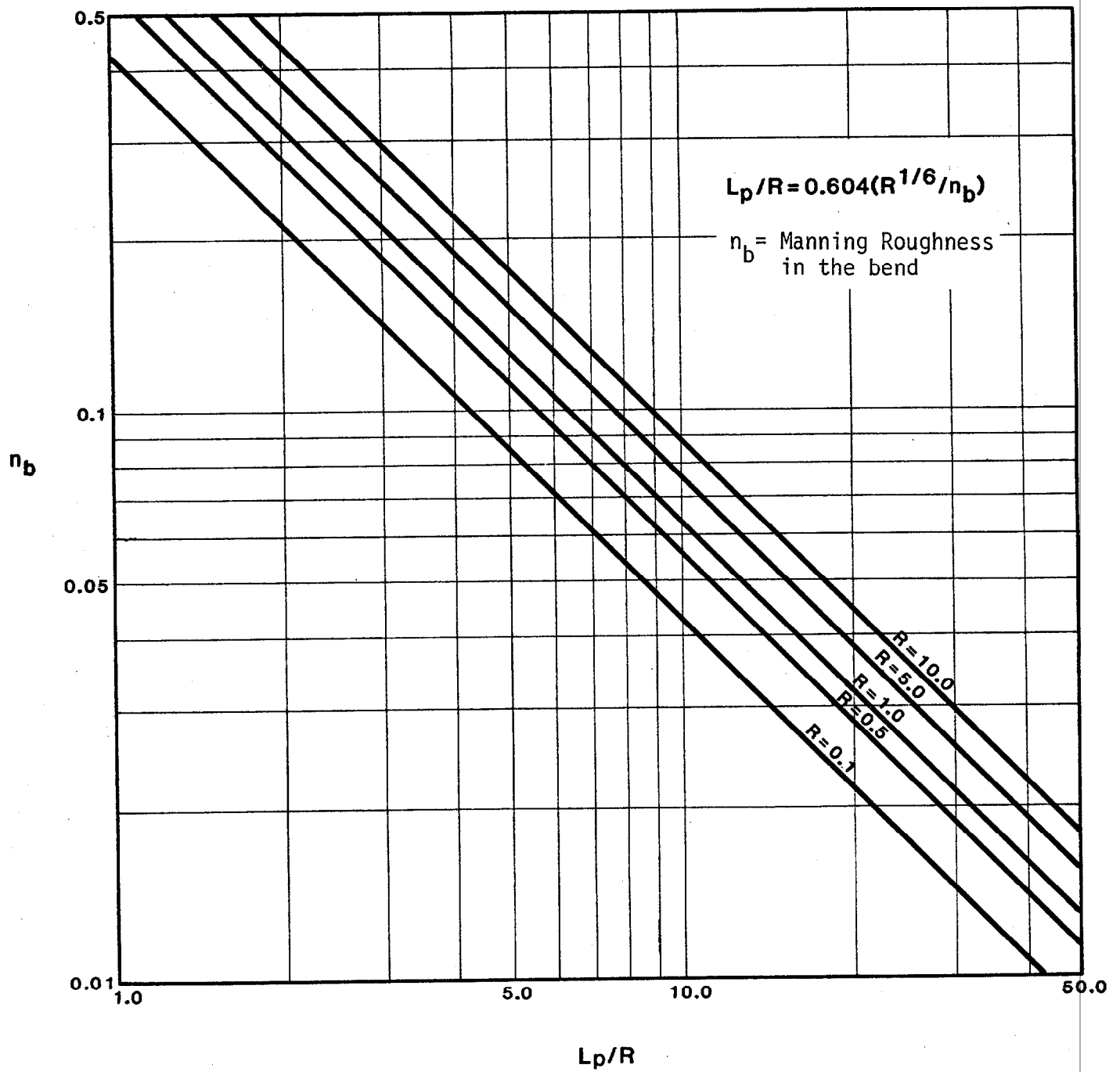


Chart 10. K_b factor for maximum shear stress on channel bends. (12)

Chart 11



**Chart 11. Protection length, L_p , downstream of channel bend.
(11)**

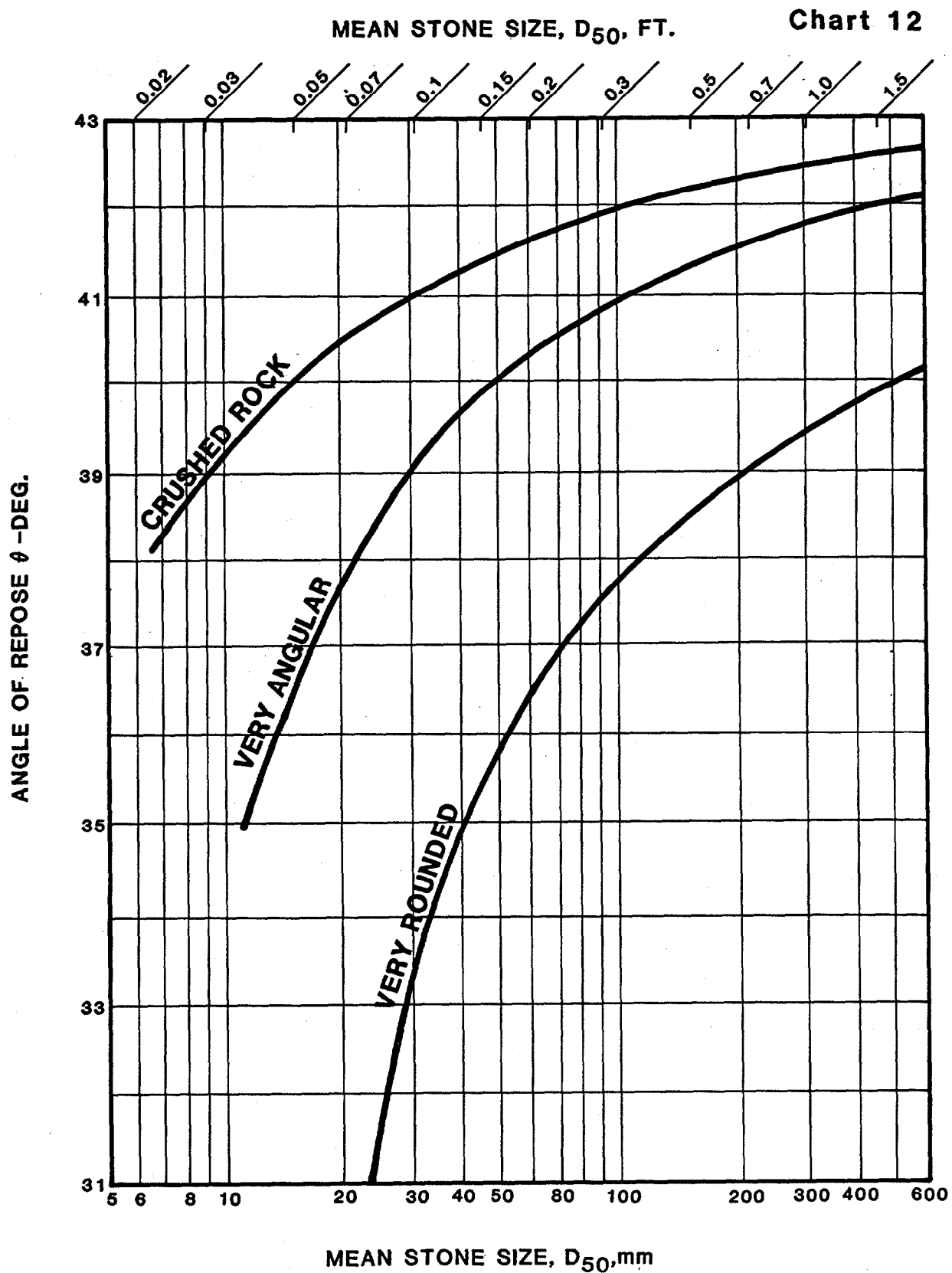


Chart 12. Angle of repose of riprap in terms of mean size and shape of stone.

Chart 13

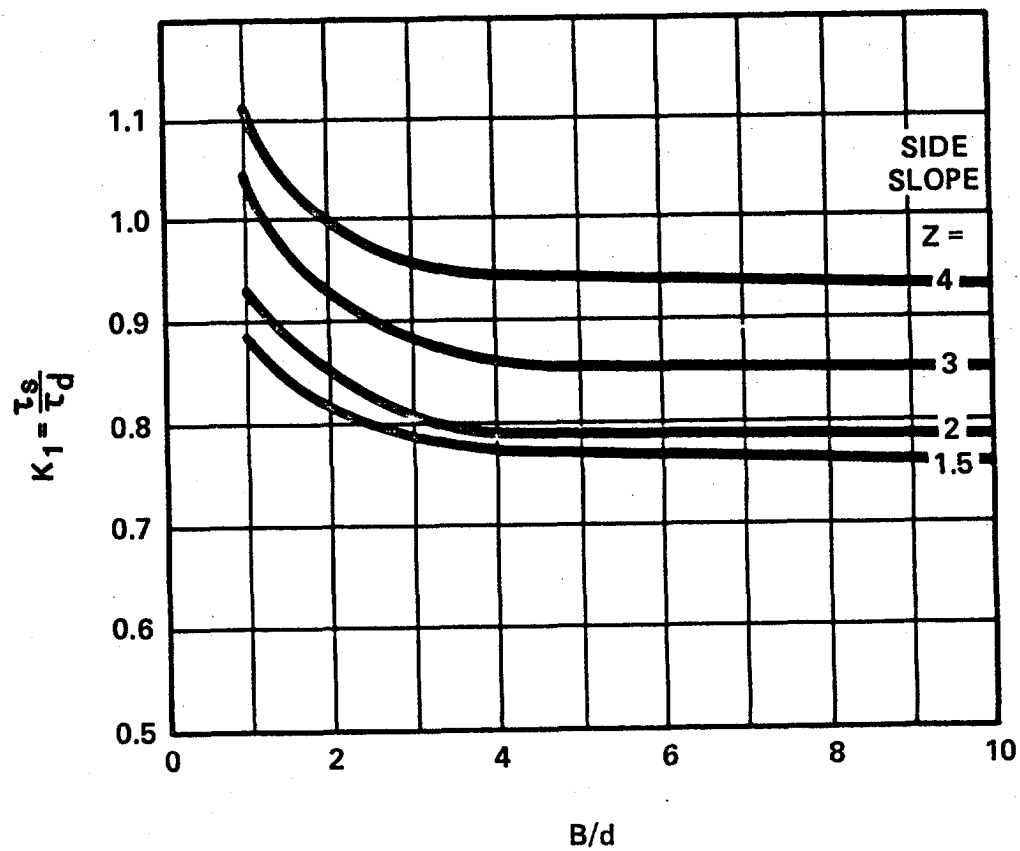


Chart 13. Channel side shear stress to bottom shear stress ratio, K_1 . (8)

Chart 14

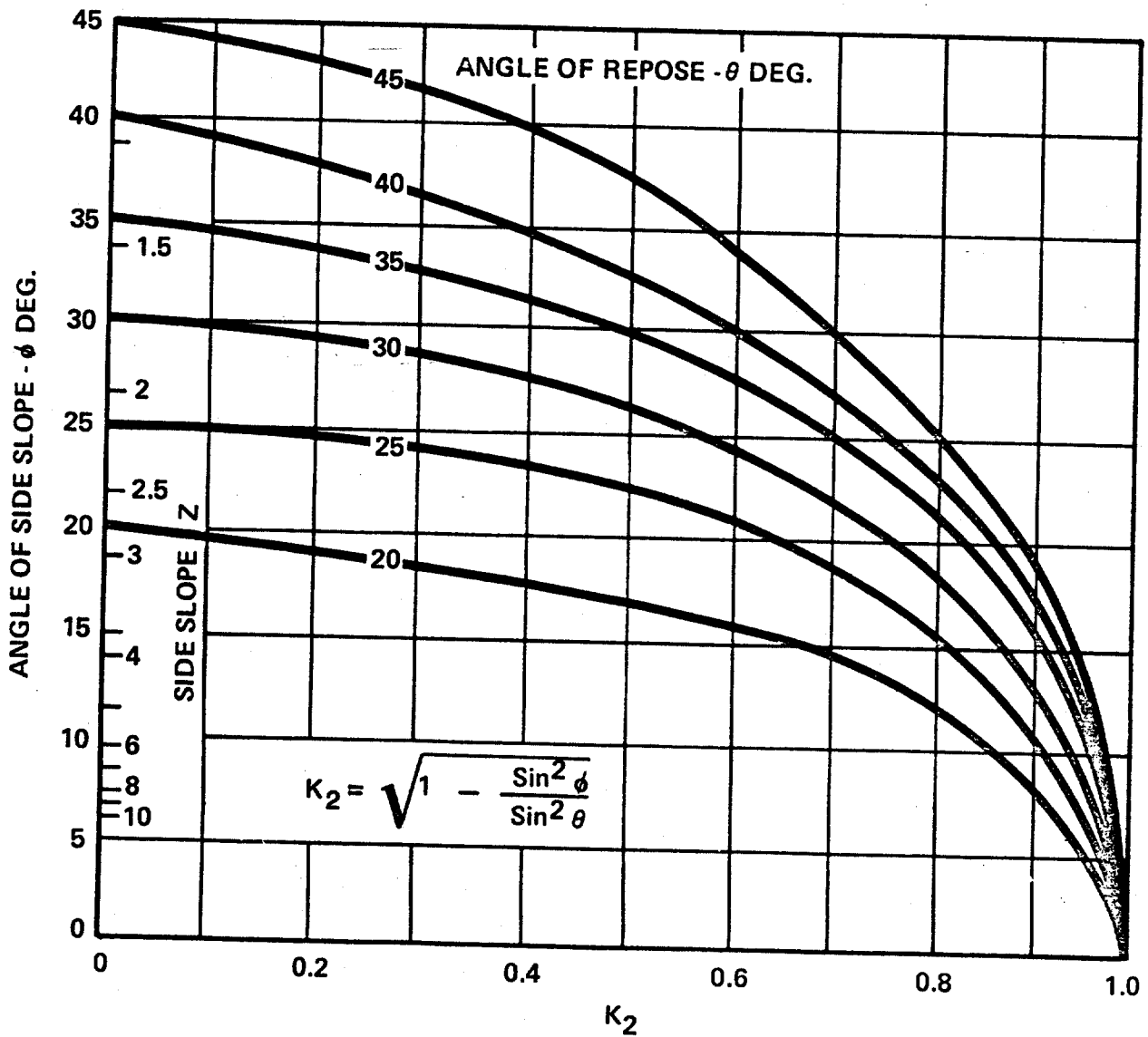


Chart 14. Tractive force ratio, K_2 . (8)

V. STEEP GRADIENT CHANNEL DESIGN

Achieving channel stability on steep gradients usually requires some type of channel lining except where the channels can be constructed in durable bedrock. This section outlines the design of two types of flexible channel linings for steep gradients, riprap, and gabion mattress. Because of the additional forces acting on riprap, results obtained using the previous design procedure should be compared to the steep gradient procedures when channel gradients approach 10 percent.

Rigid channel linings may be a more cost-effective alternative in the case of steep slope conditions. The size of riprap and gabion linings increases quickly as discharge and channel gradient increase. The decision to select a rigid or flexible lining may be based on other site conditions, such as foundation and maintenance requirements for the steep slope channel lining.

Steep Slope Design

Riprap stability on a steep slope depends on forces acting on an individual stone making up the riprap. The primary forces include the average weight of the stones and the lift and drag forces induced by the flow on the stones. On a steep slope, the weight of a stone has a significant component in the direction of flow (see figures in appendix C). Because of this force, a stone within the riprap will tend to move in the flow direction more easily than the same size stone on a mild gradient. Hence, for a given discharge, steep slope channels require larger stones to compensate for larger forces in the flow direction and higher shear stress. The riprap design procedure is based on the factor of safety method for riprap design, using a safety factor of 1.5. A description of the factor of safety method and the assumptions made in developing the design charts is presented in appendix C.

Gabion mattress stability on a steep slope is similar to that of riprap but because the stones are bound by wire mesh, they tend to act as a single unit. Movement of stones within a gabion is negligible. This permits use of smaller stone sizes compared to those required for loose riprap. Of course the stability of gabions depend on the integrity of the wire mesh. In streams with high sediment concentrations or with rocks moving along the bed of the channel, the wire mesh may be abraded and eventually fail. Under these conditions the gabion will no longer behave as a single unit but rather as individual stones. Applications of gabion mattresses and baskets under these conditions should be avoided. A worksheet is provided at the end of this chapter (figure 25) for carrying out design procedures in this chapter.

Other Considerations for Steep Slope Design

Channel Alignment and Freeboard. Bends should be avoided on steep gradient channels. A design requiring a bend in a steep channel should be reevaluated to eliminate the bend or designed using a culvert.

Extent of riprap or gabions on a steep gradient must be sufficient to protect transition regions of the channel both above and below the steep gradient section. The transition from a steep gradient to a culvert should allow for slight movement of riprap or slumping of a gabion mattress.

Riprap or gabions should be placed flush with the invert of a culvert. The break between the steep slope and culvert entrance should equal three to five times the mean rock diameter (or mattress thickness if gabions are used). The transition from a steep gradient channel to a mild gradient channel may require an energy dissipation structure such as a plunge pool. The transition from a mild gradient to a steep gradient should be protected against local scour upstream of the transition for a distance of approximately five times the uniform depth of flow in the downstream channel. (7)

Freeboard should equal the mean depth of flow, since wave height will reach approximately twice the mean depth. This freeboard height should be used for both temporary and permanent channel installations.

Gradation, Thickness, and Filter Requirements. Riprap gradation, thickness and filter requirements are the same as those for mild slopes. It is important to note that riprap thickness is measured normal to steep channel gradients. Also, the rock gradation used in gabion mattress must be such that larger stones do not protrude outside the mattress and smaller stones are retained by the wire mesh.

Design Procedures

A stepwise guideline with complete references to charts and figures is given for steep slope riprap and steep slope gabion mattress designs.

STEEP SLOPE RIPRAP DESIGN PROCEDURE

1. For given discharge and channel slope, enter chart 15 to 18 for correct channel shape and determine the flow depth and mean riprap size. For channel widths not given in charts 15 to 18, interpolate between charts to find the correct value. For channel bottom widths in excess of 6 feet, use the more detailed design procedures in Appendix C.
2. To determine flow depth and riprap size for side slopes greater than 3:1, use the following steps:
 - a. Find the flow depth using the formula:

$$d = \frac{A_3}{A_z} d_i \quad (14a)$$

where values of the A_3/A_z ratio are found from table 4 (the subscript refers to the side slope z-value) and d_i is the flow depth from the design charts.

- b. Find the riprap size using the formula:

$$D_{50} = \frac{d}{d_i} D_{50i} \quad (14b)$$

where d_i and D_{50i} are values from the design charts.

STEEP SLOPE GABION MATTRESS DESIGN

1. For given discharge and channel slope, enter chart 19 to 22 for correct channel shape and determine flow depth. For intermediate channel widths or side slopes, follow the interpolation procedures given in steep slope riprap design procedure. For channel bottom widths in excess of 6 feet, see Appendix C.
2. Determine the permissible shear stress for the gabion mattress rock fill size from Chart 23.
3. Determine the permissible shear stress for thickness of the gabion mattress from Chart 24.
4. The design permissible shear stress, τ_p , will be the larger of the two shear stress values determined in steps 2 and 3.
5. Calculate the maximum shear stress acting on the channel, τ_d .

$$\tau_d = \gamma d S \quad (5)$$

If $\tau_d > \tau_p$, the gabion mattress analyzed is not acceptable.

Example Problems

Example 9:

Determine the mean riprap size and flow depth for a steep gradient channel.

Given: $Q = 20 \text{ ft}^3/\text{sec}$
 $S = 0.15 \text{ ft/ft}$
 $B = 2 \text{ ft}$
 $Z = 3$

Find: Flow depth and mean riprap size.

Solution: Entering into chart 16, given $Q = 20 \text{ ft}^3/\text{sec}$ and $S = 0.15 \text{ ft/ft}$:

$$d = 0.75 \text{ ft}$$
$$D_{50} = 0.9 \text{ ft}$$

Example 10:

Determine the mean riprap size and flow depth for a steep gradient channel.

Given: $Q = 30 \text{ ft}^3/\text{sec}$
 $S = 0.15 \text{ ft/ft}$
 $B = 3.0 \text{ ft}$
 $Z = 3$

Find: Flow depth and mean riprap size.

Solution: (1) Enter into chart 16, for $B = 2.0$ given $Q = 30 \text{ ft}^3/\text{sec}$ and $S = 0.15 \text{ ft/ft}$,

$$\begin{aligned}d &= 0.92 \text{ ft} \\D_{50} &= 1.1 \text{ ft}\end{aligned}$$

Enter into chart 17, for $B = 4.0$ given $Q = 30 \text{ ft}^3/\text{sec}$ and $S = 0.15 \text{ ft/ft}$,

$$\begin{aligned}d &= 0.70 \text{ ft} \\D_{50} &= 0.9 \text{ ft}\end{aligned}$$

(2) Interpolating for a 3.0 ft bottom width gives,

$$\begin{aligned}d &= 0.81 \text{ ft} \\D_{50} &= 1.0 \text{ ft}\end{aligned}$$

Example 11:

Determine the mean riprap size and flow depth for a steep gradient channel.

Given: $Q = 20 \text{ ft}^3/\text{sec}$
 $S = 0.20 \text{ ft/ft}$
 $B = 2.0 \text{ ft}$
 $Z = 4$

Find: Flow depth and mean riprap size.

Solution: (1) Enter into chart 16, given $Q = 20 \text{ ft}^3/\text{sec}$ and $S = 0.20 \text{ ft/ft}$,

$$\begin{aligned}d &= 0.70 \text{ ft} \\D_{50} &= 1.2 \text{ ft}\end{aligned}$$

(2) Enter into table 4, given $d/B = 0.35$ and $Z = 4$:

$$A_3/A_4 = 0.85$$

Actual flow depth for 4:1 side slope,

$$\begin{aligned}d &= 0.85 \times 0.70 \\&= 0.60 \text{ ft}\end{aligned}$$

Actual riprap size for 4:1 side slope,

$$\begin{aligned}D_{50} &= (0.60/0.70) \times 1.2 \\&= 1.0 \text{ ft}\end{aligned}$$

Use of the worksheet for this problem is illustrated in figure 24.

Example 12:

Determine the flow depth and required thickness of a gabion mattress lining.

Given: $Q = 10 \text{ ft}^3/\text{sec}$
 $S = 0.12 \text{ ft/ft}$
 $B = 2.0 \text{ ft}$
 $Z = 3$
 $D_{50} = 0.5 \text{ ft}$

Find: Flow depth and gabion mattress thickness.

Solution: (1) From chart 20 given $Q = 10 \text{ ft}^3/\text{sec}$ and $S = 0.12 \text{ ft/ft}$,

$$d = 0.55 \text{ ft}$$

(2) Calculate the maximum shear stress from equation 5,

$$\begin{aligned}\tau_d &= \gamma d S \\ &= 62.4 \times 0.55 \times 0.12 \\ &= 4.1 \text{ lb/ft}^2\end{aligned}$$

(3) Permissible shear stress for rockfill size from chart 23,

$$\tau_p = 3.8 \text{ lb/ft}^2$$

Permissible shear stress for a 0.75-foot mattress thickness from chart 24,

$$\tau_p = 4.5 \text{ lb/ft}^2$$

Use $\tau_p = 4.5 \text{ lb/ft}^2$ for design.

(4) The gabion mattress 0.75-foot thick is acceptable, since

$$\tau_d = 4.1 < 4.5 = \tau_p$$

Use of the worksheet for this problem is illustrated in figure 24.

Worksheet for Steep Slope Channel Design

DESIGNER: _____ DATE: _____

PROJECT: Example Problems 11 & 12

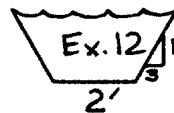
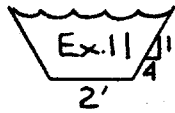
STATION: _____ TO STATION: _____

DRAINAGE AREA: _____ ACRES

DESIGN FLOW: Q _____ = 20 ft^3/sec (10 for Ex.12)

CHANNEL SLOPE (S) : 0.20 ft/ft (0.12 for Ex.12)

CHANNEL DESCRIPTION:



RIPRAP (Example 11)

d_i	D_{50i}	z	A_3/A_2	d	D_{50}	REMARKS
(1)	(1)	(2)	(3)	(4)	(5)	
0.7	1.2	4	.85	0.6	1.0	

GABION (Example 12)

Rock Fill Size	d_i	z	A_3/A_2	d	τ_p Rock	Mattress Thickness	τ_p Mattress	τ_p	$\tau_d = \gamma_d S$
(6)	(6)	(2)	(3)	(4)	(7)		(8)	(9)	(10)
0.5'	.55	3	1	.55	3.8	9"	4.5	4.5	4.1
									OK

(1) Charts 15-18

(2) side slope ($z:1$)

(3) Table 4

(4) $d = (A_3/A_2)d_i$

(5) $D_{50} = (d/d_i)D_{50i}$

(6) Charts 19-22

(7) Chart 23

(8) Chart 24

(9) τ_p = the larger of (7) or (8)

(10) τ_d must be $\leq \tau_p$

Figure 24. Worksheet for Example Problems 11 and 12

Worksheet for Steep Slope Channel Design

DESIGNER: _____ DATE: _____

PROJECT: _____

STATION: _____ TO STATION: _____

DRAINAGE AREA: _____ ACRES

DESIGN FLOW: Q _____ = _____ ft^3/sec

CHANNEL SLOPE (S) : _____ ft/ft

CHANNEL DESCRIPTION:

RIPRAP

d_i	D_{50i}	z	A_3/A_z	d	D_{50}	REMARKS
(1)	(1)	(2)	(3)	(4)	(5)	

GABION

Rock Fill Size	d_i	z	A_3/A_z	d	τ_p Rock	Mattress Thickness	τ_p Mattress	τ_p	$\tau_d = \gamma d S$
	(6)	(2)	(3)	(4)	(7)		(8)	(9)	(10)

(1) Charts 15-18

(2) side slope ($z:1$)

(3) Table 4

(4) $d = (A_3/A_z)d_i$

(5) $D_{50} = (d/d_i)D_{50i}$

(6) Charts 19-22

(7) Chart 23

(8) Chart 24

(9) τ_p = the larger of (7) or (8)

(10) τ_d must be $\leq \tau_p$

Figure 25. Worksheet for Steep Slope Channel Design

Table 4. Values of A_3/A_z for Selected Side Slopes and Depth to Bottom Width Ratios.¹

d/B	A_3/A_z				
	2:1	3:1	4:1	5:1	6:1
0.10	1.083	1.000	0.928	0.866	0.812
0.20	1.142	1.000	0.888	0.800	0.727
0.30	1.187	1.000	0.853	0.760	0.678
0.40	1.222	1.000	0.846	0.733	0.647
0.50	1.250	1.000	0.833	0.714	0.625
0.60	1.272	1.000	0.823	0.700	0.608
0.70	1.291	1.000	0.815	0.688	0.596
0.80	1.307	1.000	0.809	0.680	0.586
0.90	1.321	1.000	0.804	0.672	0.578
1.00	1.333	1.000	0.800	0.666	0.571
1.10	1.343	1.000	0.796	0.661	0.565
1.20	1.352	1.000	0.793	0.657	0.561
1.30	1.361	1.000	0.790	0.653	0.556
1.40	1.368	1.000	0.787	0.650	0.553
1.50	1.378	1.000	0.785	0.647	0.550
1.60	1.381	1.000	0.783	0.644	0.547
1.70	1.386	1.000	0.782	0.642	0.544
1.80	1.391	1.000	0.780	0.640	0.542
1.90	1.395	1.000	0.779	0.638	0.540
2.00	1.400	1.000	0.777	0.636	0.538

¹ Based on the following equation:

$$A_3/A_z = \frac{1 + 3(d/B)}{1 + Z(d/B)}$$

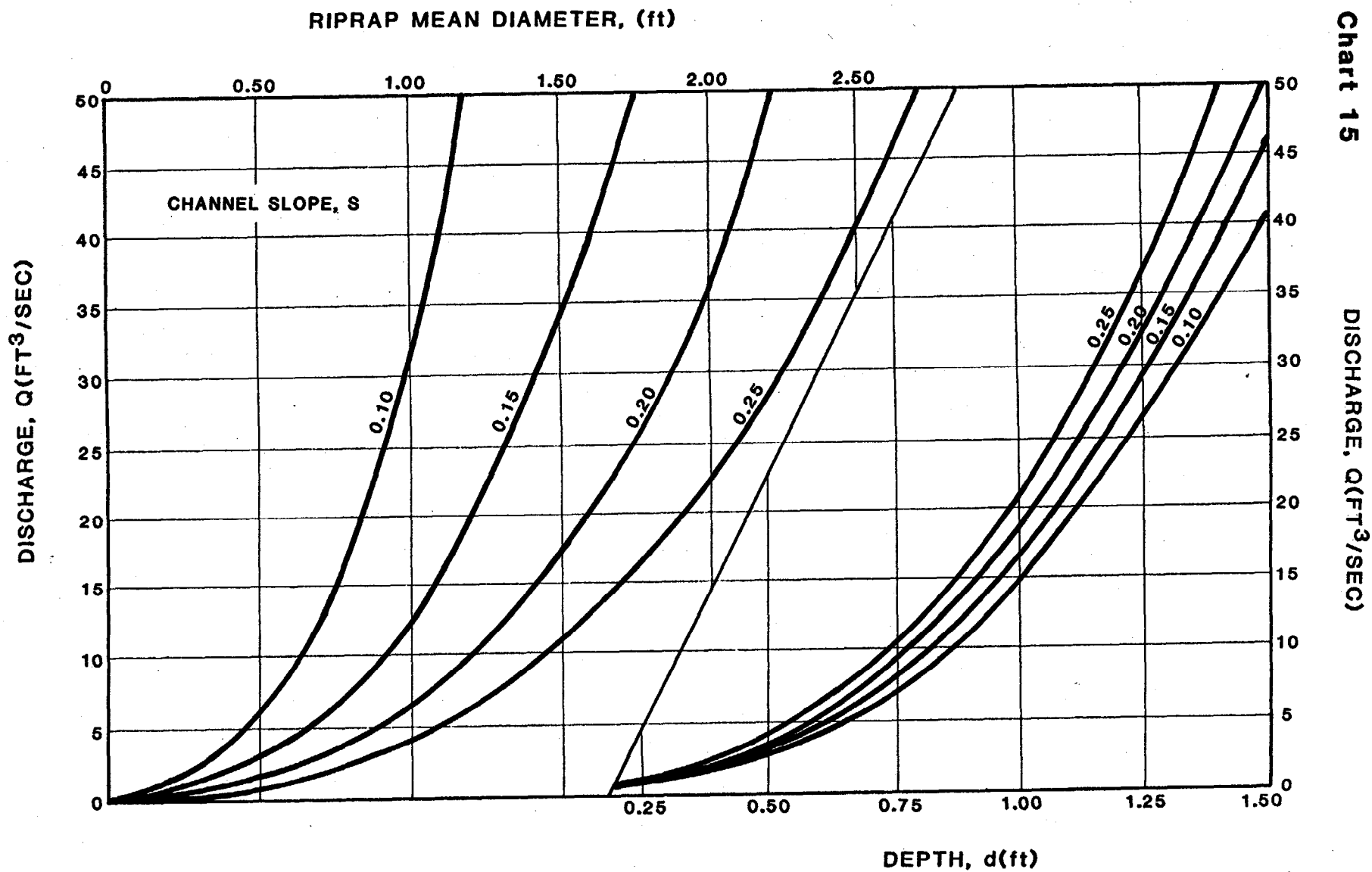


Chart 15. Steep slope riprap design, triangular channel $Z=3$.

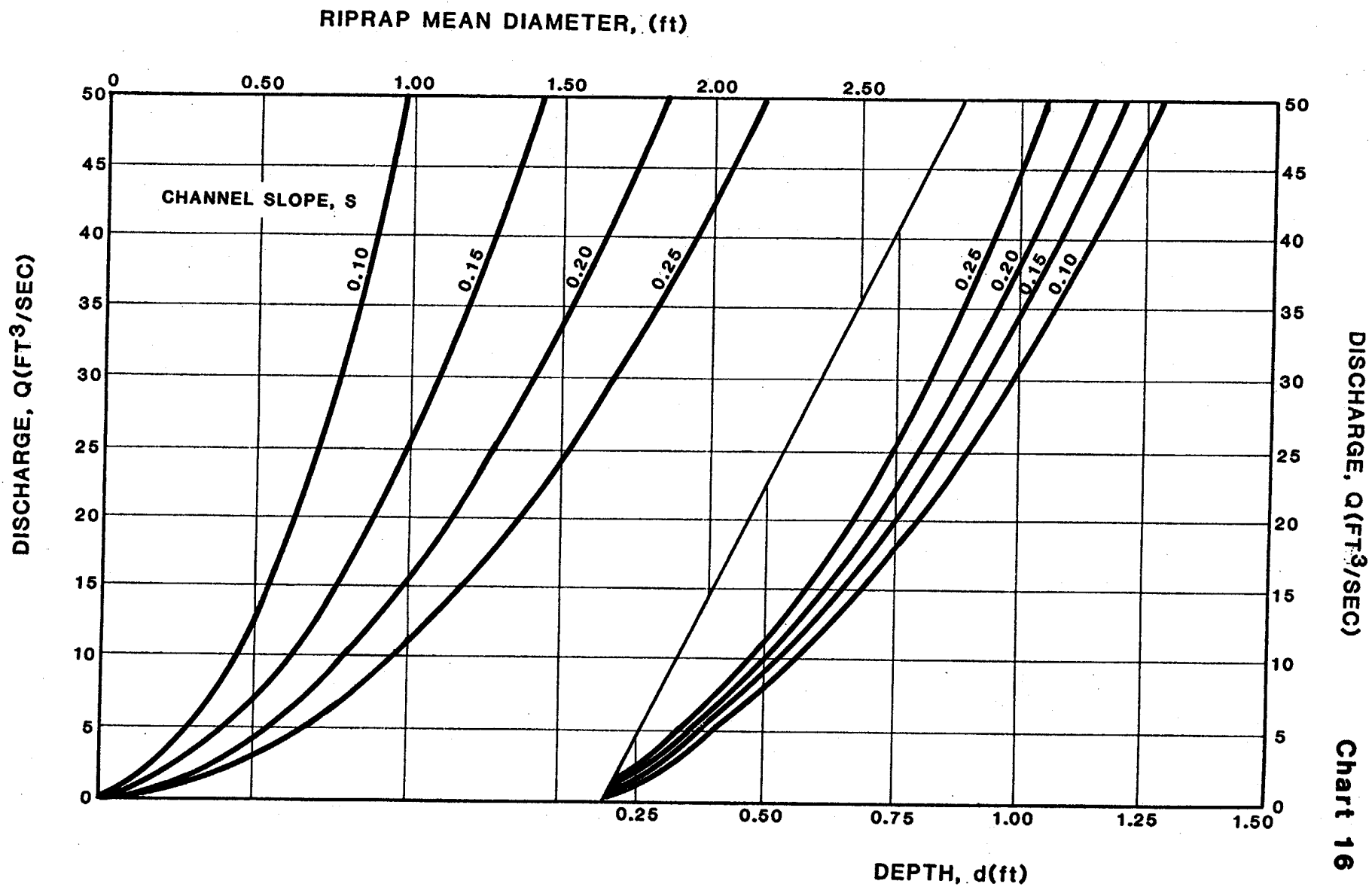


Chart 16. Steep slope riprap design, $B=2$, $Z=3$.

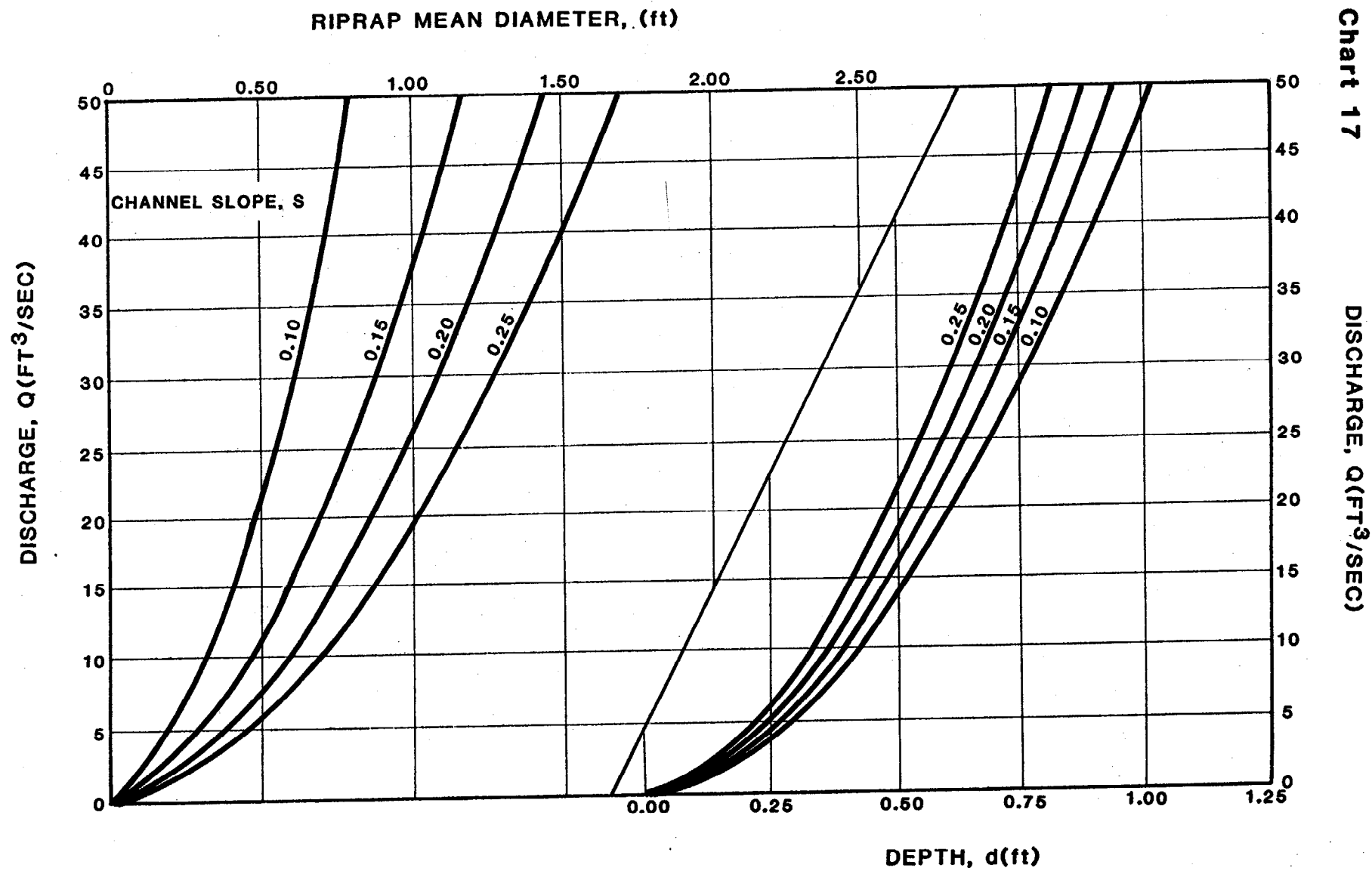


Chart 17. Steep slope riprap design, $B=4$, $Z=3$.

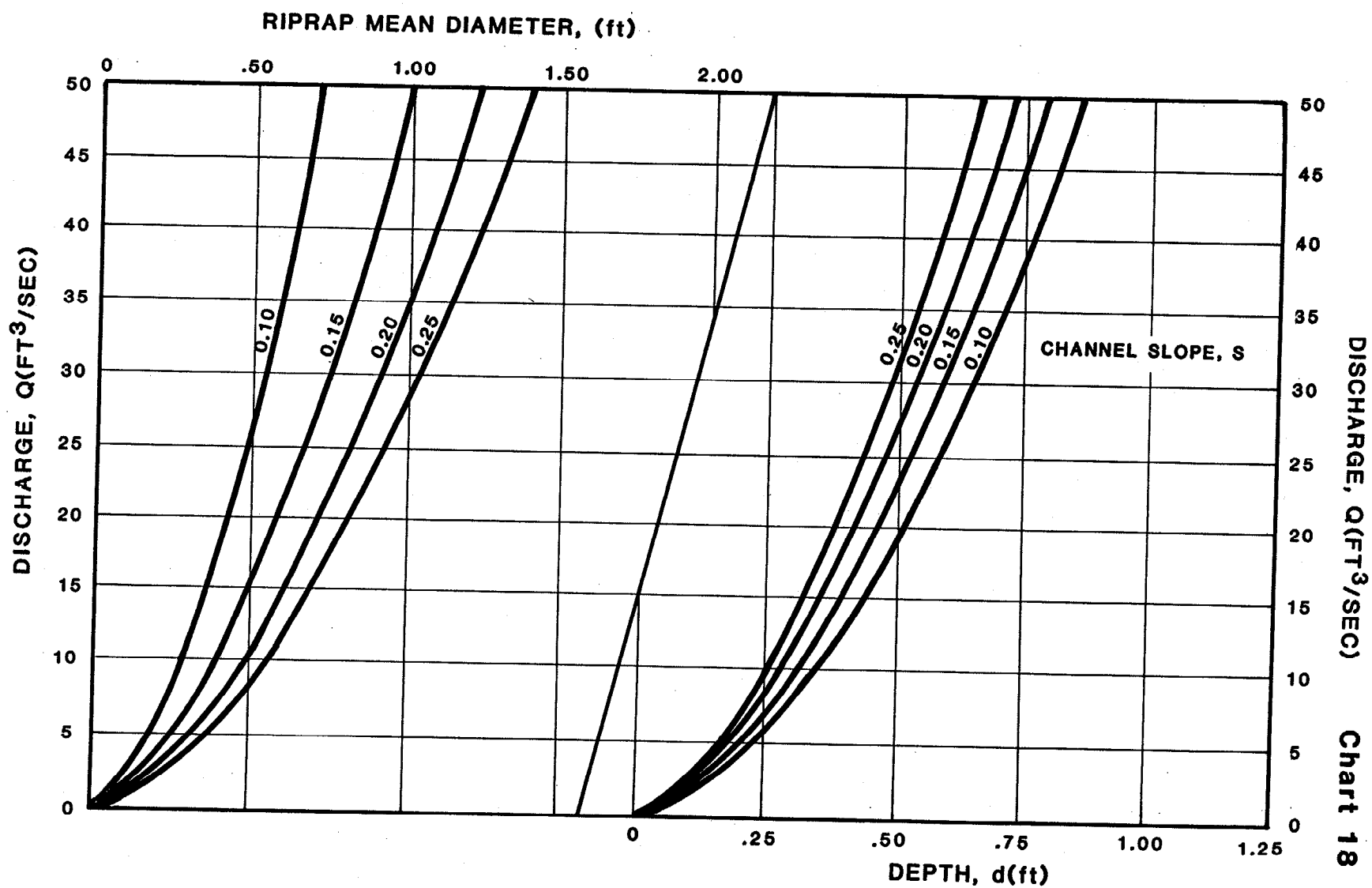


Chart 18. Steep slope riprap design, $B=6$, $Z=3$.

Chart 19

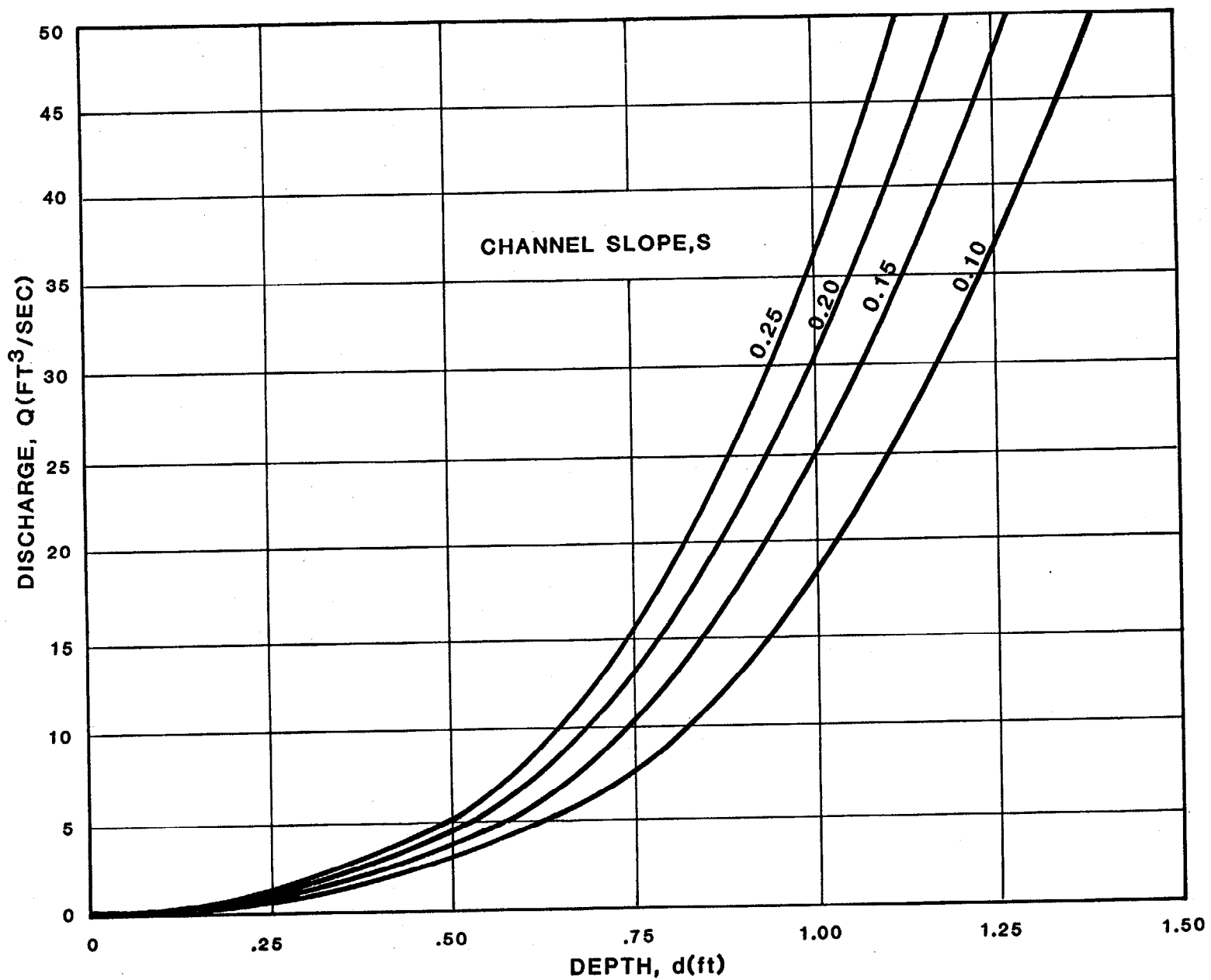


Chart 19. Steep slope gabion mattress, triangular channel, $Z = 3$.

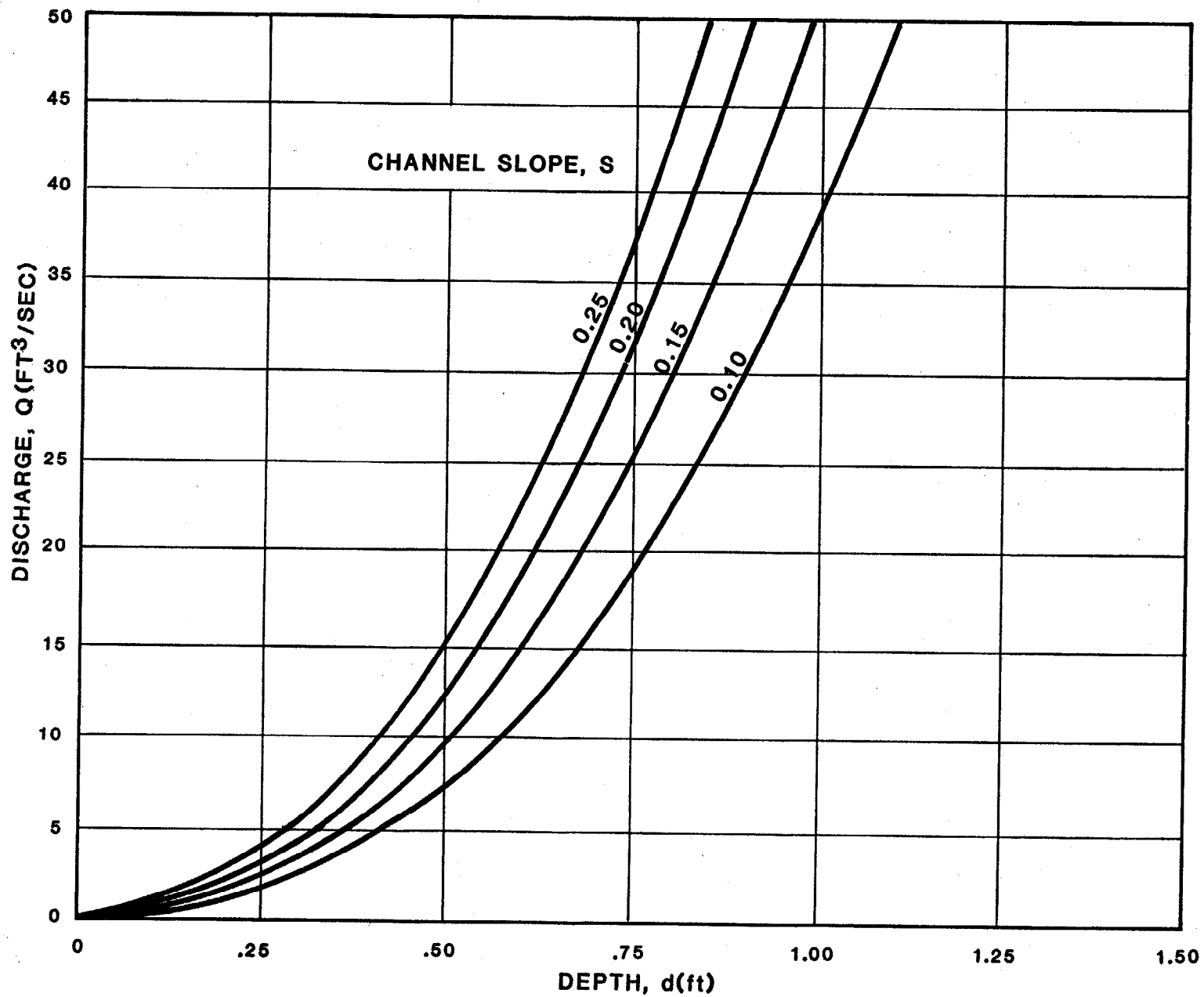


Chart 20

Chart 20. Steep slope gabion mattress, $B=2$, $Z=3$.

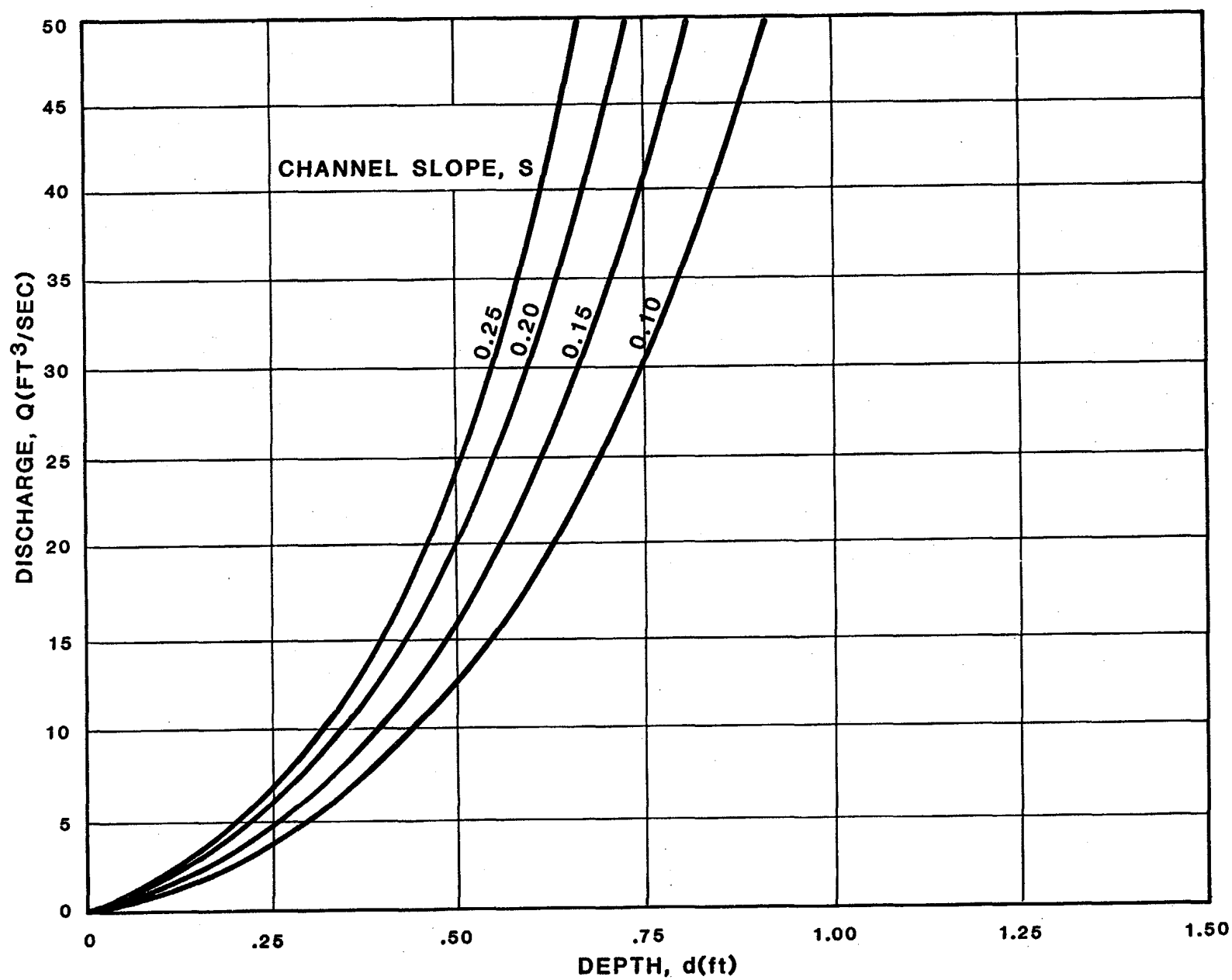


Chart 21. Steep slope gabion mattress, $B = 4$, $Z = 3$.

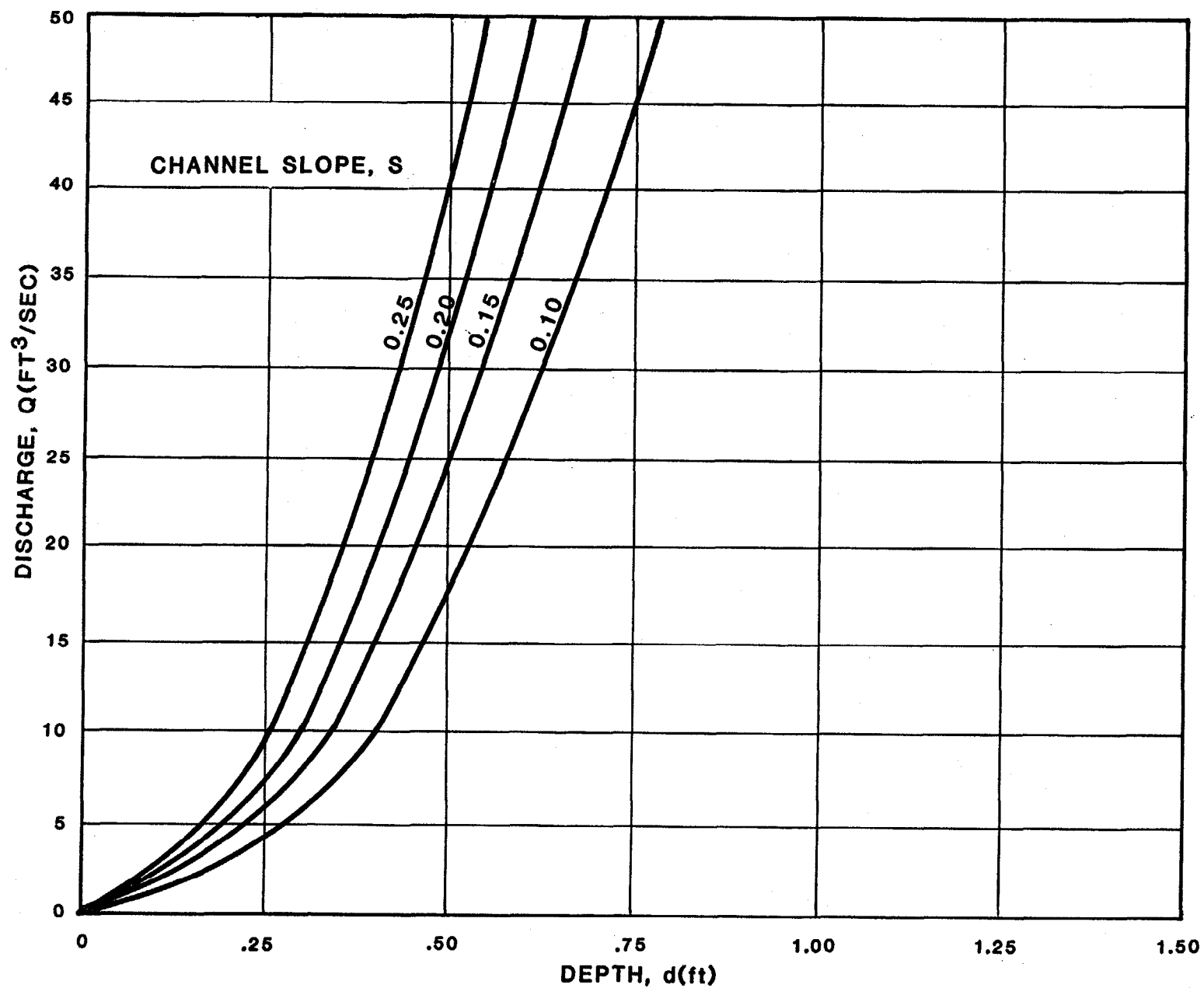


Chart 22. Steep slope gabion mattress, $B=6$, $Z=3$.

Chart 23

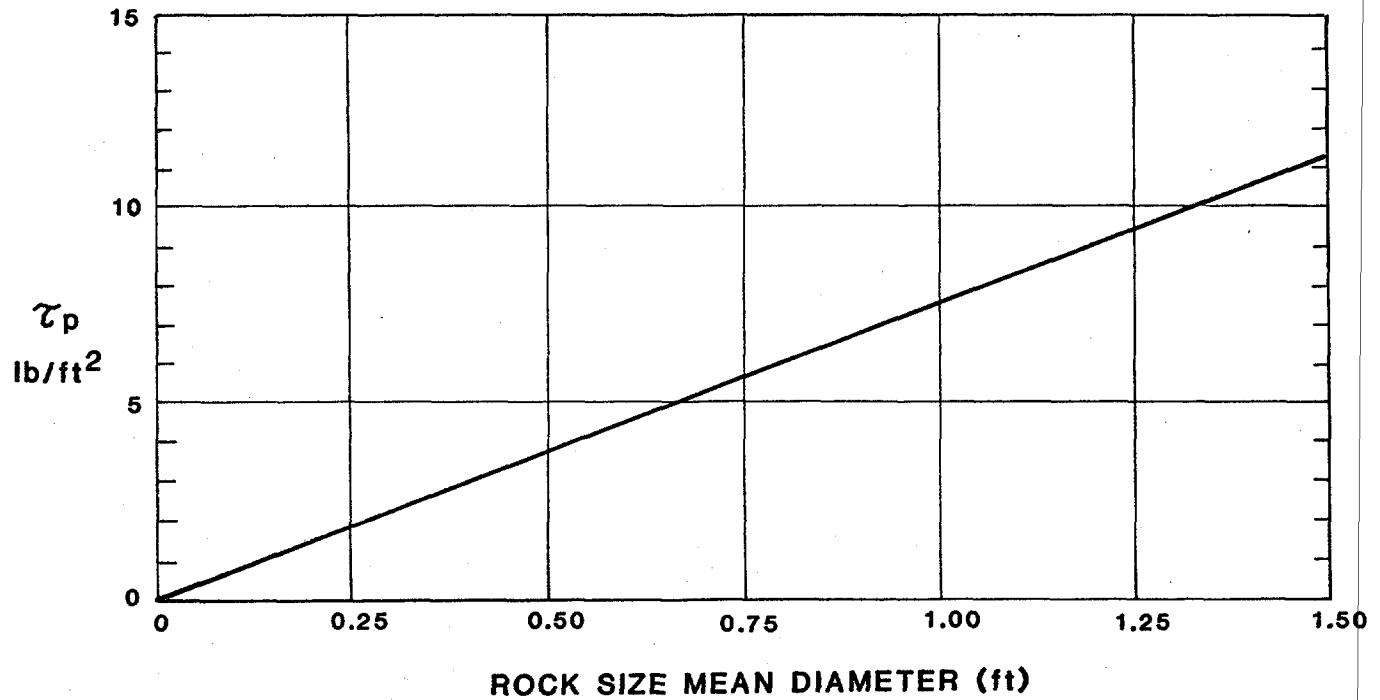


Chart 23. Permissible shear stress for gabion mattress versus rock fill size.

Chart 24

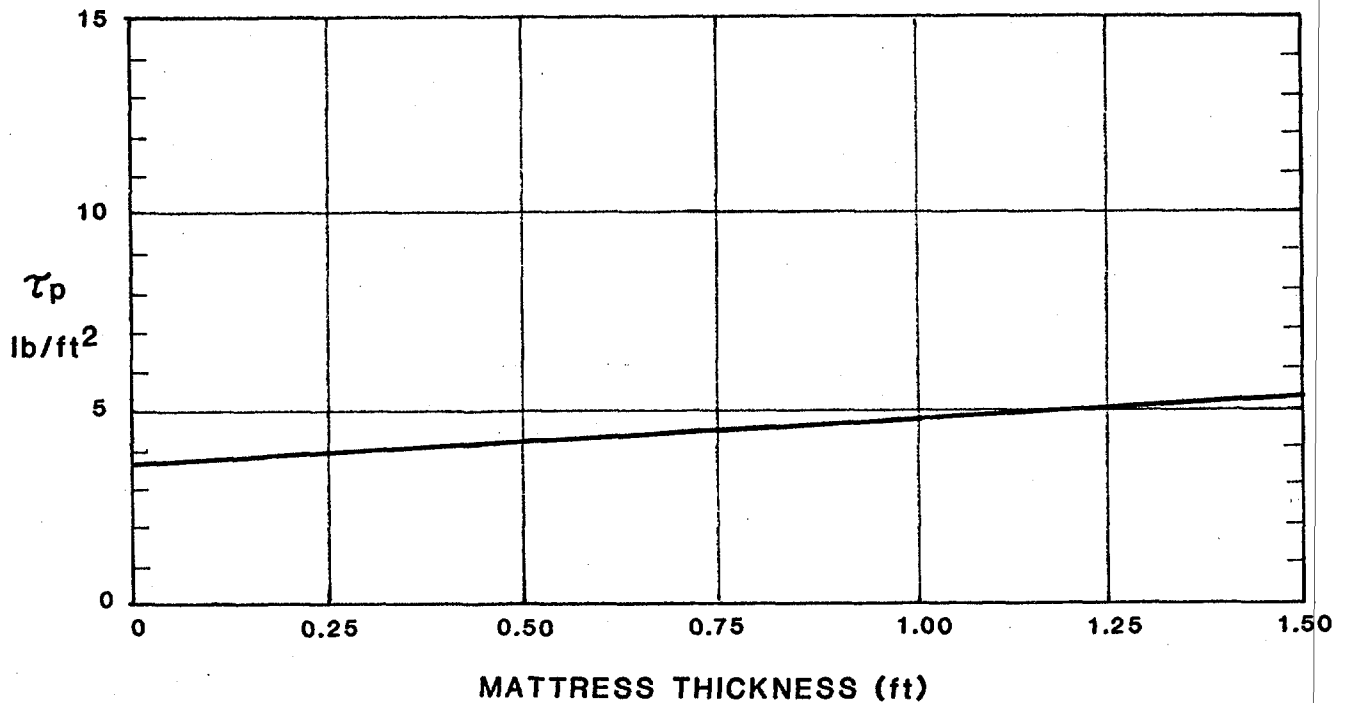


Chart 24. Permissible shear stress for gabion mattress versus mattress thickness.

VI. COMPOSITE LINING DESIGN

Composite linings protect the bed of a channel against the higher shear stress occurring in that portion of the channel. The distribution of shear stress in a trapezoidal channel section (see figure 18, chapter III) is such that the maximum shear stress on the sides of the channel is significantly less than on the channel bottom. This allows for a channel lining material to be used on the side slopes that has a lower permissible shear stress than the lining material used for the bottom of the channel. The maximum shear on the side of the channel is given by the following equation:

$$\tau_s = K_1 \tau_d \quad (15)$$

where K_1 is a function of channel geometry and is given in chart 13 (in chapter IV) and τ_d is the shear stress at maximum depth.

It is important that the bed lining material cover the entire channel bottom so that adequate protection is provided. To guarantee that the channel bottom is completely protected, the bed lining should be extended a small distance up the side slope.

Computation of flow conditions in a composite channel requires the use of an equivalent Manning's n value for the entire perimeter of the channel. For determination of equivalent roughness, the channel area is divided into two parts of which the wetted perimeters and Manning's n values of the low-flow section and channel sides are known. These two areas of the channel are then assumed to have the same mean velocity. Chart 25 provides a means of determining the equivalent roughness coefficient, K_c , for various applications of two channel linings.

Another important use of composite linings are in vegetative lined channels that have frequent low flows. These low flows will usually kill the submerged vegetation. In erodible soils, this leads to the formation of a small gully at the bottom of the channel. Gullies weaken a vegetative lining during higher flows, causing additional erosion, and can result in a safety hazard. A solution is to provide a nonvegetative low-flow channel lining such as concrete or riprap. The dimensions of the low-flow channel are sufficient to carry frequent low flows but only a small portion of the design flow. The remainder of the channel is covered with vegetation.

Special Considerations

When two lining materials with significantly different roughness values are adjacent to each other, erosion may occur near the boundary of the two linings. Erosion of the weaker lining material may damage the lining as a whole. In the case of composite channel linings with vegetation on the banks, this problem can occur in the early stages of vegetative establishment. A temporary lining should be used adjacent to the low-flow channel to provide erosion protection until the vegetative lining is well established.

Design Procedure

COMPOSITE LINING DESIGN PROCEDURE

The procedure for composite lining designs consists of the following steps.

1. Determine the permissible shear stress τ_p , for both lining types. (see table 2)
2. Estimate the depth of flow, d_i .
3. Determine Manning's n for each lining type. (Table 3 for nonvegetative linings and charts 5 to 9 for vegetative linings.)
4. Compute the ratio of rougher to smoother Manning's n values, n_2/n_1 .
5. Determine the hydraulic radius, R , and the wetted perimeter, P , for the entire channel section (chart 4 or equations in appendix A).
6. Compute the ratio of low-flow channel wetted perimeter, P_ℓ , to total wetted perimeter, P , (P_ℓ/P).
7. Determine a compound lining factor, K_c , from chart 25. Calculate the effective Manning's n from,

$$n = K_c n_1$$

where n_1 = Manning's n for smoother lining.

8. Determine channel flow depth, d , using the effective Manning's n .
9. Compare estimated flow depth, d_i , with calculated flow depth, d . If the difference is greater than 0.1 ft, repeat steps 3 through 8.
10. Determine the shear stress at maximum depth, τ_d , and the shear stress on the channel side slopes, τ_s

$$\tau_d = \gamma d S$$

and

$$\tau_s = K_1 \tau_d \quad (15)$$

where K_1 is from chart 13.

11. Compare the shear stresses, τ_d and τ_s , to the permissible shear stress, τ_p , for each of the channel linings. If τ_d or τ_s is greater than τ_p for the respective lining, a different combination of linings should be evaluated.

The design procedure is demonstrated in the following example. The worksheet at the end of this chapter (figure 28) is provided for carrying out the compound lining design procedure computations.

Example Problem

Example 13:

Determine the channel design for a composite concrete and vegetation lining.

Given: $Q = 10.0 \text{ ft}^3/\text{sec}$
 $S = 0.02 \text{ ft/ft}$
 Trapezoidal channel shape
 $Z = 3$
 Concrete low-flow channel, 3.0 ft wide

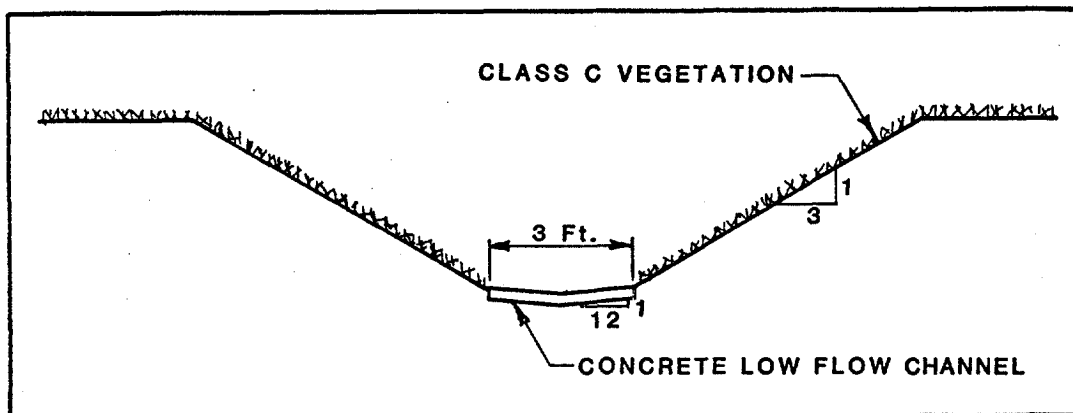


Figure 26. Compound Lining Example.

Find: (1) Effective Manning's n .
 (2) Flow depth in channel.
 (3) Suitability of channel lining materials.

Solution:

- (1) Permissible shear stress for Class C vegetation, $\tau_p = 1.00 \text{ lb/ft}^2$ and concrete is a nonerodible, rigid lining.
- (2) Initial depth is estimated at 1.0 ft
- (3) From chart 4, given $d/B = 0.33$

$$\begin{aligned} R/d &= 0.64 \\ R &= 0.64 \text{ ft} \\ A/Bd &= 2.0 \\ A &= 2.0 \times 3.0 \times 1.0 = 6.0 \text{ ft}^2 \\ P &= A/R = 6.0/0.64 \\ &= 9.4 \text{ ft} \end{aligned}$$

The concrete lining provides the low-flow channel, as given in the sketch,

$$\begin{aligned} P_L &= 3.0 \\ P_L/P &= 3.0/9.4 \\ &= 0.32 \end{aligned}$$

- (4) From chart 7 for Class C vegetation, $n_2 = 0.083$
 From table 3 for concrete, $n_1 = 0.013$
 $n_2/n_1 = 0.083/0.013$
 $= 6.4$

- (5) From chart 25, given $P_L/P = 0.32$ and $n_2/n_1 = 6.4$,
 $K_C = 5.0$
 $n = 5.0 \times 0.013$
 $= 0.065$

- (6) From chart 3 for $S = 0.02$, given $Qn = 0.65$ and $B = 3$,
 $d/B = 0.28$
 $d = 0.84$ ft

The difference between calculated depth and estimated depth is greater than 0.1 feet; therefore repeat steps 3 through 6.

- (3) The revised depth of flow is 0.84 ft. From chart 4, given $d/B = 0.28$,

$$\begin{aligned} R/d &= 0.66 \\ R &= 0.56 \\ A/Bd &= 1.84 \\ A &= 4.64 \text{ ft}^2 \\ P &= 4.64/0.56 = 8.3 \text{ ft} \\ P_L/P &= 3.0/8.3 = 0.36 \end{aligned}$$

- (4) From chart 7 for Class C vegetation, $n_2 = 0.095$.

$$\begin{aligned} n_2/n_1 &= 0.095/0.013 \\ &= 7.3 \end{aligned}$$

- (5) From chart 25, given $P_L/P = 0.36$ and $n_2/n_1 = 7.3$,
 $K_C = 5.5$
 $n = 5.5 \times 0.013$
 $= 0.072$

- (6) From chart 3 for $S = 0.020$, given $Qn = 0.72$ and $B = 3$,
 $d/B = 0.29$
 $d = 0.87$

The calculated and previous values of depth are within 0.1 feet.
The results are,

$$\begin{aligned}n &= 0.072 \\d &= 0.87 \text{ ft}\end{aligned}$$

- (7) The shear stress, at maximum depth from equation 5,

$$\begin{aligned}\tau_d &= \gamma d S \\&= 62.4 \times 0.87 \times 0.02 \\&= 1.09 \text{ lb/ft}^2\end{aligned}$$

The maximum shear stress on the sides of the channel is determined from equation 15.

$$\tau_s = K_1 \tau_d$$

where the shear stress ratio, K_1 , is determined from chart 13 given $Z = 3$ and $B/d = 3.45$, as $K_1 = 0.87$

$$\begin{aligned}\tau_s &= 0.87 \times 1.09 \\&= 0.95 \text{ lb/ft}^2\end{aligned}$$

- (8) The maximum shear stress on the channel side slopes is less than permissible, so the lining is acceptable.

Worksheet for Compound Lining Design

DESIGNER: _____ DATE: _____

PROJECT: _____

STATION: _____ TO STATION: _____

DRAINAGE AREA: _____ ACRES

DESIGN FLOW: Q _____ = _____ ft^3/sec

DESIGN FLOW FOR TEMPORARY LINING: Q _____ = _____ ft^3/sec

CHANNEL SLOPE (S) : _____ ft/ft

CHANNEL DESCRIPTION:

Lining	Type	τ_p (1)	n (2)	P_ℓ (3)
Lowflow				
Side				

d_j (4)	R (5)	$\frac{n_2}{n_1}$ (6)	P (7)	$\frac{P_\ell}{P}$ (8)	K_C (9)	n (10)	d (11)	τ_d (12)	K_1 (13)	τ_s (14)	REMARKS

- | | |
|--------------------------------------|--|
| (1) Table 2 | (8) Chart 25 |
| (2) Non-vegetative linings, table 3 | (9) $n = K_C n_1$ |
| (3) Vegetative linings, charts 5-9 | (10) Chart 3, trapezoidal channels |
| (4) Lowflow channel wetted perimeter | (11) $\tau_d = \gamma ds$ |
| (5) Flow depth, estimate | τ_d must be $\leq \tau_p$ for lowflow |
| (6) Chart 4, trapezoidal channels | (12) Chart 13 |
| (7) Ratio of rougher to smoother n | (13) $\tau_s = K_1 \tau_d$ |
| | τ_s must be $\leq \tau_p$ for sides |

Figure 27. Worksheet for Compound Lining Design

Worksheet for Compound Lining Design

DESIGNER: _____ DATE: _____

PROJECT: Example Problem 13

STATION: _____ TO STATION: _____

DRAINAGE AREA: _____ ACRES

DESIGN FLOW: Q _____ = 10 ft³/sec

DESIGN FLOW FOR TEMPORARY LINING: Q _____ = _____ ft³/sec

CHANNEL SLOPE (S) : 0.02 ft/ft

CHANNEL DESCRIPTION:



Lining	Type	τ_p (1)	n (2)	P_ℓ (3)
Lowflow	concrete	—	.013	3
Side	grass-classc	1.00	.095	for .84' .083 for 1.0'

d_i (4)	R (5)	$\frac{n_2}{n_1}$ (6)	P (7)	$\frac{P_\ell}{P}$ (8)	K_c (9)	n (10)	d (11)	τ_d (12)	K_1 (13)	τ_s (14)	REMARKS
1.0	.64	6.4	9.4	.32	5	.065	.84	—	—	—	$d < d_i$
.84	.56	7.3	8.3	.36	5.5	.072	.87	1.09	.87	.95	$\tau_s < \tau_p$
											OK

- | | |
|--------------------------------------|--|
| (1) Table 2 | (8) Chart 25 |
| (2) Non-vegetative linings, table 3 | (9) $n = K_c n_1$ |
| (3) Lowflow channel wetted perimeter | (10) Chart 3, trapezoidal channels |
| (4) Flow depth, estimate | (11) $\tau_d = \gamma ds$ |
| (5) Chart 4, trapezoidal channels | τ_d must be $\leq \tau_p$ for lowflow |
| (6) Ratio of rougher to smoother n | (12) Chart 13 |
| (7) Total channel wetted perimeter | (13) $\tau_s = K_1 \tau_d$ |
| | τ_s must be $\leq \tau_p$ for sides |

Figure 28. Worksheet for Example Problem 13

Chart 25

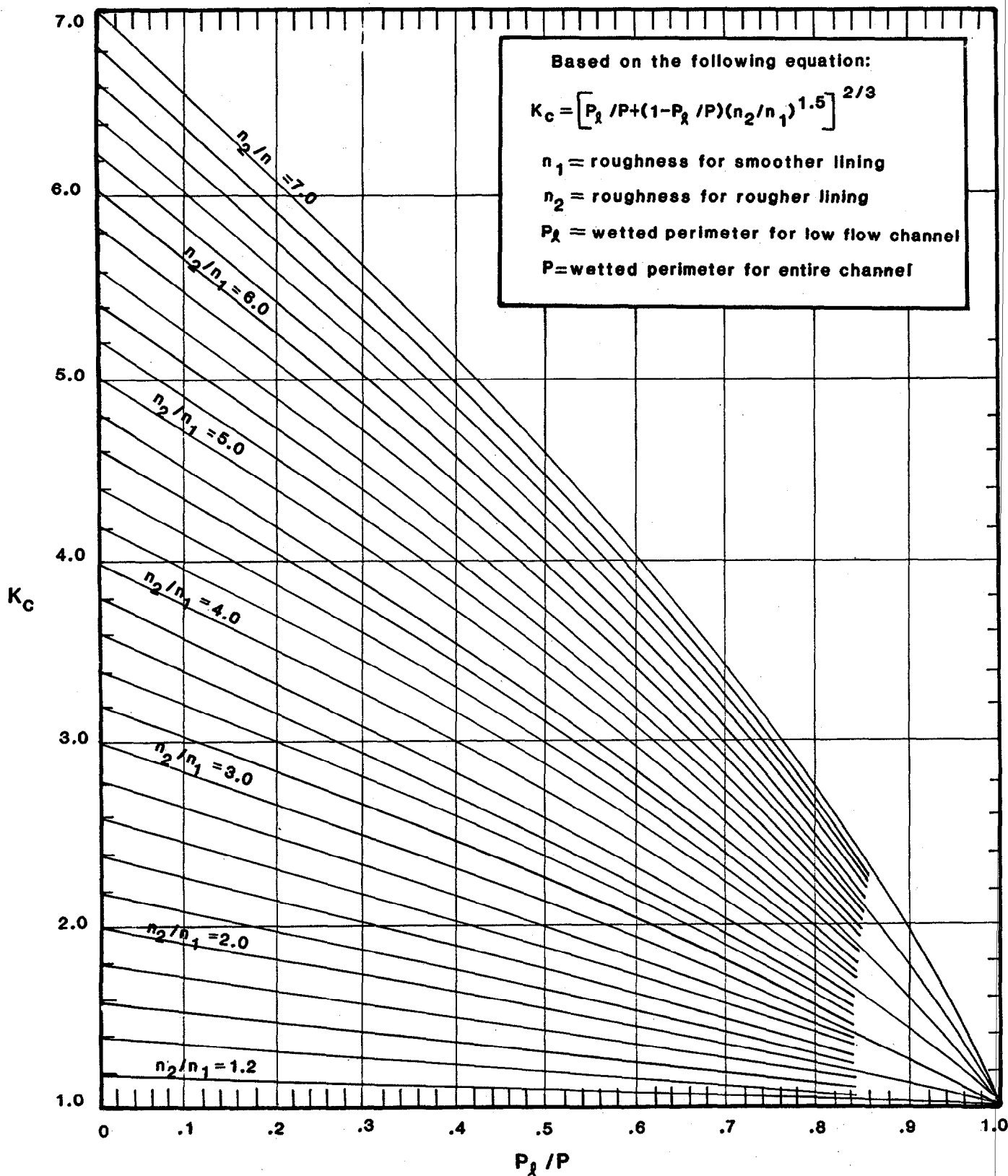
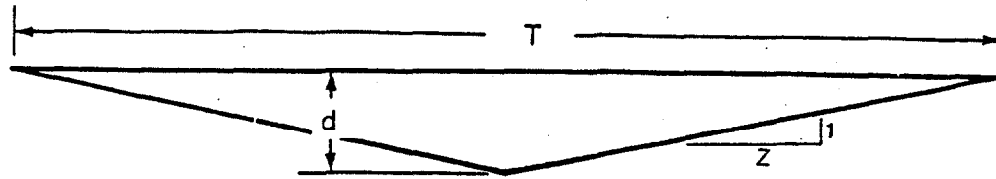


Chart 25. Roughness factor for compound channel linings.

APPENDIX A

EQUATIONS FOR VARIOUS CHANNEL GEOMETRIES

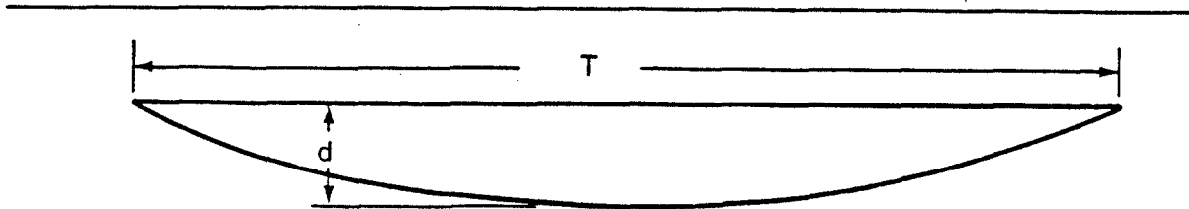


$$A = Zd^2$$

$$P = 2d\sqrt{Z^2 + 1}$$

$$T = 2dZ$$

V-SHAPE

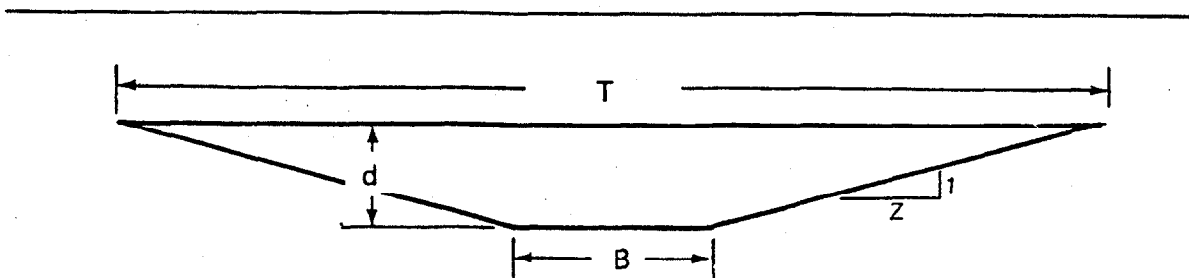


$$A = \frac{2}{3}Td$$

$$P = \frac{1}{2}\sqrt{16d^2 + T^2} + \left(\frac{T^2}{8d}\right)\ln_e\left(\frac{4d + \sqrt{16d^2 + T^2}}{T}\right)$$

$$T = 1.5\frac{A}{d}$$

PARABOLIC



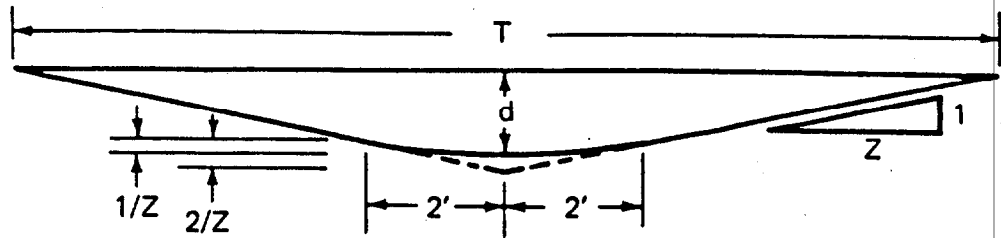
$$A = Bd + Zd^2$$

$$P = B + 2d\sqrt{Z^2 + 1}$$

$$T = B + 2dZ$$

TRAPEZOIDAL

Figure 29. Equations for Various Channel Geometries.



2 CASES

NO. 1

IF $d \leq 1/Z$, THEN:

$$A = \frac{8d}{3} \sqrt{dZ}$$

$$P = 2Z \ln_e \left(\sqrt{\frac{d}{Z}} + \sqrt{1 + \frac{d}{Z}} \right) + 2\sqrt{d^2 + dZ}$$

$$T = 4\sqrt{dZ}$$

NO. 2

IF $d > 1/Z$, THEN:

$$A = \frac{8Z}{3} + 4 \left(d - \frac{1}{Z} \right) + Z \left(1 - \frac{1}{Z} \right)^2$$

$$P = 2Z \ln_e \left(\frac{1}{Z} + \sqrt{\frac{Z^2 + 1}{Z}} \right) + 2\sqrt{\frac{1 + Z^2}{Z}} + 2 \left(d - \frac{1}{Z} \right) \sqrt{1 + Z^2}$$

$$T = 2Z \left(d + \frac{1}{Z} \right)$$

V-SHAPE WITH ROUNDED BOTTOM

Figure 29. Equations for Various Channel Geometries (continued).

APPENDIX B

DEVELOPMENT OF DESIGN CHARTS AND PROCEDURES

Resistance Equations

Resistance to flow in open channels with flexible linings can be accurately described using the universal-velocity-distribution law. (7) The form of the resulting equation is:

$$V = V_* [a + b \log (R/k_s)] \quad (16)$$

where V = mean channel velocity;
 V_* = shear velocity which is $(gRS)^{0.5}$;
 a, b = empirical coefficients;
 R = hydraulic radius;
 k_s = roughness element height; and
 g = acceleration due to gravity.

Values of k_s and the empirical coefficients, a and b , for different lining material are given in table 5. These values are based on an analysis of data collected by McWhorter et al. and Thibodeaux (14,15) for the Department of Transportation. The coefficients for riprap were developed by Blodgett and McConaughy (19) and the coefficients for vegetation are from work by Kouwen et al. (6)

Manning's equation (equation 1) and equation 16 can be combined to give Manning's roughness coefficient n in terms of the relative roughness. The resulting equation is:

$$\frac{n}{k_s^{1/6}} = \frac{(R/k_s)^{1/6}}{3.82 [a + b \log (R/k_s)]} \quad (17)$$

The n value is divided by the roughness height to the one-sixth power in order to make both sides of the equation dimensionless.

Figure 29 shows the behavior of Manning's n versus relative roughness. It can be seen that for values of relative roughness less than 10, there is significant variation in the n value. Flow conditions in small to moderate sized channels will typically fall in the range of relative roughness from 10 to 100. Over this range, the n value varies about 20 percent.

The relative roughness of vegetative channel linings depends on physical characteristics of the grass as well as the shear stress exerted on the grass. With grasses, the relative roughness will vary depending on the bending of the vegetation with the degree of bending being a function of the stiffness of the

Table 5. Empirical Coefficients for Resistance Equation.

Lining Material	k_s		a	b
	(ft)	(cm)		
Woven Paper	0.004	0.12	0.73	8.00
Jute Mesh	0.038	1.16	0.74	8.04
Fiberglass Roving	0.035	1.07	0.73	8.00
Straw With Net	0.12	3.66	0.72	7.83
Curled Wood Mat	0.11	3.35	0.65	7.10
Synthetic Mat	0.065	1.98	0.96	8.13
Riprap	D ₅₀		2.25	5.23
Vegetation	equation 19		0.42	5.23

Table 6. Relative Roughness Parameters for Vegetation.

Retardance Class	Average Height, h		Stiffness MEI	
	(ft)	(cm)	(lb © ft ²)	(Newton © m ²)
A	3.0	91	725	300
B	2.0	61	50	20
C	0.66	20	1.2	0.5
D	0.33	10	0.12	0.05
E	0.13	4	0.012	0.005

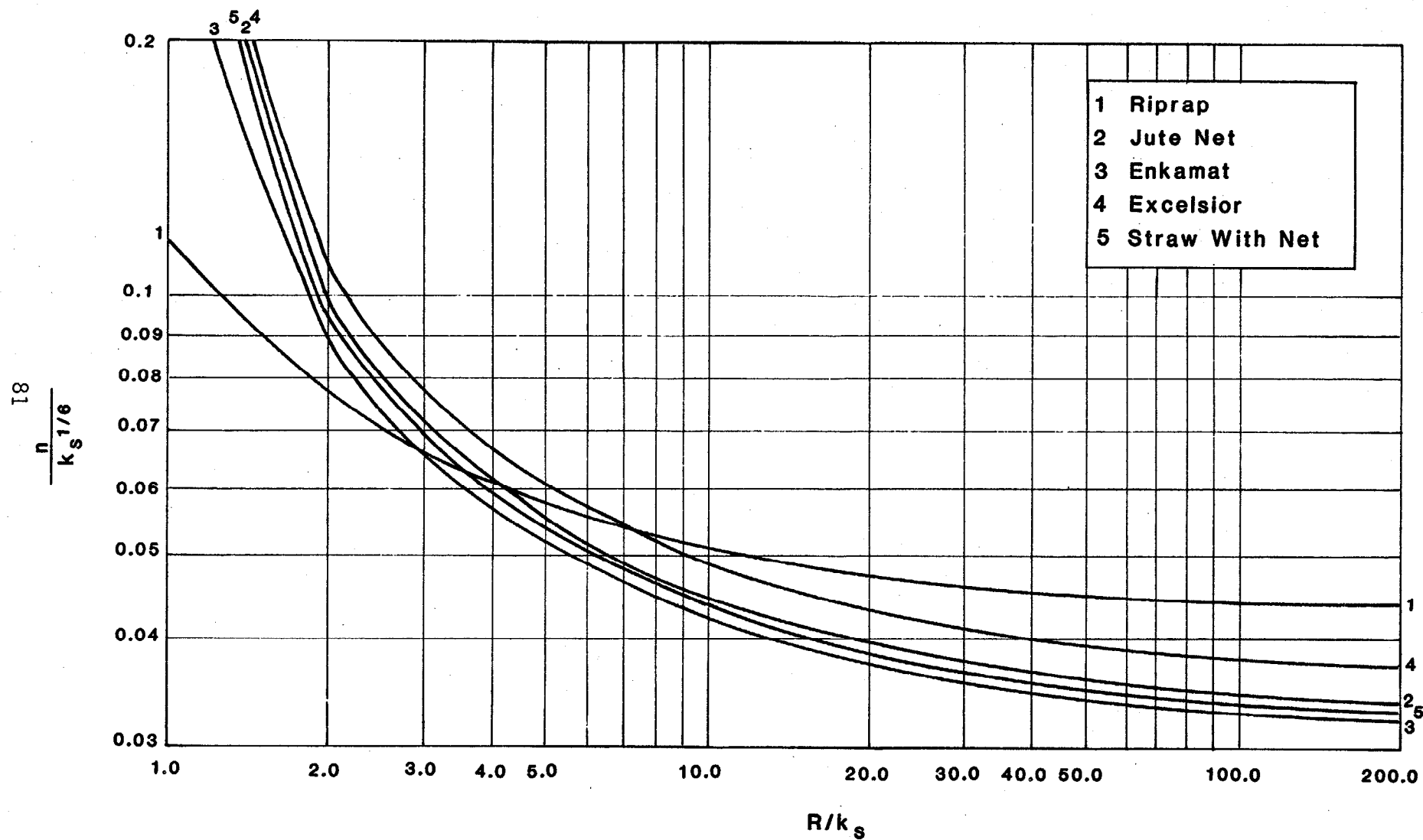


Figure 30. Manning's n Versus Relative Roughness for Selected Lining Types.

vegetation and the shear stress conditions. (6) Roughness height for vegetation is given by:

$$\frac{k_s}{h} = 0.14 \left[\left(\frac{MEI}{\tau} \right)^{1/4} / h \right]^{1.59} \quad (18)$$

where h = average height of vegetation;
 τ = ave. shear stress; and
 MEI = stiffness factor.

Values of h and MEI for various classifications of vegetative roughness, known as retardance classifications, are given in table 6.

The relative roughness for grasses in classifications A through E is typically less than 10. In this range, the variation in the Manning's roughness coefficient is substantial, and it is not acceptable to use only an average value. By combining equations 17 and 18, the Manning's roughness coefficient can be described as a function of hydraulic radius and mean tractive force. The resulting equation is:

$$n = \frac{R^{1/6}}{C + 19.97 \log (R^{1.4} S^{0.4})} \quad (19)$$

where C is $19.97 \log (44.8 h^{0.6} MEI^{-0.4})$ and depends on the class of vegetation. Design charts for determining Manning's n for vegetative channel linings were developed by plotting values given by equation 19.

APPENDIX C

DEVELOPMENT OF STEEP GRADIENT DESIGN CHARTS AND PROCEDURES

General

The design of riprap for steep gradient channels presents special problems. On steep gradients, the riprap size required to stabilize the channel is often of the same order of magnitude as the depth of flow. The riprap elements often protrude from the flow, creating a very complex flow condition.

Laboratory studies and field measurements (20) of steep gradient channels have shown that additional factors need to be considered when computing hydraulic conditions and riprap stability. The development of design procedures for this manual has, therefore, been based on equations that are more general in nature and account directly for several additional forces affecting riprap stability. The Bathurst resistance equation is used to predict hydraulic conditions in steep gradient channels and the factor of safety method is used to assess riprap stability. A brief discussion of both methods is given in this appendix and the assumptions used in developing the design procedures are presented.

Bathurst Resistance Equation

Most of the flow resistance in channels with large-scale roughness is derived from the form drag of the roughness elements and the distortion of the flow as it passes around roughness elements. Consequently, a flow resistance equation for these conditions has to account for skin friction and form drag. Because of the shallow depths of flow and the large size of the roughness elements, the flow resistance will vary with relative roughness area, roughness geometry, Froude number (the ratio of inertial forces to gravitational forces), and Reynolds number (the ratio of inertial forces to viscous forces).

Bathurst's experimental work quantified these relationships in a semi-empirical fashion. The work shows that for Reynolds numbers in the range of 4×10^4 to 2×10^5 , resistance is likely to fall significantly as Reynolds number increases. For Reynolds numbers in excess of 2×10^5 , the Reynolds effect on resistance remains constant. When roughness elements protrude through the free surface, resistance increases significantly due to Froude number effects, i.e., standing waves, hydraulic jumps, and free-surface drag. For the channel as a whole, free-surface drag decreases as the Froude number and relative submergence increase. Once the elements are submerged, Froude number effects related to free-surface drag are small, but those related to standing waves are important.

The general dimensionless form of the Bathurst equation is:

$$\frac{V}{V_*} = \frac{1.49}{\sqrt{g}} \left(\frac{d^{1/6}}{n} \right) = f_n(Fr) \times f_n(REG) \times f_n(CG) \quad (20)$$

where $\frac{V}{V_*}$ = mean velocity divided by the shear velocity;

$$V_* = (gdS)^{0.5};$$

d = mean flow depth;

g = acceleration due to gravity;

n = Manning's roughness coefficient;

Fr = Froude number;

REG = roughness element geometry; and

CG = channel geometry.

The functions of Froude number, roughness element geometry, and channel geometry are given by the following equations:

$$f_n(Fr) = \left(\frac{0.28}{b} Fr \right)^{\log(0.755/b)} \quad (21)$$

$$f_n(REG) = 13.434 \left(\frac{T}{Y_{50}} \right)^{0.492} \frac{1.025(T/Y_{50})^{0.118}}{b} \quad (22)$$

$$f_n(CG) = \left(\frac{T}{d} \right)^{-b} \quad (23)$$

where T = channel topwidth;

Y_{50} = mean value of the distribution of the average of the long and median axes of a roughness element; and

b = parameter describing the effective roughness concentration.

The parameter b describes the relationship between effective roughness concentration and relative submergence of the roughness bed. This relationship is given by:

$$b = a \left(\frac{d}{S_{50}} \right)^c \quad (24)$$

where S_{50} = mean of the short axis lengths of the distribution of roughness elements; and

a, c = constants varying with bed material properties.

The parameter, c, is a function of the roughness size distribution and varies with respect to the bed-material gradation, σ , where:

$$c = 0.648 \sigma^{-0.134} \quad (25)$$

For standard riprap gradations the log standard deviation is assumed to be constant at a value of 0.182, giving a c value of 0.814.

The parameter, a , is a function of channel width and bed material size in the cross stream direction, and is defined as:

$$a^{1/c} = 1.175 \left(\frac{Y_{50}}{T} \right)^{0.557} \quad (26)$$

In solving equation 20 for use with this manual, it is assumed that the axes of a riprap element are approximately equal for standard riprap gradations. The mean diameter, D_{50} , is therefore substituted for S_{50} and Y_{50} parameters.

Riprap Stability

The stability of riprap is determined by analyzing the forces acting on an individual riprap element and calculating the factor of safety against its movements. The forces acting on a riprap element are its weight (W_s), the drag force acting in the direction of flow (F_d), and the lift force acting to lift the particle off the bed (F_L). Figure 30 illustrates an individual element and the forces acting on it. The geometric terms required to completely describe the stability of a riprap element include:

- α = angle of the channel bed slope;
- $\beta \delta$ = angles between the two vectors: weight and drag, and their resultant in the plane of the side slope, respectively;
- θ = angle of the channel side slope; and
- ϕ = angle of repose for the riprap.

As the element will tend to roll rather than slide, its stability is analyzed by calculating the moments causing the particle to roll about the contact point, c , with an adjacent riprap element as shown in figure 30. The equation describing the equilibrium of the particle is:

$$\ell_2 W_s \cos \theta = \ell_1 W_s \sin \theta \cos \beta + \ell_3 F_d \cos \delta + \ell_4 F_L \quad (27)$$

The factor of safety against movement is the ratio of moments resisting motion over the moments causing motion. This yields:

$$SF = \frac{\ell_2 W_s \cos \theta}{\ell_1 W_s \sin \theta \cos \beta + \ell_3 F_d \cos \delta + \ell_4 F_L} \quad (28)$$

where SF = safety factor.

Evaluation of the forces and moment arms for equation 28 involves several assumptions and a complete derivation is given in Simons and Senturk. (21) The resulting set of equations are used to compute the factor of safety:

$$SF = \frac{\cos \theta \tan \phi}{\eta \tan \phi + \sin \theta \cos \beta} \quad (29)$$

$$b = \tan^{-1} \frac{\cos \alpha}{\frac{2 \sin \theta}{\eta \tan \phi} + \sin \alpha} \quad (30)$$

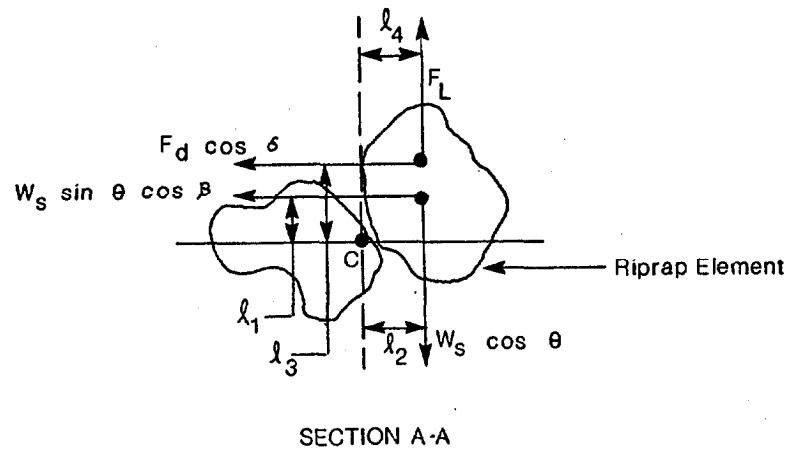
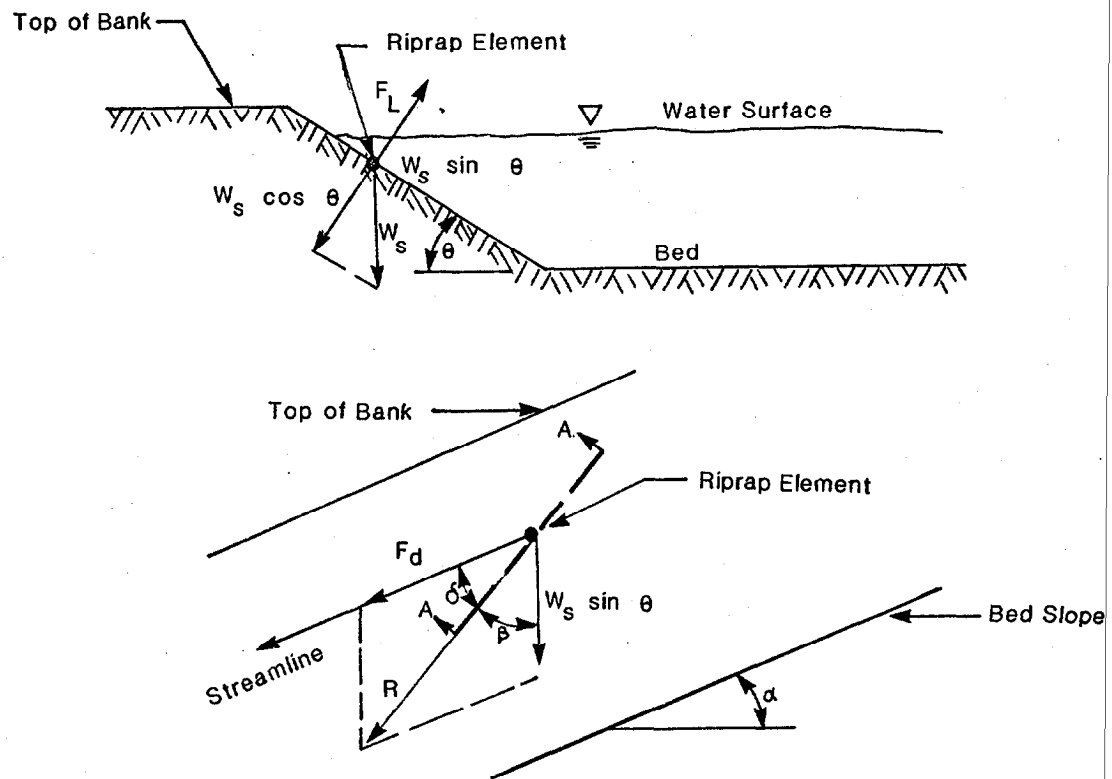


Figure 31. Hydraulic Forces Acting on a Riprap Element.

Effective July 2023

$$\eta = \frac{\tau_s}{F_* (\gamma_s - \gamma) D_{50}} \quad (31)$$

$$\text{and } \eta' = \eta \frac{1 + \sin(\alpha + \beta)}{2} \quad (32)$$

where τ_s = side slope shear stress;
 F_* = dimensionless critical shear stress;
 γ_s = specific weight of the rock;
 γ = specific weight of water;
 D_{50} = median diameter of the riprap;
 η = stability number; and
 η' = side slope stability number.

The side slope shear stress can be computed as:

$$\tau_s = K_1 \tau_o \quad (33)$$

K_1 can be obtained from chart 13. The angle of repose ϕ may be obtained from chart 12.

In the derivation given in Simons and Senturk (21), F_* was equal to 0.047. Recent studies (22) have shown F_* to take on much larger values for large-diameter particles in flow conditions having a high Reynolds number. Based on this work and Reynolds numbers encountered in steep gradient channels, the design procedure sets F_* equal to 0.15.

Solution Procedure

The solution procedure using the Bathurst resistance equation and factor-of-safety approach to riprap stability is outlined in the flow chart given in figure 31. A factor of safety of 1.5 is used. This value was used in developing the design charts of this manual (charts 15 through 18).

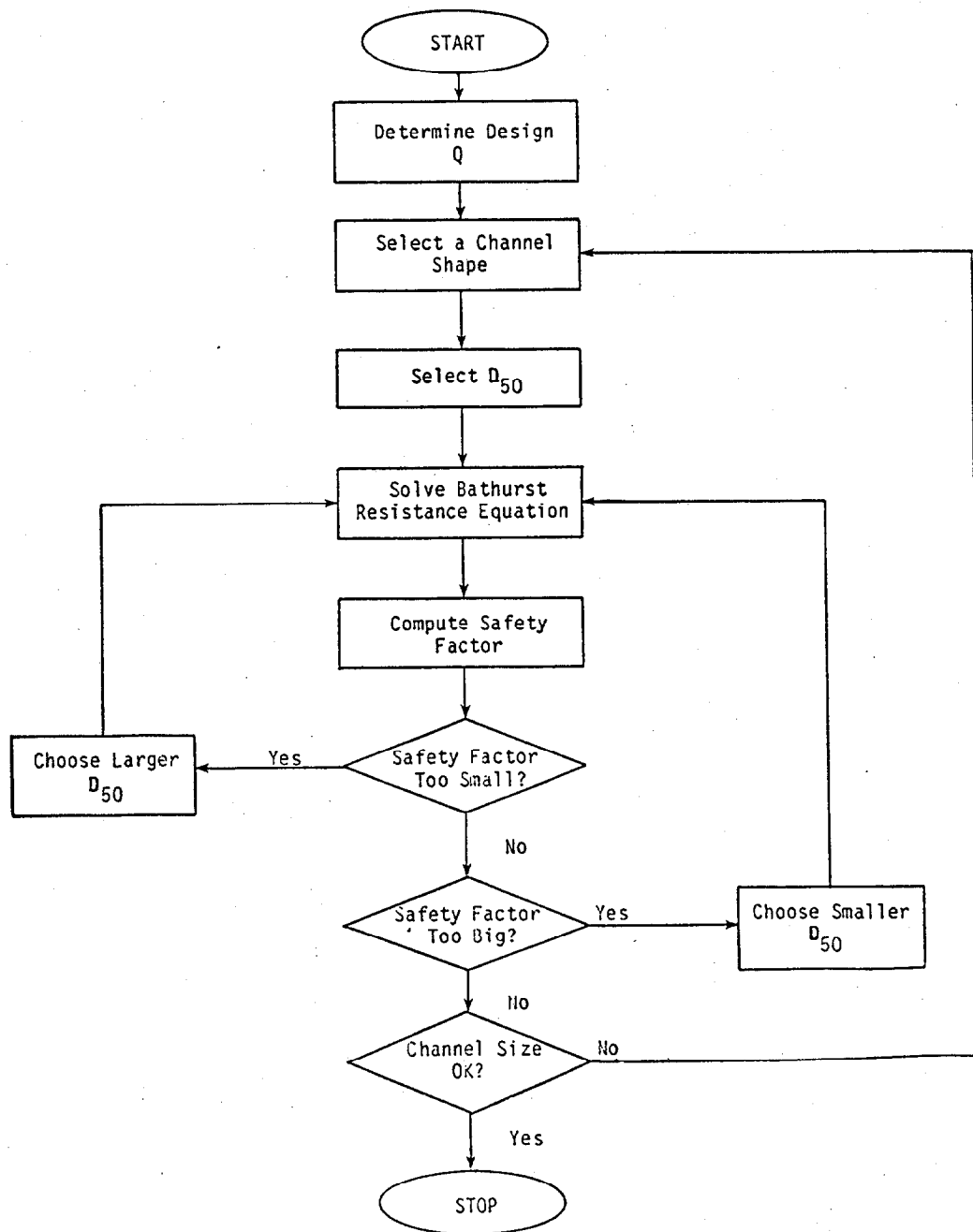


Figure 32. Steep Slope Design Procedure..

APPENDIX D

SUGGESTED GUIDE SPECIFICATIONS

The Specifications in this appendix are presented for the information of the designer, and should be modified as required for each individual design.

RIPRAP

Description

This work consists of furnishing materials and performing all work necessary to place riprap on bottoms and side slopes of channels, or as directed by the engineer.

The types of riprap included in this specification are:

- a. Rock riprap. Riprap consists of stone dumped in place on a filter blanket or prepared slope to form a well graded mass with a minimum of voids.
- b. Gravel channel lining. Gravel placed on filter blanket or prepared slope to form a well graded mass with a minimum of voids.

Materials

- a. Rock riprap. Stone used for riprap shall be hard, durable, angular in shape; resistant to weathering and to water action; free from overburden, spoil, shale and organic material; and shall meet the gradation requirements specified. Neither breadth nor thickness of a single stone should be less than one-third its length. Rounded stone or boulders will not be accepted unless authorized by special provisions. Shale and stone with shale seams are not acceptable. The minimum weight of the stone shall be 155 pounds per cubic foot as computed by multiplying the specific gravity (bulk-saturated-surface-dry basis, AASHTO Test T 85) times 62.3 pounds per cubic foot.

The sources from which the stone will be obtained shall be selected well in advance of the time when the stone will be required in the work. The acceptability of the stone will be determined by service records and/or by suitable tests. If testing is required, suitable samples of stone shall be taken in the presence of the engineer at least 25 days in advance of the time when the placing of riprap is expected to begin. The approval of some rock fragments from a particular quarry site shall not be construed as constituting the approval of all rock fragments taken from that quarry.

In the absence of service records, resistance to disintegration from the type of exposure to which the stone will be subjected will be determined by any or all of the following tests as stated in the special provisions:

1. When the riprap must withstand abrasive action from material transported by the stream, the abrasion test in the Los Angeles

Effective July 2023

machine shall also be used. When the abrasion test in the Los Angeles machine (AASHTO Test T 96) is used, the stone shall have a percentage loss of not more than 40 after 500 revolutions.

2. In locations subject to freezing or where the stone is exposed to salt water, the sulfate soundness test (AASHTO Test T 104 for ledge rock using sodium sulfate) shall be used. Stones shall have a loss not exceeding 10 percent with the sulfate test after 5 cycles.
3. When the freezing and thawing test (AASHTO Test 103 for ledge rock procedure A) is used as a guide to resistance to weathering, the stone should have a loss not exceeding 10 percent after 12 cycles of freezing and thawing.

Each load of riprap shall be reasonably well graded from the smallest to the maximum size specified. Stones smaller than the specified 10 percent size and spalls will not be permitted in an amount exceeding 10 percent by weight of each load.

Control of gradation will be by visual inspection. The contractor shall provide two samples of rock of at least 5 tons each, meeting the gradation specified. The sample at the construction site may be a part of the finished riprap covering. The other sample shall be provided at the quarry. These samples shall be used as a frequent reference for judging the gradation of the riprap supplied. Any difference of opinion between the engineer and the contractor shall be resolved by dumping and checking the gradation of two random truck loads of stone. Mechanical equipment, a sorting site, and labor needed to assist in checking gradation shall be provided by the contractor at no additional cost to the State.

- b. Gravel channel lining. Gravel riprap shall consist of gravel or crushed rock of the thickness and gradations shown on project drawings. All material comprising the riprap shall be composed of tough durable particles reasonably free of thin, flat, or elongated particles and shall not contain organic matter.

Construction Requirements

- a. General. Slopes to be protected by riprap shall be free of brush, trees, stumps, and other objectionable materials and be dressed to smooth surface. All soft or spongy material shall be removed to the depth shown on the plans or as directed by the engineer and replaced with approved native material. Filled areas will be compacted and a toe trench as shown on the plans shall be dug and maintained until the riprap is placed.

Protection for structured foundations shall be provided as early as the foundation construction permits. The area to be protected shall be cleared of waste materials and the surfaces to be protected prepared as shown on the plans. The type of riprap specified will be placed in accordance with these specifications as modified by the special provisions.

When shown on the plans, a filter blanket or filter fabric shall be placed on the prepared slope or area to be provided with foundation protection as specified before the stone is placed.

The contractor shall maintain the riprap until all work on the contract has been completed and accepted. Maintenance shall consist of the repair of areas where damaged by any cause.

- b. Rock riprap. Stone for riprap shall be placed on the prepared slope or area in a manner which will produce a reasonably well-graded mass of stone with the minimum practicable percentage of voids. The entire mass of stone shall be placed so as to be in conformance with the lines, grades, and thicknesses shown on the plans. Riprap shall be placed to its full course thickness at one operation and in such a manner as to avoid displacing the underlying material. Placing of riprap in layers, or by dumping into chutes, or by similar methods likely to cause segregation, will not be permitted.

The larger stones shall be well distributed and the entire mass of stone shall conform to the gradation specified by the engineer. All material going into riprap protection shall be so placed and distributed so that there will be no large accumulations of either the larger or smaller sizes of stone.

It is the intent of these specifications to produce a fairly compact riprap protection in which all sizes of material are placed in their proper proportions. Hand placing or rearranging of individual stones by mechanical equipment may be required to the extent necessary to secure the results specified.

Unless otherwise authorized by the engineer, the riprap protection shall be placed in conjunction with the construction of the embankment with only sufficient lag in construction of the riprap protection as may be necessary to allow for proper construction of the portion of the embankment protected and to prevent mixture of embankment and riprap. The contractor shall maintain the riprap protection until accepted, and any material displaced by any cause shall be replaced to the lines and grades shown on the plans at no additional cost to the State.

When riprap and filter material are dumped under water, thickness of the layers shall be increased as shown on the plans; and methods shall be used that will minimize segregation.

- c. Gravel channel lining. Gravel for riprap shall be placed on the prepared slope or area.

Measurement for Payment

The quantity of riprap to be paid for, of specified thickness and extent, in place and accepted, shall be measured by the number of cubic yards as computed from surface measurements parallel to the riprap surface and thickness measured normal to the riprap surface. Riprap placed outside the specified limits will not be measured or paid for, and the contractor may be required to remove and dispose of the excess riprap without cost to the State.

Basis of Payment

Quantities shall be paid for at the contract unit price per cubic yard and shown in the bid schedule which price shall be full compensation for furnishing all material, tools, and labor; the preparation of the subgrade; the placing of the riprap; the grouting when required; and all other work incidental to finished construction in accordance with these specifications.

WIRE ENCLOSED RIPRAP

Description

This work will consist of furnishing all materials and performing all work necessary to place wire enclosed riprap on bottoms and side slopes of channels or as directed by the engineer. Wire enclosed riprap consists of mats or baskets fabricated from wire mesh, filled with stone, connected together, and anchored to the slope. Details of construction may differ depending upon the degree of exposure and the service, whether used for revetment or used as a toe protection for the other types of riprap.

Materials

Material requirements shall meet those given for riprap, except for size and gradation of stone. Stone used shall be well graded and the smallest dimension of 70 percent of stone, by weight, shall exceed the wire mesh opening. The maximum size of stone, measured normal to the slope, shall not exceed the mat or basket thickness.

Wire mesh shall be galvanized woven fencing conforming to the specifications for fence fabric, and shall be of the gage and dimensions shown on the plans. Ties and lacing wire shall be No. 9 gage galvanized unless otherwise specified.

Construction Requirements

Construction requirements shall meet those given for rock riprap. Wire enclosed segments shall be hand- or machine-formed to the dimensions shown on the plans. These units shall be placed, laced, and filled to provide a uniform, dense, protective coat over the area specified.

Perimeter edges of wire enclosed units are to be securely selvaged or bound so that the joints formed by tying the selvages have approximately the same strength as the body of the mesh. Wire-enclosed units shall be tied to its neighbors along all contacting edges at 1-foot intervals in order to form a continuous connecting structure.

Mattresses and baskets on channel side slopes should be tied to the banks by anchor stakes driven 4 feet into tight soil (clay) and 6 feet into loose soil (sand). The anchor stakes should be located at the inside corners of mattress or basket diaphragms along an upslope (highest) wall, so that the stakes are an integral part of the mattress or basket. The exact maximum spacing of the stakes depends upon the configuration of the mattress or basket; however, the following is the minimum spacing: Stakes every 6 feet along and down the slope for slopes 2.5:1 and steeper, and every 9 feet along and down the slope for slopes flatter than 2.5:1.

Channel linings should be tied to the channel banks with wire-enclosed riprap counterforts at least every 12 feet. Counterforts should be keyed at least 12 inches into the existing banks with slope mattress or basket linings and should be keyed at least 3 feet by turning the counterfort endwise when the lining is designed to serve as a retaining wall.

Measurement for Payment

The quantity of wire-enclosed riprap of specified thickness and extent in place and accepted, shall be measured by the number of square yards obtained by measurements parallel to the riprap surface. Riprap placed outside the specified limits will not be measured or paid for, and the contractor may be required to remove and dispose of the excess riprap without cost to the State.

Basis of Payment

Quantities shall be paid for at the contract unit price per square yard and shown in the bid schedule, which price shall be full compensation for furnishing all material, tools, and labor; the preparation of the subgrade; the placing of the stone; and all other work incidental to finished construction in accordance with these specifications.

WOVEN PAPER NET

Description

This work shall consist of furnishing materials and all work necessary to install woven paper net fabric for erosion control on roadway, ditches, or slopes, or as directed by the engineer.

Materials

Materials shall consist of knitted plastic net, interwoven with paper strips. The yarn shall be of photodegradable synthetic types and the paper shall be biodegradable. Staples shall be 6 inches and 12 inches in length, and composed of high carbon iron.

Construction Requirements

Woven paper net shall be placed on the prepared slope or seedbed area which has been prepared and leveled according to various other sections in these specifications. If seeding and fertilizer are in the provisions, they should be applied immediately before laying the fabric.

Woven paper net shall be applied on slopes with the fabric running vertical from the top of the slope. In drainages, woven paper net shall be applied in the direction of the water flow. The fabric shall be secured and buried in a 4-inch trench, 1 foot back from the crown and at the bottom of the slope. Heavy gauge staples shall secure the fabric at 9-inch intervals along the edges and overlaps and at 3-foot intervals down the center of the fabric roll. Rolls shall overlap 4 inches. Woven paper net shall be draped rather than stretched across the surface.

The contractor shall maintain the fabric blanket until all work on the contract has been completed and accepted. Maintenance shall consist of the repair of areas where damaged by any cause. All damaged areas shall be repaired to reestablish the condition and grade of the soil prior to application of the covering and shall be refertilized, reseeded, and remulched as directed.

Measurement for Payment

The quantity of woven paper net, including staples, completely in place and accepted, shall be measured by the square yard of finished surface. No allowance will be made for overlap. Woven paper net placed outside the specified limits will not be measured or paid for and the contractor may be required to remove or dispose of the excess without cost to the State.

Basis of Payment

Quantities shall be paid for at the contract unit price per square yard which price shall be full compensation for furnishing all materials, tools, and labor; the preparation of the subgrade; the placing of the woven paper net; and all other work incidental to finished construction in accordance with these specifications.

JUTE NET

Description

This work consists of furnishing materials and performing all work necessary to install jute net on roadway ditches or slopes or as directed by the engineer.

Materials

Jute net shall consist of heavy mesh of a uniform open plain weave of unbleached, smolder-resistant, single jute yarn. The yarn shall be of a loosely twisted construction having an average twist of not less than 1.6 turns per inch and shall not vary in thickness by more than one-half its normal diameter. The jute net shall be furnished in approximately 90-pound rolled strips and shall meet the following requirements:

Length	approximately 75 yards
Width	48 inches + 1 inch
	78 warp ends per width of cloth
	41 weft ends per yard
Weight	1.22 pounds per linear yard with \pm 5 percent

Staples shall be 3, 6, and 12 inches in length, and composed of high carbon iron or as specified by the engineer.

Construction Requirements

The blankets shall be placed in designated locations immediately after seeding and mulching operations have been completed. The material shall be applied smoothly but loosely to the soil surface without stretching. The upslope end of each piece of jute net shall be buried in a narrow trench 6 inches deep. After the jute is buried, the trench shall be firmly tamped closed.

In cases where one roll of jute mesh ends and a second roll starts, the upslope piece should be brought over the buried end of the second roll so that there is a 12-inch overlap to form a junction slot. Where two or more widths of jute net are applied side by side, an overlap of at least 4 inches must be made.

Check slots should be made before the jute net is rolled out. A narrow trench should be dug across the slope perpendicular to the direction of flow. A piece of jute, cut the same length as the trench, is folded lengthwise. The fold is placed in the trench and the trench is tamped closed. The portion of the jute remaining above ground is unfolded and laid flat on the soil surface. Check slots will be spaced so that one check slot or junction slot occurs without each 50 feet of slope. Overlaps which run down the slope, outside edges and centers shall be stapled on 2-foot intervals. Each width of jute net will have a row of staples down the center as well as along each edge. Check slots and junction slots will be stapled across at 6-inch intervals.

For extra hard soil, use 3-inch sharp-pointed fence-type staples, composed of hardened steel.

The jute net must be spread evenly and smoothly and be in contact with the seeded area at all points. The contractor shall maintain the jute mesh until all work on the contract has been completed and accepted. Maintenance shall consist of the repair of areas where damaged by any cause. All damaged areas shall be repaired to reestablish the condition and grade of the soil prior to application of the covering and shall be refertilized, reseeded and remulched as directed.

Measurement of Payment

The quantity of jute net, including staples, completely in place and accepted, shall be measured by the square yard of finished surface. No allowance will be made for overlap. Mat placed outside the specified limits will not be measured or paid for, and the contractor may be required to remove and dispose of the excess mat without cost to the State.

Basis of Payment

Quantities shall be paid for at the contract unit price per square yard which price shall be full compensation for furnishing all materials, tools, and labor; the preparation of the subgrade; the placing of the jute net; and all other work incidental to finished construction in accordance with these specifications.

FIBERGLASS ROVING

Description

This work consists of furnishing materials and performing all work necessary to install fiberglass roving on roadway ditches or slopes, or as directed by the engineer.

Materials

- a. General requirements. The material shall be formed from continuous fibers drawn from molten glass, coated with a chrome-complex sizing compound, collected into strands and lightly bound together into roving without the use of clay, starch, or like deleterious substances. The roving shall be wound into a cylindrical package approximately 1 foot high in such a manner that the roving can be continuously fed from the center of the package through an ejector driven by compressed air and expanded into a mat of glass fibers on the soil surface. The material shall contain no petroleum solvents or other agents known to be toxic to plant or animal life.

Liquid asphaltic materials shall conform to the requirements of AASHTO M81, M82, and M141 for the designated types and grades.

- b. Detailed requirements. The fiberglass roving shall conform to these detailed requirements:

Property	Limits	Test Method
Strands/Rove	56-64	End Count
Fibers/Strand	184-234	
Fiber Diameter, inch (Trade Designation-G)	0.00035-0.0004	ASTM D 578
Yd/lb of Sand	13,000-14,000	ASTM D 578
Yd/lb of Rove	210-230	ASTM D 578
Organic content, percent maximum	0.75	ASTM D 578
Package Weight, lb	30-35	ASTM D 578

Construction Requirements

The fiberglass roving shall be applied over the designated area within 24 hours after the normal seeding operations have been completed.

The fiberglass roving shall be spread uniformly over the designated area to form a random mat of continuous glass fibers at the rate of 0.25 pounds per cubic yard. This rate may be varied as directed by the engineer.

The fiberglass roving shall be anchored to the ground with the asphaltic materials applied uniformly over the glass fibers at the rate of 0.25 gallon per square yard. This rate may be varied as directed by the engineer.

The upgrade end of the lining shall be buried to a depth of 1 foot to prevent undermining. Instructions for slope and ditch protection may be stipulated by the engineer to fit the field conditions encountered.

The contractor shall maintain the roving until all work on the contract has been completed and accepted. Maintenance shall consist of the repair of areas where damaged by any cause. All damaged areas shall be repaired to reestablish the condition and grade of the soil prior to application of the covering and shall be refertilized, reseeded and remulched as directed.

Measurement for Payment

Fiberglass roving will be measured by the pound, and the quantity to be measured will be that actually used on the project. Roving placed outside the specified limits will not be paid for and the contractor may be required to remove and dispose of the excess roving without cost to the State.

Basis of Payment

Quantities shall be paid for at the contract unit price per pound and shown in the bid schedule, which price shall be full compensation for furnishing all materials, tools, and labor; the preparation of the subgrade; the placing of the roving; and all other work incidental to finished construction in accordance with these specifications.

CURLED WOOD MAT

Description

This work consists of furnishing materials and performing all work necessary to install curled wood mat on roadway ditches or slopes, or as directed by the engineer.

Materials

All materials shall meet the requirements of the following specifications. The blanket shall consist of a machine produced mat of curled wood excelsior of 80 percent, 8 inches or longer fiber length with consistent thickness and the fiber evenly distributed over the entire area of the blanket. The top side of the blanket shall be covered with a biodegradable extruded plastic mesh. The blanket shall be made smolder resistant without the use of chemical additives.

Width	48 inch + 1 inch
Length	180 ft average
Weight per roll	78 lb + 8 lb
Weight per yd ²	0.875 lb + 10 percent
Volume per roll	80 yd ³ , average

Pins and staples shall be made of high carbon iron wire 0.162 or larger in diameter. "U" shaped staples shall have legs 8 inches long and a 1-inch crown. "T" shaped pins shall have a minimum length of 8 inches after bending. The bar of the "T" shall be at least 4 inches long with the single wire end bent downward approximately 3/4-inch.

Construction Requirements

The area to be covered shall be properly prepared, fertilized, and seeded before the blanket is placed. When the mat is unrolled, the netting shall be on top and the fibers shall be in contact with the soil. In ditches, blankets shall be unrolled in the direction of the flow of water. The end of the upstream blanket shall overlap the buried end of the downstream blanket a maximum of 8 inches and a minimum of 4 inches, forming a junction slot. This junction slot shall be stapled across at 8-inch intervals. Adjoining blankets (side by side) shall be offset 8 inches from center of ditch and overlapped a minimum of 4 inches. Use 6 staples across the start of each roll, at 4-foot intervals, alternating the center row so that the staples form an "X" pattern. A common row of staples shall be used on adjoining blankets.

The contractor shall maintain the blanket until all work on the contract has been completed and accepted. Maintenance shall consist of the repair of areas where damaged by any cause. All damaged areas shall be repaired to reestablish the condition and grade of the soil prior to application of the covering and shall be refertilized, reseeded, and remulched as directed.

Measurement for Payment

Curled wood mat, including staples, completely in place and accepted, will be measured by the square yard of finished surface. No allowance will be made for overlap. Mat placed outside the specified limits will not be measured or paid for, and the contractor may be required to remove and dispose of the excess without cost to the State.

Basis of Payment

Quantities shall be paid for at the contract unit price per square yard and shown in the bid schedule, which price shall be full compensation for furnishing all materials, tools, and labor; the preparation of the subgrade; the placing of the matting; and all other work incidental to finished construction in accordance with these specifications.

STRAW WITH NET

Description

This work consists of furnishing materials and performing all work necessary to install straw with net on roadway ditches or slopes, or as directed by the engineer.

Materials

- a. Straw. Straw shall be derived from wheat, oats, or barley. The contractor shall furnish evidence that clearance has been obtained from the county agricultural commissioner, as required by law, before straw obtained from outside the county in which it is to be used is delivered to the site of the work. Straw that has been used for stable bedding shall not be used.
- b. Plastic net shall be an extruded polypropylene or other approved plastic material, extruded in such a manner as to form a net of 3/4-inch minimum square openings. The net shall be furnished in rolls to meet the following characteristics:

Width	48 inch, minimum
Length	50 yard, minimum, convenient lengths
Weight	2.6 lb/1,000 ft ² , minimum
- c. Pins and staples shall be made of high carbon iron wire 0.162 or larger in diameter. "U" shaped staples shall have legs 8 inches long and a 1-inch crown. "T" shaped pins shall have a minimum length of 8 inches after bending. The bar of the "T" shall be at least 4 inches long with the single wire end bent downward approximately 3/4-inch.

Construction Requirements

Plastic net shall be placed as soon as possible after mulching operations have been completed in locations designated in the plans. Net shall be used only to secure straw mulch to the finished slope or ditch.

Preparation shall include all the work required to make ready the areas for incorporating straw. Areas on which straw is to be applied shall be prepared such that the straw will be incorporated into the soil to the degree specified. Removing and disposing of rocks and debris from embankments constructed as part of the work will be considered as included in the contract price paid per ton for straw and no additional compensation will be allowed therefore.

Straw shall be uniformly spread at the rate specified in the special provisions. When weather conditions are suitable, straw may be pneumatically applied by means of equipment which will not render the straw unsuitable for incorporation into the soil.

Straw shall be incorporated into the soil with a roller equipped with straight studs, made of approximately 7/8-inch steel plate, placed approximately 8 inches apart, and staggered. The studs shall not be less than 6 inches long or more than 6 inches wide, and shall be rounded to prevent withdrawing the straw from the soil. The roller shall be of such weight as to incorporate the straw sufficiently into the soil so that the straw will not support combustion and will leave a uniform surface.

The net shall be applied smoothly but loosely on the mulched surface without stretching. The net shall be unrolled from the top to the bottom of the slope. The top edge of the net shall be buried and stapled at the top end of the slope in a narrow trench 6 inches deep. After the edge is buried and stapled, the trench shall be backfilled and tamped.

In cases where one roll of net ends and a second roll starts, the upslope piece shall be brought over the start of the second roll so that there is a 4-inch overlap.

Where two or more widths of net are applied side by side, an overlap of at least 4 inches must be made. Insert 1 staple every foot along top and bottom of edges of the net. Also, insert staples over 4 feet on each edge and down center of net so that the staples alternate between edges and center to form an "X" shape pattern.

The contractor shall maintain the straw with net until all work on the contract has been completed and accepted. Maintenance shall consist of the repair of areas where damaged by any cause. All damaged areas shall be repaired to reestablish the condition and grade of the soil prior to application of the covering and shall be refertilized, reseeded, and remulched as directed.

Measurement for Payment

Straw with net, including staples, completely in place and accepted, will be measured by the square yard of finished surface. No allowance will be made for overlap. Straw and net placed outside the specified limits will not be measured or paid for, and the contractor may be required to remove and dispose of the excess net without cost to the State.

Basis of Payment

Quantities shall be paid for at the contract unit price per square yard and shown in the bid schedule which price shall be full compensation for furnishing all materials, tools, and labor; the preparation of the subgrade; and all other work incidental to finished construction in accordance with these specifications.

SYNTHETIC MAT

Description

This work consists of furnishing materials and performing all work necessary to install nylon mat on roadway ditches or slopes, or as directed by the engineer.

Materials

Synthetic mat shall consist of three-dimensional structure of entangled nylon monofilaments, melt-bonded at their intersections, forming a stable mat of suitable weight and configuration. The mat shall be crush-resistant, pliable, resilient, water-permeable, and highly resistant to chemicals and environmental degradation. The mat shall comply with the following physical properties:

Material type	Nylon 6 plus a minimum content of 0.5 percent by weight of carbon black
Filament diameter	0.0157 inch, minimum
Weight	0.747 + 0.075 lb/yd ²
Thickness	0.70 inch, minimum
Nominal width of roll	38 inch
Nominal length of roll	109 yard
Color	Black
Tensile properties ¹	
Strength	
Length direction	7.5 lb/inch, minimum
Width direction	4.4 lb/inch, minimum
Elongation	
Length direction	50 percent, minimum
Width direction	50 percent, minimum
Resiliency ²	
30 minute recovery (3 cycles)	80 percent, minimum

Pins shall be 1 inch x 2 inch x 12 inch wedge-shaped wood stakes or 12 inch x 12 inch x 6 inch, 0.162-inch gauge or larger, one-piece or two-piece, ungalvanized steel "T" pins.

Construction Requirements

All surfaces to be protected shall be graded and finished so as to be stable and firm. Prepared surfaces that become crusted shall be reworked to an acceptable condition before placing the mat.

¹ ASTM D 1682 Strip test procedure modified to obtain filament bond strength to indicate tensile properties.

² Compression load cycling of 100 lb/in² on 2 inch x 2 inch sample size, crosshead speed of 2 in/min.

Synthetic mat used as a ditch lining shall be applied with the length of roll laid parallel to the flow of water. Start the installation with the initial strip placed in the center of the ditch to avoid an overlap in the center of the ditch. Where more than one width is required, a longitudinal lap joint of not less than 3 inches shall be used, with the upslope width on top. All lap joints and upslope edges shall be pinned or staked at intervals of 3 feet or less.

All wood stakes shall be driven to within 2 inches of the ground surface. All steel pins shall be driven flush to the ground surface.

An anchor slot shall be placed at the upslope and downslope ends of the mat placement. At least 12 inches of the end of the mat shall be buried vertically in a slot dug in the soil. The mat shall be secured in the anchor slot by pins or stakes at intervals of 3 feet or less prior to burying. The soil shall be firmly tamped against the mat in the slot.

Successive lengths of mat shall be overlapped at least 3 feet, with the upstream length on top. Pin or stake the overlap by placing 3 pins or stakes evenly spaced across the end of each of the overlapping lengths and by placing 3 pins or stakes across the width of the center of overlap area. Check slots shall be constructed by placing a tight fold at least 8 inches vertically into the soil. Check slots shall be spaced so that a check slot occurs within each 25 feet. Pin or stake the mat in the check slot at each edge overlap and in the center of mat.

Upslope edges of mat used as ditch lining shall terminate on 6-inch wide horizontal shelves running parallel to the axis of the ditch for the full length of the ditch. Edges of the mat shall be pinned or staked at 3-foot intervals, backfilled with soil, and tamped to original slope.

After the mat has been placed, the area shall be evenly seeded as specified, allowing the seeds to drop to the grade through the openings in the mat.

The contractor shall maintain the blanket until all work on the contract has been completed and accepted. Maintenance shall consist of the repair of areas where damaged by any cause.

Measurement for Payment

Synthetic mat, including pins or stakes, complete, in place, and accepted, will be measured by the square yard of finished surface. Mat placed outside the specified limits will not be measured or paid for and the contractor may be required to remove and dispose of the excess mat without cost to the State.

Basis of Payment

Quantities shall be paid for at the contract unit price per square yard and shown in the bid schedule, which price shall be full compensation for furnishing all materials, tools, and labor; the preparation of the subgrade; placing of the mats; and all other work incidental to finished construction in accordance with these specifications.

FILTER BLANKET

Description

This work consists of furnishing materials and performing all work necessary to install filter blanket on roadway ditches or slopes, or as directed by the engineer.

Materials

The filter blanket will consist of one or more layers of gravel, crushed rock, or sand, of the thickness shown on the plans. The gradation of material in each layer of the filter blanket shall meet the requirements of the special provisions. All material comprising the filter blanket shall be composed of tough, durable particles; reasonably free from thin, flat, and elongated pieces; and shall be free from organic matter.

Construction Requirements

A filter blanket shall be placed on the prepared slope or area to the full specified thickness of each layer in one operation, using methods which will not cause segregation of particle sizes within the filter material. The surface of the finished layer should be reasonably even and free from mounds or windows. Multiple layers of filter material, when shown on the plans, shall be placed in the same manner, using methods which will not cause mixture of the material in the different layers.

The filter blanket shall be placed in accordance with various sections of these specifications requiring the use of a filter blanket or as specified by the engineer.

The contractor shall maintain the blanket until all work on the contract has been completed and accepted. Maintenance shall consist of the repair of areas where damaged by any cause.

Measurement for Payment

The quantity of filter blanket to be paid for, of specified thickness and extent, in place and accepted, shall be measured by the number of cubic yards as computed from surface measurement parallel to the riprap surface and thickness measured normal to the riprap surface. Blanket placed outside the specified limits will not be measured or paid for, and the contractor may be required to remove and dispose of the excess without cost to the State.

Basis of Payment

Quantities shall be paid for at the contract unit price per cubic yard, which price shall be full compensation for furnishing all materials, tools, and labor; the preparation of the subgrade; placing of the filter blanket; and all other work incidental to finished construction in accordance with these specifications.

ENGINEERING FABRIC

Description

This work consists of furnishing materials and performing all work necessary to install engineering fabric on roadway ditches or slopes, or as directed by the engineer.

Materials

The filter fabric shall be manufactured of polyester, nylon, or polypropylene material, or a combination thereof. The material shall not act as a wicking agent, shall be permeable, and shall conform to the following criteria:

	<u>For Edge Drains</u>	<u>For Underdrains</u>
Weight, ounces/yd ² , minimum ASTM Designation D 1910	40	4.0
Grab tensile strength (1-inch grip), lb, minimum ¹	50	90
Elongation, percent, minimum ASTM Designation, D 1682	10	30
Toughness, lb, minimum (percent elongation x grab tensile strength)	3,000	4,000

Construction Requirements

Engineering fabric shall be placed to the specified thickness in accordance with various sections of these specifications requiring the use of an engineering fabric or as specified by the engineer.

The contractor shall maintain the fabric until all work on the contract has been completed and accepted. Maintenance shall consist of the repair of areas where damaged by any cause.

Measurement for Payment

Engineering fabric to be paid for, of specified thickness and extent, in place and accepted, will be measured in square yards in accordance with the provisions in the various sections of these specifications, requiring the use of engineering fabric.

Basis of Payment

Quantities shall be paid for in accordance with the provisions in the various sections of these specifications requiring the use of engineering fabric.

¹ In each direction

GLOSSARY

ANGLE OF REPOSE. Angle of slope formed by particulate material under the critical equilibrium condition of incipient sliding.

APPARENT OPENING SIZE (AOS). Measure of the largest effective opening in an engineering fabric, as measured by the size of a glass bead where five percent or less by weight will pass through the fabric (formerly called the equivalent opening size, EOS).

COMPACTION. The closing of pore spaces among the particles of soil and rock, generally caused by running heavy equipment over the soil during construction.

DEPTH OF FLOW. Vertical distance from the bed of a channel to the water surface.

DESIGN DISCHARGE. Discharge at a specific location defined by an appropriate return period to be used for design purposes.

ENGINEERING FABRIC. Permeable textile (or filter fabric) used below riprap to prevent piping and permit natural seepage to occur.

FILTER BLANKET. One or more layers of graded noncohesive material placed below riprap to prevent soil piping and permit natural drainage.

FREEBOARD. Vertical distance from the water surface to the top of the channel at design condition.

GABION. Compartmented rectangular containers made of galvanized steel hexagonal wire mesh and filled with stone.

HYDRAULIC RADIUS. Flow area divided by wetted perimeter.

HYDRAULIC RESISTANCE. Resistance encountered by water as it moves through a channel, commonly described by Manning's n .

HYDROSTATIC PRESSURE. Pressure exerted at a depth below the water surface for flow at constant velocity or at rest.

INCIPIENT MOTION. Conditions at that point in time when any increase in factors responsible for particle movement causes motion.

LINING, COMPOSITE. Combination of lining materials in a given cross section (e.g., riprap in low-flow channel and vegetated upper banks).

LINING, FLEXIBLE. Lining material with the capacity to adjust to settlement typically constructed of a porous material that allows infiltration and exfiltration.

LINING, PERMANENT. Lining designed for long term use.

LINING, RIGID. Lining material with no capacity to adjust to settlement constructed of nonporous material with smooth finish that provides a large conveyance capacity (e.g., concrete, soil cement).

LINING, TEMPORARY. Lining designed for short term utilization, typically to assist in development of a permanent vegetative lining.

NORMAL DEPTH. Depth of a uniform channel flow.

PERMEABILITY. Property of a soil that enables water or air to move through it.

RETARDANCE CLASSIFICATION. Qualitative description of the resistance to flow offered by various types of vegetation.

RIPRAP. Broken rock, cobbles, or boulders placed on side slopes or in channels for protection against the action of water.

RIPRAP, DUMPED. Consists of stone or graded broken concrete dumped in place on a filter blanket or prepared slope to form a well-graded mass with a minimum of voids.

RIPRAP, GROUTED. Consists of riprap with all or part of the interstices filled with portland cement mortar.

RIPRAP, WIRE-ENCLOSED. Consists of wire baskets filled with stone, connected together, and anchored to the slope.

ROADWAY CHANNEL. Stabilized drainageway used to collect water from the roadway and adjacent areas and to deliver it to an inlet or main drainageway.

SHEAR STRESS. Force developed on the wetted area of the channel that acts in the direction of the flow; force per unit wetted area.

SHEAR STRESS, CHANNEL. Value of shear stress occurring in a channel section for a given set of hydraulic conditions.

SHEAR STRESS, PERMISSIBLE. Force at which the channel lining will fail.

SIDE SLOPE. Slope of the sides of a channel. It is customary to name the horizontal distance first as 1.5 to 1.0, or frequently 1-1/2:1, meaning a horizontal distance of 1.5 feet to 1-foot vertical.

SUPERELEVATION. Local increases in water surface on the outside of a bend.

TRACTIVE FORCE. Force developed due to the shear stress acting on the perimeter of a channel section which acts in the direction of flow on the channel bed. Equals the shear stress on the channel section multiplied by the wetted channel area.

UNIFORM FLOW. The flow condition where the rate of head loss due to friction is equal to bed slope of the channel (i.e., $S_f = S_0$ where S_f is the friction slope and S_0 is the bed slope).

VELOCITY, MEAN. Discharge divided by the area of the water cross section.

VELOCITY, PERMISSIBLE. Mean velocity that will not cause serious erosion of the channel.

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FHWA HEC-14, Chapter XI

Riprap Basins

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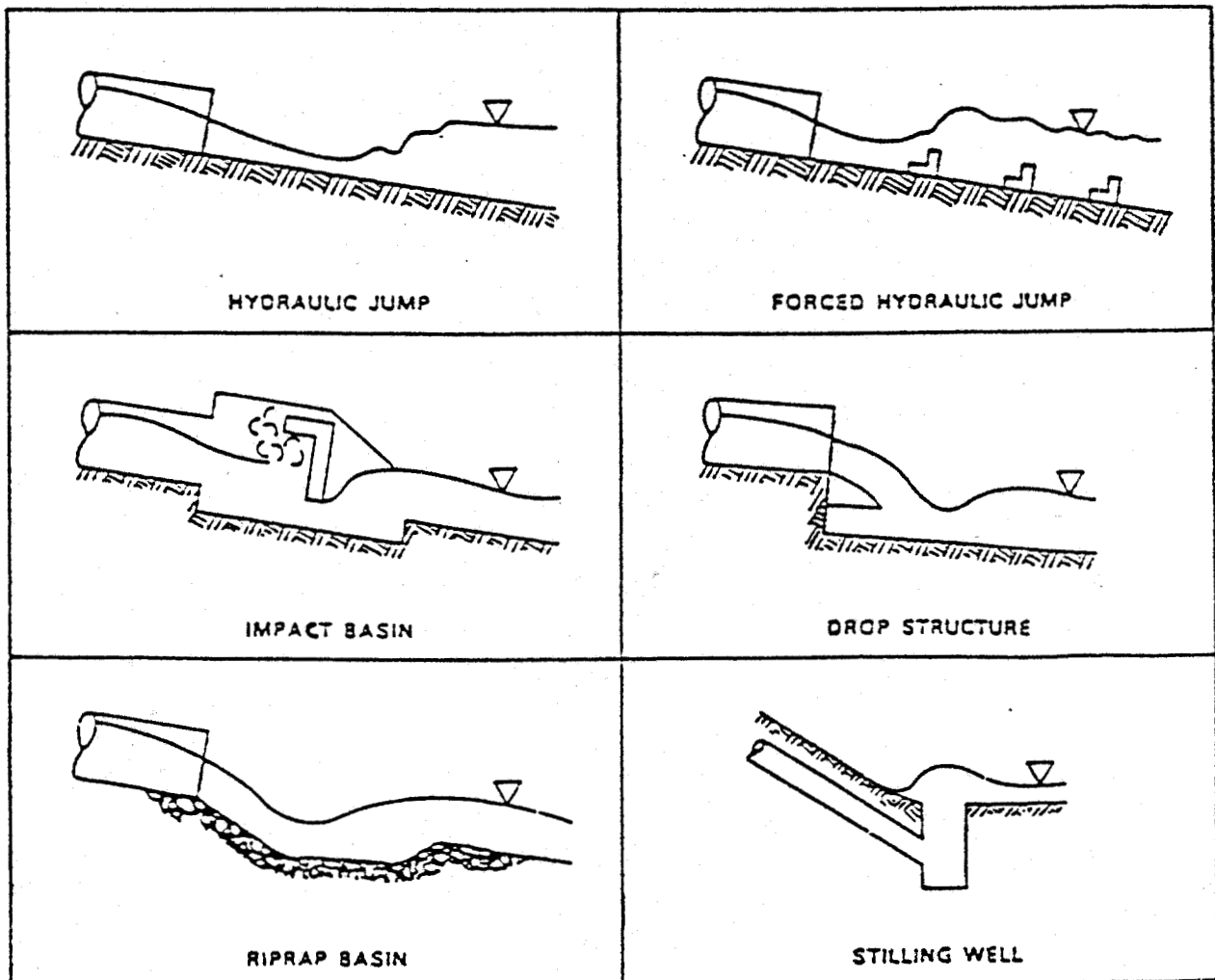
Hydraulic Design of Energy Dissipators for Culverts and Channels

Hydraulic Engineering
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U.S. Department
of Transportation
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PREFACE

The purpose of this circular is to provide design information for analyzing energy dissipation problems at culvert outlets and in open channels. The first five chapters of the circular provide general information to support the remaining design chapters. Design chapters VI-XI cover the general types of dissipators: hydraulic jump, forced hydraulic jump, impact, drop structure, stilling well, and riprap. The design concept presented in chapter I is illustrated in chapter 12, Design Selection. In this chapter, the different dissipator types are compared using design problems.

Much of the information presented has been taken from the literature and adapted, where necessary, to fit highway needs. Recent research results have been incorporated, wherever possible, and a field survey was conducted to determine the States' present practice and experience.

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TABLE OF CONTENTS

THE HYDRAULIC DESIGN OF ENERGY DISSIPATORS

<u>Chapter</u>	<u>Subject</u>	<u>Page</u>
Preface and Acknowledgments		i
Table of Contents		ii
List of Symbols		v
Metrication Conversion		vii
I. Design Concept		I
II. Erosion Hazards		II-1
A. Erosion Hazards At Culvert Inlets		II-1
Depressed Inlets		II-1
Headwalls and Wingwall		II-2
Inlet Failures		II-3
B. Erosion Hazards At Culvert Outlets		II-3
Types of Scour		II-4
Standard Culvert Outlet Treatments		II-5
C. Riprap Protection		II-5
III. Culvert Outlet Velocity and Velocity Modification		III-1
On Mild Slopes		III-1
On Steep Slopes		III-3
IV. Flow Transitions		IV-1
A. Culverts in Outlet Control		IV-1
Abrupt Expansion		IV-3

Design of Subcritical Flow Transitions	IV-6
B. Culverts in Inlet Control	IV-18
Supercritical Flow Contraction	IV-18
Supercritical Flow Expansion	IV-25
V. Estimating Erosion of Culvert Outlets	V-1
VI. Hydraulic Jump	VI-1
A. Nature of the Hydraulic Jump	VI-1
B. Hydraulic Jump Expressions	VI-4
Horizontal Channels	VI-4
Sloping Channels	VI-12
C. Jump Efficiency	VI-16
VII. Forced Hydraulic Jump and Increased Resistance	
A. Colorado State University (CSU) Rigid Boundary Basin	VII-A-1
B. Tumbling Flow in Culverts	VII-B-1
C. Increased Culvert Resistance	VII-C-1
D. U.S. Bureau of Reclamation (USBR) Type II . .	VII-D-1
E. USBR Type III	VII-E-1
F. USBR Type IV	VII-F-1
G. St. Anthony Falls (SAF) Basin	VII-G-1
VIII. Impact Basins	
A. Contra Costa	VIII-A-1
B. Hook	VIII-B-1
C. USBR Type VI	VIII-C-1

D. Forest Service (Metal)	VIII-D-1
IX. Drop Structures	IX-1
X. Stilling Wells	
A. Manifold Type	X-A-1
B. Corps of Engineers	X-B-1
XI. Riprap	XI-1
XII. Design Selection	XII-1
Appendix A (Computation Forms)	A-1

LIST OF SYMBOLS

Note: For specific definitions refer to each chapter.

A	Cross-sectional area of flow
a	Acceleration
B	Width of rectangular culvert barrel
c	Proportionality constant; subscript for critical conditions
D	Diameter or height of culvert barrel
E	Energy
Fr	Froude number
f	Darcy-Weisbach resistance coefficient
F	Force
g	Acceleration of gravity
H	Energy head
h	Vertical dimension
H _L	Head loss (total)
H _f	Friction head loss
L	Distance, length, longitudinal dimension
M	Momentum
m	Mass
N	Number
n	Manning roughness coefficient; coordinate normal to flow direction
o	Subscript for culvert outlet parameters
P	Wetted perimeter
p	Pressure
Q	Discharge

q	Discharge per unit width
R	Hydraulic radius
Re	Reynolds number
r	Radius; cylindrical coordinate
S	Slope
S _f	Slope of energy grade line
S _o	Slope of the bed
S _w	Slope of the water surface
T	Top width of water surface
TW	Tailwater Depth
t	Time variable; thickness dimension
V	Mean velocity
V	Volume
v	Velocity at a point
W	Transverse dimension; width
w	Weight
y	Depth of flow
y _e	Equivalent depth = $(A/2)^{1/2}$
y _m	Hydraulic depth: area/top width (A/T)
y _n	Normal depth of flow
y _c	Critical depth of flow
z	Side slope; stream bed elevation
Z	Water surface elevation

- α Kinetic energy coefficient; inclination angle
- β Velocity (momentum) coefficient; wave front angle
- γ Specific weight
- Δ Small increment
- θ Angle: inclination, contraction, central
- μ Dynamic viscosity
- ν Kinetic viscosity
- ρ Mass density of fluid (1.94 slugs/cu. ft. for water)
- Σ Summation symbol
- τ Shear stress

Conversion Factors for British to Metric Units

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
inches	2.54	centimeters
feet	0.3048	meters
feet per second	0.3048	meters per second
cubic feet per second	0.028317	cubic meters per second
pounds	0.453592	kilograms

XI. RIPRAP BASINS

The design procedure for riprap energy dissipators is based on data obtained during a study "Flood Protection at Culvert Outfalls" (XI-1, XI-2) sponsored by the Wyoming Highway Department and conducted at Colorado State University. The purpose of the experimental program was to establish relationships between flow properties and the dimensions of riprapped basins at culvert outfalls.

Tests were conducted with 6-inch, 12-inch, 18-inch, and 36-inch pipes, and 6 by 12-inch, 6 by 18-inch, and 6 by 24-inch model box culverts with discharges ranging from 0.1 to 100 cfs. Both angular and rounded rock with an average size (d_{50}) ranging from 1.05 to 4.29 were tested. Two pipe slopes were considered, 0 and 3.75%. In all, 459 model basins were studied.

The following conclusions were drawn from an analysis of the experimental data and observed operating characteristics.

The depth (h_s), length (L_s), and width (W_s) of the scour hole were related to the characteristic size of riprap (d_{50}), discharge (Q), brink depth (y_o), and tailwater depth (TW).

The dimensions of a scour hole in a basin constructed with angular rock were approximately the same as the dimensions of a scour hole in a basin constructed of rounded material when rock size and other variables were similar.

When the ratio of tailwater depth to brink depth (TW/y_o) was less than 0.75 and the ratio of scour depth to size of riprap (h_s/d_{50}) was greater than 2.0, and the scour hole functioned very efficiently as an energy dissipator. The concentrated flow at the culvert brink plunged into the hole, a jump formed against the downstream extremity of the scour hole, and flow was generally well dispersed as it left the basin.

The mound of material which formed on the bed downstream of the scour hole contributed to the dissipation of energy and reduced the size of the scour hole; i.e., if the mound from a stable scoured basin was removed and the basin was again subjected to design flow, the scour hole enlarged somewhat.

For high tailwater basins (TW/y_o greater than 0.75) the high velocity core of water emerging from the culvert retained its jetlike character as it passed through the basin, and diffused in a manner very similar to that of a concentrated jet diffusing in a large body of water. As a result, the scour hole was much shallower and generally longer. Consequently, riprap may be required for the channel downstream of the rock-lined basin.

General details of the basin recommended in this report are shown on figure XI-1. Principal features of the basin are:

1. The basin is preshaped and lined with riprap.
2. The surface of the riprapped floor of the energy dissipating pool is constructed at an elevation h_s below the culvert invert. h_s is the approximate depth of scour that would occur in a thick pad of riprap, constructed at the outfall of the culvert, if subjected to the design discharge. The ratio of h_s to d_{50} of the material should be greater than 2 and less than 4.
3. The length of the energy dissipating pool is $10(h_s)$ or $3W_o$ which ever is larger. The overall length of the basin is $15(h_s)$ or $4W_o$ which ever is larger.

DESIGN PROCEDURE

1. Estimate the flow properties at the brink of the culvert. Establish the brink invert elevation such that $TW/y_o \leq 0.75$ for design discharge.
2. For subcritical flow conditions (culvert set on mild or horizontal slope) utilize figures III-9 or III-10 to obtain y_o/D , then obtain V_o by dividing Q by the wetted area associated with y_o . D is the height of a box culvert. If the culvert is on a steep slope, V_o will be the normal velocity obtained by using the Manning equation for appropriate slope, section, and discharge.
3. From site inspection and from field experience in the area, determine whether or not channel protection is required at the culvert outlet.

4. If channel protection is required, compute the Froude number for brink conditions ($y_e = (A/2)^{1/2}$). Select d_{50}/y_e appropriate for locally available riprap (usually the most satisfactory results will be obtained if $0.25 < d_{50}/y_e < 0.45$). Obtain h_s/y_e from figure XI-2, and check to see that $2 < h_s/d_{50} < 4$. Recycle computations if h_s/d_{50} falls out of this range.
5. Size basin as shown in figure XI-1.
6. Design procedures where allowable dissipator exit velocity is specified:
 - a. Determine the average normal flow depth in the natural channel for the design discharge.
 - b. Extended the length of the energy basin (if necessary) so that the width of the energy basin at section A-A, figures XI-1, times the average normal flow depth in the natural channel is approximately equal to the design discharge divided by the specified exit velocity.
7. In the exit region of the basin, the walls and apron of the basin should be warped (or transitioned) so that the cross section of the basin at the exit conforms to the cross section of the natural channel. Abrupt transition of surfaces should be avoided to minimize separation zones and resultant eddies.
8. If high tailwater is a possibility and erosion protection is necessary for the downstream channel, the following design procedure is suggested:

Design a conventional basin for low tailwater conditions in accordance with the instructions above. Estimate centerline velocity at a series of downstream cross sections using the information shown in figure XI-3. Shape downstream channel and size riprap using figure II-C-1 and the stream velocities obtained above. Material, construction techniques, and design details for riprap should be in accordance with specifications in HEC No. 11 (XI-3) or similar highway department specifications.

Design Example No. 1

Given: 8 ft. by 6 ft. box culvert, $Q=800$ cfs, supercritical flow in culvert, normal flow depth = brink depth $y_o=4$ ft., Tailwater depth $TW=2.8$ ft.

Find: Riprap basin dimensions for these conditions:

Solution:

1. $y_o = y_e$ for rectangular section, $y_e = 4$ ft.
2. $V_o = Q/A = 800/(4)(8) = 25$ fps
3. $Fr = V_o / [(32.2)(y_e)]^{1/2} = 25 / [(32.2)(4)]^{1/2} = 2.20$
4. $TW/y_e = 2.8/4.0 = 0.7$ $TW/y_e < 0.75$ O.K.
5. Try $d_{50}/y_e = 0.45$, $d_{50} = (0.45)(4) = 1.80$ ft.

From figure XI-2, $h_s/y_e = 1.6$

$$h_s = (4)(1.6) = 6.4 \text{ ft.}$$

$$h_s/d_{50} = 6.4/1.8 = 3.6 \text{ ft.} \quad 2 < h_s/d_{50} < 4 \text{ O.K.}$$

6. $L_s = (10)(6.4) = 64$ ft.
 $L_{s \text{ min}} = (3)(W_o) = (3)(8) = 24$ ft., use $L_s = 64$ ft.
 $L_B = (15)(6.4) = 96$ ft.
 $L_{B \text{ min}} = (4)(W_o) = (4)(8) = 32$ ft., use $L_B = 96$ ft.

Other basin dimensions designed in accordance with details shown in figure XI-1.

Design Example No. 2

Given: 8 ft. by 6 ft. box culvert, $Q = 800$ cfs, supercritical flow in culvert, normal flow depth = brink depth, $y_o = 4$ ft., tailwater depth, $TW = 4.2$ ft., downstream channel can tolerate 7 fps for design discharge.

Find: Riprap basin dimensions for these conditions.

Solution:

Note--High tailwater depth, $TW/y_o = 1.05 > 0.75$

1. Design riprap basin (Design Example 1) use steps 1-7
 $d_{50} = 1.8$ ft., $h_s = 6.4$ ft., $L_s = 64$ ft., $L_B = 96$ ft.
8. Design riprap for downstream channel. Utilize figure XI-3 for estimating average velocity along the channel. Compute equivalent circular diameter D_e for brink area from:

$$A = \pi D_e^2 / 4 = (y_o)(W_o) = (4)(8) = 32 \text{ ft.}^2$$

$$D_e = [32(4)/\pi]^{1/2}$$

$$D_e = 6.4 \text{ ft.}$$

$$V_o = 25 \text{ fps (Design Example 1)}$$

<u>L/De</u>	<u>L</u>	<u>V_L/V_O</u>	<u>V_L</u>	<u>Rock size d₅₀</u>
	(Compute)	(Figure XI-3)		Figure II-C-1
	ft.		ft./ sec	ft.
10	64	0.59	14.7	1.4
15	96	0.36	9.0	0.6
20	128	0.30	7.5	0.4
21	135	0.28	7.0	0.4

Riprap should be at least the size shown. As a practical consideration, the channel can be lined with the same size rock used for the basin. Protection must extend at least 135 feet downstream from the culvert brink. Channel should be shaped and riprap should be installed in accordance with details shown in HEC No. 11.

Design Example No. 3

Given: 6 feet diameter cmp, $Q=135$ cfs, $S_o=0.004$, Mannings $n=0.024$ normal depth in pipe for $Q=135$ cfs is 4.5 feet, normal velocity is 5.9 fps, flow is subcritical, tailwater depth (TW) is 2.0 feet.

Find: Riprap basin dimensions for these conditions:

Solution:

1. Determine y_o and V_o :

$$Q/D^{2.5} = 135/(6)^{2.5} = 1.53$$

$$TW/D = 2.0/6 = 0.33$$

From figure III-9, $y_o/D = 0.45$

$$y_o = (0.45)(6) = 2.7 \text{ ft.}$$

$$TW/y_o = 2.0/2.70 = 0.74 \quad TW/y_o < 0.75 \quad \text{O.K.}$$

Brink Area (A) for $y_o/D = 0.45$ is

$$A = (0.343)(36) = 12.3 \text{ sq. ft.}$$

(0.343 is from table III-2)

$$V_o = Q/A = 135/12.3 = 11.0 \text{ fps}$$

2. $y_e = (A/2)^{1/2} = (12.3/2)^{1/2} = 2.48 \text{ ft.}$

3. $Fr = V_o / [(32.2)(y_e)]^{1/2} = 11 / [(32.2)(2.48)]^{1/2} = 1.23$

4. Try $d_{50}/y_e = 0.25$, $d_{50} = (0.25)(2.48) = 0.62 \text{ ft.}$

From figure XI-2, $h_s/y_e = 0.75$, $h_s = (0.75)(2.48) = 1.86 \text{ ft.}$

check: $h_s/d_{50} = 1.86/0.62 = 3$, $2 < h_s/d_{50} < 4$ O.K.

$$5. \quad L_S = (10) (h_S) = (10) (1.86) = 18.6 \text{ ft.}$$

$$\text{or } L_S = (3) (W_O) = (3) (6) = 18 \text{ ft., Use } L_S = 18.6 \text{ ft.}$$

$$L_B = (15) (h_S) = (15) (1.86) = 27.9 \text{ ft.}$$

$$\text{or } L_B = (4) (W_O) = (4) (6) = 24 \text{ ft., Use } L_B = 27.9 \text{ ft.}$$

$$d_{50} = 0.62 \text{ ft. use } d_{50} = 8 \text{ in.}$$

Other basin dimensions are designed in accordance with details shown on figure XI-1.

The design procedure recommended in this chapter is a compromise between the design procedure utilizing the CSU experimentally derived functional relationships and traditional design methods for riprapped basins. It is recognized that there is some chance of limited degradation of the floor of the dissipator pool for rare event discharges. With the protection afforded by the $2(d_{50})$ thickness of riprap by the heavy layer of riprap adjacent to the roadway prism, and the apron riprap in the downstream portion of the basin, the damage should be superficial.

Concerning the use of filter material, several factors should be considered. Bank material adjacent to a culvert is not subjected to flow for long continuous periods. Also, the streambed material may be sufficiently well graded and not require a filter. If some siltation of the basin accompanied by plant growth is anticipated, it may be that a filter will not be required. If required, a filter cloth or filter material designed in accordance with instructions in reference XI-3 should be specified.

DISCUSSION

CSU Design Procedure

Design criteria were developed for three types of rock riprapped basins, the "standard non-scouring basin," the "hybrid basin," and the "standard scoured basin" (XI-2). Experimental data were used to establish empirical relationships between the following dimensionless parameters:

1. Froude number at the culvert outfall
2. relative grain size of riprap
3. relative tailwater depth
4. relative depth of scour hole

5. relative width of scour hole
6. relative length of scour hole

An excellent correlation of data was achieved by utilizing a weighted particle size (d_m) for scaling the grain size of riprap. However, the weighted particle size, d_m , is an unfamiliar parameter to most hydraulic engineers and is also difficult to obtain for quarry-run rock. For these reasons, the more familiar d_{50} (the median size of rock by weight) is used to characterize rock size in the design procedures presented in this manual.

The design procedure suggested by the CSU study is also very sensitive to tailwater depth and is somewhat cumbersome to use. The method requires a conversion of Froude numbers when a culvert operates with a free surface (the usual case) and requires a conversion of Froude numbers from circular pipe flow to rectangular pipe flow (or vice versa) if the designer wishes to use the complete range of design data for both pipe and box culvert basins. Because of these complexities, a simplified design procedure was developed. The information and design procedures from the CSU studies suggested the design parameters and the CSU data (XI-1) were utilized for developing design relationships.

Design Procedure Development

The design criteria specified in this report were developed in the following manner:

1. All CSU scour data for circular and rectangular pipes, angular and rounded material, sloping and horizontal pipes for plain outfall conditions were used for development of design aids. (Note, data for scour holes formed below model culverts constructed with standard or modified end sections were not used and data for $d_{50}/y_e < 0.1$ were not used.)

In all, data from 347 runs were used for this development. This included data for 6-inch, 12-inch, 18-inch, and 36-inch pipes and 6 by 12-inch, 6 by 18-inch, and 6 by 24-inch model box culverts. Two pipe slopes were considered, 0 and 3.75%. Discharges ranged from 0.1 to 100 cfs for basins constructed with angular and rounded rock with median rock size (d_{50}) ranging from 0.02 to 0.58 ft. Only data from runs with gradation coefficients ranging from 1.05 to 2.66 were used.

The gradation coefficient σ is defined as

$$\sigma = 1/2(d_{84}/d_{50} + d_{50}/d_{16})$$

and is a means of describing whether the rock mixture is predominantly one size or a range of sizes. When σ is near one, all material is about the same size. Where rock sizes extend over a large range, σ takes on larger values. The gradation coefficient σ of riprap will be satisfactory for design purposes if the gradation curve for the riprap is similar to curves for rock A(24) or B(16) shown in figure 8 of HEC No. 11, (XI-3).

2. Based upon an examination of CSU plots and data, the following significant dimensionless parameters were selected:
 - a. d_{50}/y_e --the relative size of riprap defined as the ratio of the median size by weight of the rock mixture to the equivalent depth of water at the brink of the culvert. The equivalent depth y_e is defined as the brink depth for box culverts, and $(A/2)^{1/2}$ for non-rectangular sections, where A is the wetted area at the brink of the culvert. y_e computed in this manner is the height of a rectangle twice as wide as it is high with an area equal to the wetted area of the non-rectangular section.
 - b. h_s/y_e --the relative depth of scour. h_s is the depth from the invert of the culvert at the brink to the lowest point in the scour hole (figure XI-1).
 - c. $Fr = V_o/[(g)(y_e)]^{1/2}$ --the Froude number at the brink of the culvert. V_o is the average velocity of flow at the brink of the culvert (discharge Q divided by wetted area, A) and g is the acceleration of gravity. This definition of the Froude number eliminates the intervening steps of converting non-full pipe flow to full-pipe flow and Froude numbers for circular pipe flow to Froude numbers for rectangular pipe flow (or vice versa) as is required by the CSU procedure.
 - d. TW/y_e --the relative depth of tailwater. TW is the depth of tailwater referenced to the culvert invert.

3. The dimensionless parameters cited above were computed for each set of data and were segregated into the following categories:

$$0.10 < d_{50}/y_e < 0.2$$

$$0.21 < d_{50}/y_e < 0.3$$

$$0.31 < d_{50}/y_e < 0.4$$

$$0.41 < d_{50}/y_e < 0.5$$

$$0.51 < d_{50}/y_e < 0.6$$

$$0.61 < d_{50}/y_e < 0.7$$

4. For each subset of data (as an example, all data for the condition that $0.21 < d_{50}/y_e < 0.30$) the data were further subdivided into the following categories:

- a. model pipe culverts with a diameter equal to or less than 1 ft., basin constructed with rounded material,
- b. model pipe culvert with a diameter equal to or less than 1 ft., basin constructed with angular material,
- c. model pipe culvert with a diameter greater than 1 ft., basin constructed with rounded material,
- d. model pipe culvert with a diameter greater than 1 ft., basin constructed with angular material, and
- e. model box culverts with a height of 0.5 ft., basin constructed with rounded material (the only material tested for box culverts).

5. A symbol associated with the magnitude of the relative tailwater depth (in increments of 0.2) was assigned to each data point for each of the categories designated in 4) above (i.e., if $TW/y_e = 0.51$ for a particular run, the symbol associated with $0.41 < TW/y_e < 0.6$ was assigned to the data point).

6. A series of plots of relative depth of scour h_s/y_e versus the Froude number $V_o/[(g)(y_e)]^{1/2}$ were constructed with the relative size of riprap d_{50}/y_e as a third variable. By symbol and color code the various categories described in 4) and 5) above could be identified on the plots. Additional supplemental plots were also constructed to help identify significant parameters.

The parameters selected grouped the data in a systematic way though there was significant scatter. Scour depth did not appear to be a function of angular or rounded riprap. Data from pipe runs could not be segregated from data for box culvert. The only scale effect that could be detected were associated with high Froude number (>3.0) runs where model flow depths were on the order of one-half foot with tailwater depths of 0 to 2 inches. The scaled riprap was approximately one-half inch in size.

Because of the difficulty in obtaining precise measurements in models of this size and also because of the possibility of scale effects with small scale models these data points were not given quite as much consideration when design curves were developed. However, these data were used to establish the approximate slope of design curves.

Relative tailwater depth was a significant variable. For conditions where all other variables were similar, maximum scour depths were associated with low tailwater depths. Maximum length of scour holes were associated with high tailwater depths.

When considering a culvert installation, several points are obvious. For ephemeral, flashy streams usually associated with culvert crossings, the tailwater depth will lag significantly when the stream is rising. Thus, low tailwater will always exist at least up to the point when and if equilibrium conditions occur. Also, because of seasonal changes in vegetation, changes in downstream channel cross section as a result of flood events or man's activity, and the general difficulty in obtaining channel properties in poorly defined ephemeral streams, the computed tailwater depth will be at best an estimate. For these reasons it was decided to base design criteria on the assumption that the worst possible tailwater conditions exist, i.e., low tailwater conditions.

On the basis of the above assumptions, envelope curves were constructed for each plot of h_s/y_e versus $V_o/[(g)y_e]^{1/2}$ with d_{50}/y_e as the third variable.

On each plot, the curve was drawn to the left of approximately 98% of the data points and thus the predicted scour based on the use of a curve will be as deep or deeper than was actually measured in the model basin for the worst possible tailwater condition. These envelope curves were then transposed to one plot (figure XI-2) and are the basic design curves for determining h_s as a function of exit velocity, equivalent brink depth, and d_{50} .

Additional information necessary to design a basin includes geometric dimensions, minimum thickness of riprap, approximate shape of gradation curve of riprap, sideslopes of basin, and a determination of whether or not a filter blanket is required.

Length of Basin

Frequency tables for both box culvert data and pipe culvert data of relative length of scour hole ($L_s/h_s < 6$, $6 < L_s/h_s < 7$, $7 < L_s/h_s < 8$. . . $25 < L_s/h_s < 30$), with relative tailwater depth TW/y_e in increments of 0.1 feet as a third variable were constructed utilizing all data from 347 experimental runs. For box culvert runs L_s/h_s was less than 10 for 78% of the data and L_s/h_s was less than 15 for 98% of the data. For pipe culverts, L_s/h_s was less than 10 for 91% of the data and, L_s/h_s was less than 15 for all data.

For all cases the data considered were restricted to relative tailwater depths of less than 0.75. Large values of relative length of scour L_s/h_s were always associated with high tailwater conditions. The curves to be used to predict h_s (the value of h_s to be used for computing L_s the length of energy dissipating pool, in the design procedure) are based on maximum observed scour depths which in turn were always associated with minimum tailwater depths. Based on this argument, a conservative prediction ratio for obtaining a design estimate of relative length of preshaped scour hole is $L_s/h_s > 10$ and relative overall length of basin is $L_B/h_s > 15$. From a practical viewpoint, the length of the pool L_s should be at least $3W_o$ and L_B should be at least $4W_o$. W_o is the width of the culvert outlet. The dimension L_B is the out-to-out length of the riprap basin measured from the culvert brink to the end of the basin.

Other Basin Details

The $2(d_{50})$ or $1.50(d_{max})$, d_{max} is the maximum size of rock in the riprap mixture, thickness of riprap for the floor and sides of basin are based on experience with conventional riprap design. Thickening of the riprap layer to $3(d_{50})$ or $2(d_{max})$ on the foreslope of the roadway culvert outlet is warranted because of the severity of attack in the area and the necessity for preventing significant undermining and consequent collapse of the culvert.

A 3:1 flare angle is recommended for the basins walls. This angle will provide a sufficiently wide energy dissipating pool for good basin operation.

The mixture of stone used for riprap should meet the specifications (material, gradation, etc.) described in HEC No. 11, (XI-3).

- XI-1. Stevens. M. A., and Simons, D. B., EXPERIMENTAL PROGRAMS AND BASIC DATA FOR STUDIES OF SCOUR IN RIPRAP AT CULVERT OUTFALLS, Colorado State University, Fort Collins, Colorado, CER 70-71-MAS-DBS-57, 1971.
- XI-2. Simons, D. B., Stevens, M. A., Watts, F. J., FLOOD PROTECTION AT CULVERT OUTLETS, Colorado State University, Fort Collins, Colorado, CER 69-70 DBS-MAS-FJW4, 1970.
- XI-3. U. S. Department of Transportation, USE OF RIPRAP FOR BANK PROTECTION, Hydraulic Engineering Circular No. 11, Government Printing Office, Washington, D.C., 1967.
- XI-4. U.S. Army, Corps of Engineers, RIPRAP STABILITY ON EARTH EMBANKMENTS TESTED IN LARGE- AND SMALL-SCALE WAVE TANKS, Technical Memorandum No. 37, Coastal Engineering Research Center, Washington, D.C., 1972.

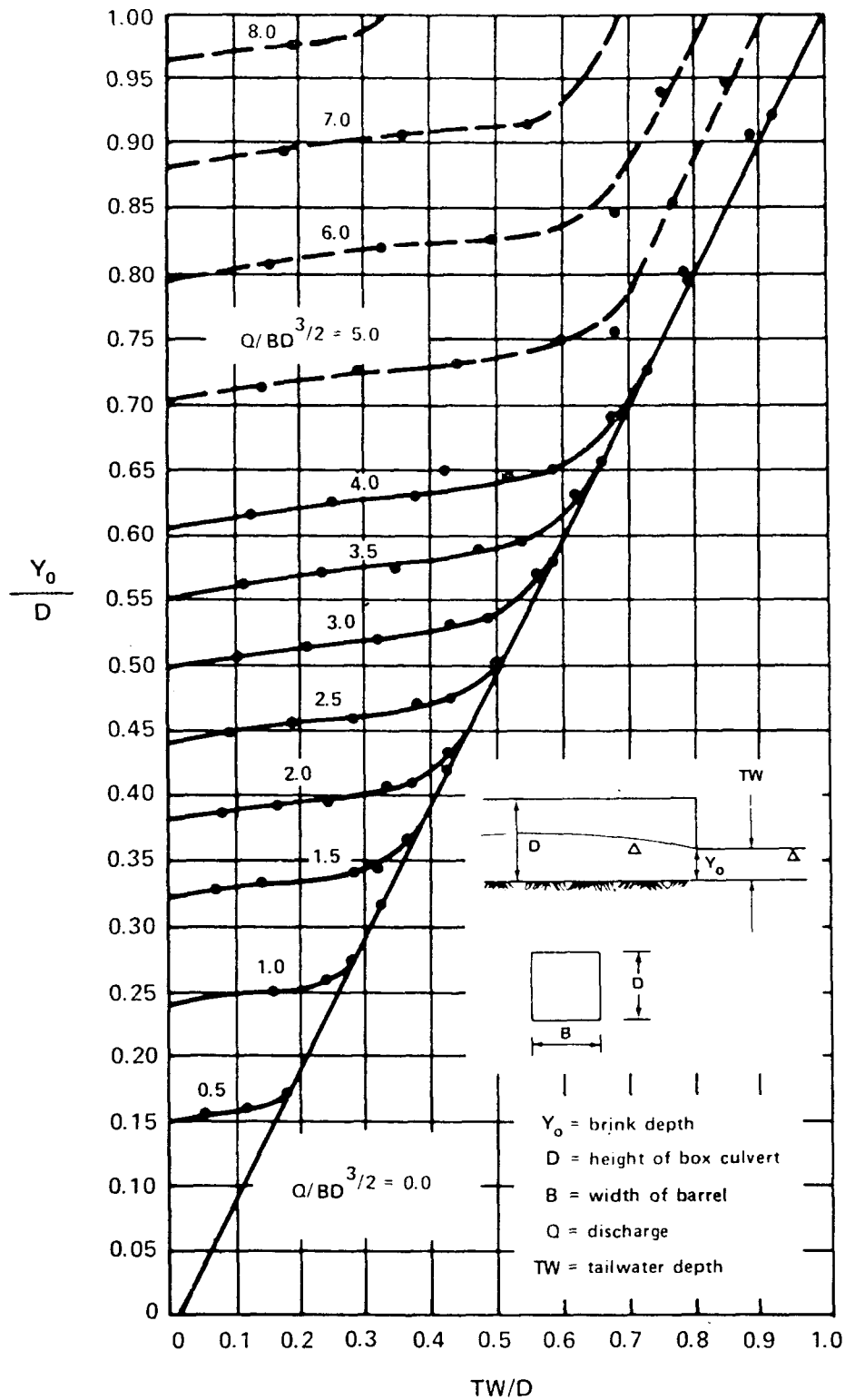


Figure III-9 Dimensionless Rating Curves for the Outlets of Rectangular Culverts on Horizontal and Mild Slopes from Reference III-2

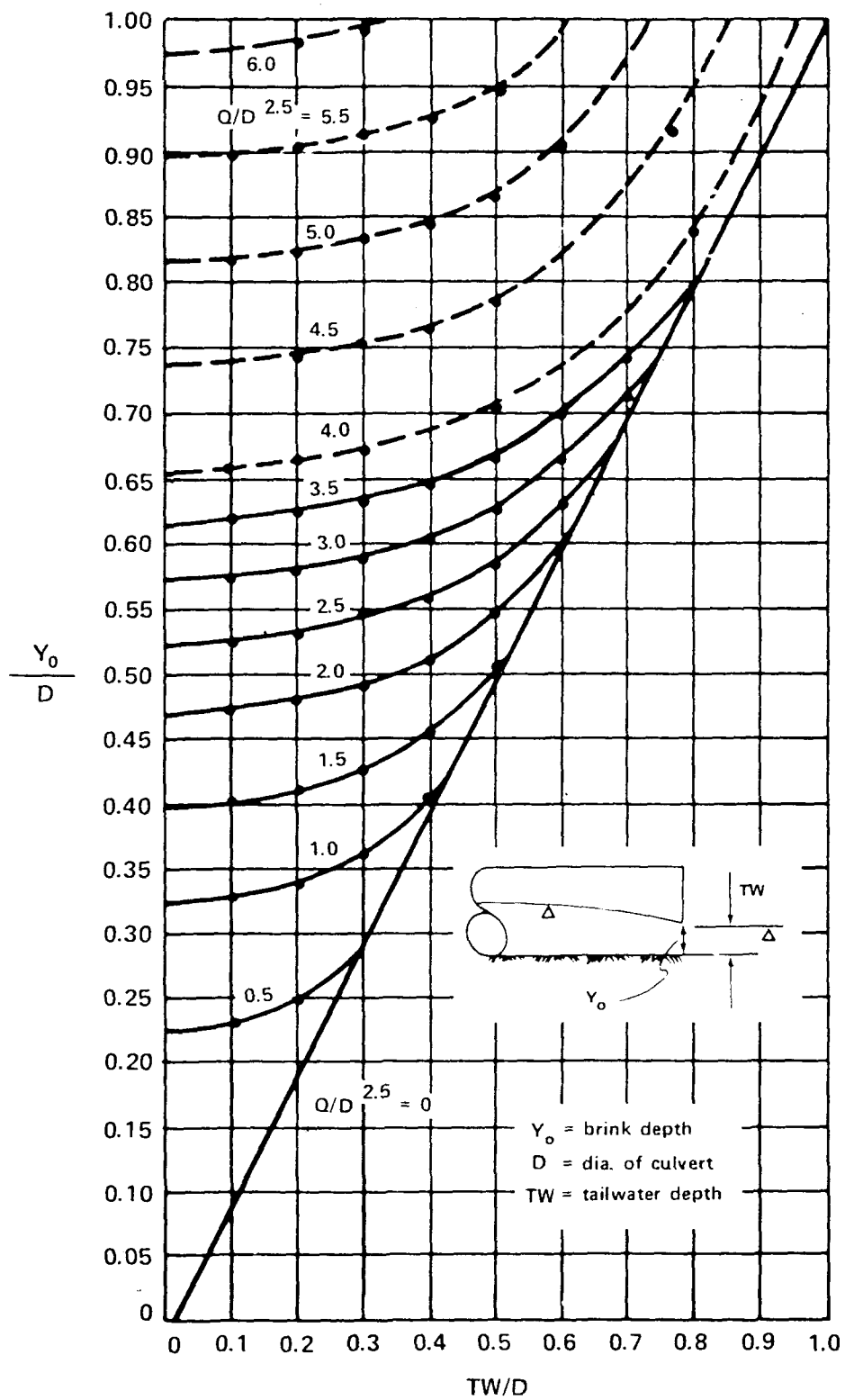


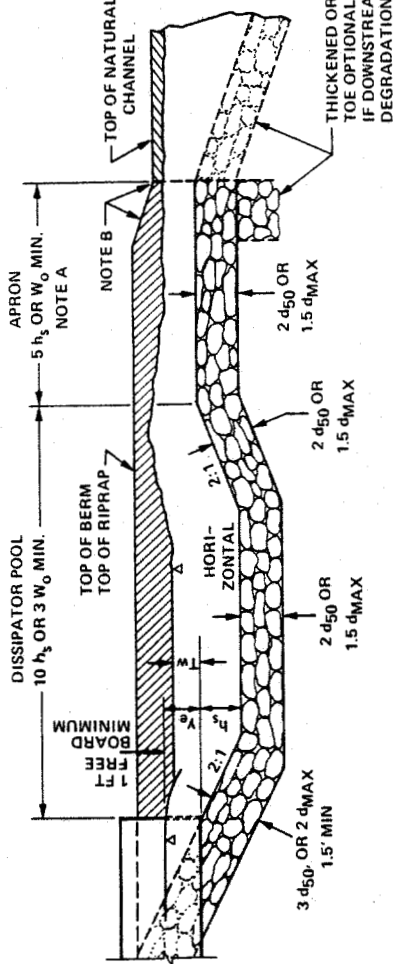
Figure III-10 Dimensionless Rating Curve for the Outlets of Circular Culverts on Horizontal and Mild Slopes from Reference III-2

Table III-2.—Uniform flow in circular sections flowing partly full. From Reference III-3.

d = depth of flow D = diameter of pipe A = area of flow R = hydraulic radius					Q = discharge in cubic feet per second by Manning's formula n = Manning's coefficient S = slope of the channel bottom and of the water surface				
$\frac{d}{D}$	$\frac{A}{D^2}$	$\frac{R}{D}$	$\frac{Qn}{D^{8/3}S^{1/2}}$	$\frac{Qn}{d^{8/3}S^{1/2}}$	$\frac{d}{D}$	$\frac{A}{D^2}$	$\frac{R}{D}$	$\frac{Qn}{D^{8/3}S^{1/2}}$	$\frac{Qn}{d^{8/3}S^{1/2}}$
0.01	0.0013	0.0066	0.00007	15.04	0.51	0.4027	0.2531	0.239	1.442
0.02	0.0037	0.0132	0.00031	10.57	0.52	0.4127	0.2562	0.247	1.415
0.03	0.0069	0.0197	0.00074	8.56	0.53	0.4227	0.2592	0.255	1.388
0.04	0.0105	0.0262	0.00138	7.38	0.54	0.4327	0.2621	0.263	1.362
0.05	0.0147	0.0325	0.00222	6.55	0.55	0.4426	0.2649	0.271	1.336
0.06	0.0192	0.0389	0.00328	5.95	0.56	0.4526	0.2676	0.279	1.311
0.07	0.0242	0.0451	0.00455	5.47	0.57	0.4625	0.2703	0.287	1.286
0.08	0.0294	0.0513	0.00604	5.09	0.58	0.4724	0.2728	0.295	1.262
0.09	0.0350	0.0575	0.00775	4.76	0.59	0.4822	0.2753	0.303	1.238
0.10	0.0409	0.0635	0.00967	4.49	0.60	0.4920	0.2776	0.311	1.215
0.11	0.0470	0.0695	0.01181	4.25	0.61	0.5018	0.2799	0.319	1.192
0.12	0.0534	0.0755	0.01417	4.04	0.62	0.5115	0.2821	0.327	1.170
0.13	0.0600	0.0813	0.01674	3.86	0.63	0.5212	0.2842	0.335	1.148
0.14	0.0668	0.0871	0.01952	3.69	0.64	0.5308	0.2862	0.343	1.126
0.15	0.0739	0.0929	0.0225	3.54	0.65	0.5404	0.2882	0.350	1.105
0.16	0.0811	0.0985	0.0257	3.41	0.66	0.5499	0.2900	0.358	1.084
0.17	0.0885	0.1042	0.0291	3.28	0.67	0.5594	0.2917	0.366	1.064
0.18	0.0961	0.1097	0.0327	3.17	0.68	0.5687	0.2933	0.373	1.044
0.19	0.1039	0.1152	0.0365	3.06	0.69	0.5780	0.2948	0.380	1.024
0.20	0.1118	0.1206	0.0406	2.96	0.70	0.5872	0.2962	0.388	1.004
0.21	0.1199	0.1259	0.0448	2.87	0.71	0.5964	0.2975	0.395	0.985
0.22	0.1281	0.1312	0.0492	2.79	0.72	0.6054	0.2987	0.402	0.965
0.23	0.1365	0.1364	0.0537	2.71	0.73	0.6143	0.2998	0.409	0.947
0.24	0.1449	0.1416	0.0585	2.63	0.74	0.6231	0.3008	0.416	0.928
0.25	0.1535	0.1466	0.0634	2.56	0.75	0.6319	0.3017	0.422	0.910
0.26	0.1623	0.1516	0.0686	2.49	0.76	0.6405	0.3024	0.429	0.891
0.27	0.1711	0.1566	0.0739	2.42	0.77	0.6489	0.3031	0.435	0.873
0.28	0.1800	0.1614	0.0793	2.36	0.78	0.6573	0.3036	0.441	0.856
0.29	0.1890	0.1662	0.0849	2.30	0.79	0.6655	0.3039	0.447	0.838
0.30	0.1982	0.1709	0.0907	2.25	0.80	0.6736	0.3042	0.453	0.821
0.31	0.2074	0.1756	0.0966	2.20	0.81	0.6815	0.3043	0.458	0.804
0.32	0.2167	0.1802	0.1027	2.14	0.82	0.6893	0.3043	0.463	0.787
0.33	0.2260	0.1847	0.1089	2.09	0.83	0.6969	0.3041	0.468	0.770
0.34	0.2355	0.1891	0.1153	2.05	0.84	0.7043	0.3038	0.473	0.753
0.35	0.2450	0.1935	0.1218	2.00	0.85	0.7115	0.3033	0.477	0.736
0.36	0.2546	0.1978	0.1284	1.958	0.86	0.7186	0.3026	0.481	0.720
0.37	0.2642	0.2020	0.1351	1.915	0.87	0.7254	0.3018	0.485	0.703
0.38	0.2739	0.2062	0.1420	1.875	0.88	0.7320	0.3007	0.488	0.687
0.39	0.2836	0.2102	0.1490	1.835	0.89	0.7384	0.2995	0.491	0.670
0.40	0.2934	0.2142	0.1561	1.797	0.90	0.7445	0.2980	0.494	0.654
0.41	0.3032	0.2182	0.1633	1.760	0.91	0.7504	0.2963	0.496	0.637
0.42	0.3130	0.2220	0.1705	1.724	0.92	0.7560	0.2944	0.497	0.621
0.43	0.3229	0.2258	0.1779	1.689	0.93	0.7612	0.2921	0.498	0.604
0.44	0.3328	0.2295	0.1854	1.655	0.94	0.7662	0.2895	0.498	0.588
0.45	0.3428	0.2331	0.1929	1.622	0.95	0.7707	0.2865	0.498	0.571
0.46	0.3527	0.2366	0.201	1.590	0.96	0.7749	0.2829	0.496	0.553
0.47	0.3627	0.2401	0.208	1.559	0.97	0.7785	0.2787	0.494	0.535
0.48	0.3727	0.2435	0.216	1.530	0.98	0.7817	0.2735	0.489	0.517
0.49	0.3827	0.2468	0.224	1.500	0.99	0.7841	0.2666	0.483	0.496
0.50	0.3927	0.2500	0.232	1.471	1.00	0.7854	0.2500	0.463	0.463

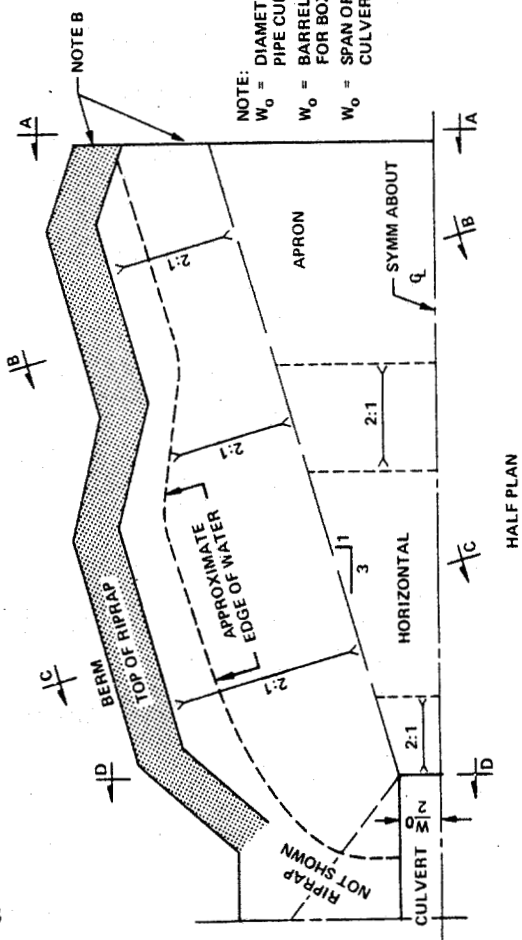
NOTE A -- IF EXIT VELOCITY OF BASIN IS SPECIFIED, EXTEND BASIN AS REQUIRED TO OBTAIN SUFFICIENT CROSS-SECTIONAL AREA AT SECTION A-A SUCH THAT $Q_{des}/(CROSS SECTION AREA AT SEC. A-A) = SPECIFIED EXIT VELOCITY$.

NOTE B -- WARP BASIN TO CONFORM TO NATURAL STREAM CHANNEL. TOP OF RIPRAP IN FLOOR OF BASIN SHOULD BE AT THE SAME ELEVATION OR LOWER THAN NATURAL CHANNEL BOTTOM AT SEC. A-A.



SECTION

XI-13



NOTE:
 W_0 = DIAMETER FOR PIPE CULVERT
 W_0 = BARREL WIDTH FOR BOX CULVERT
 W_0 = SPAN OF PIPE-ARCH CULVERT

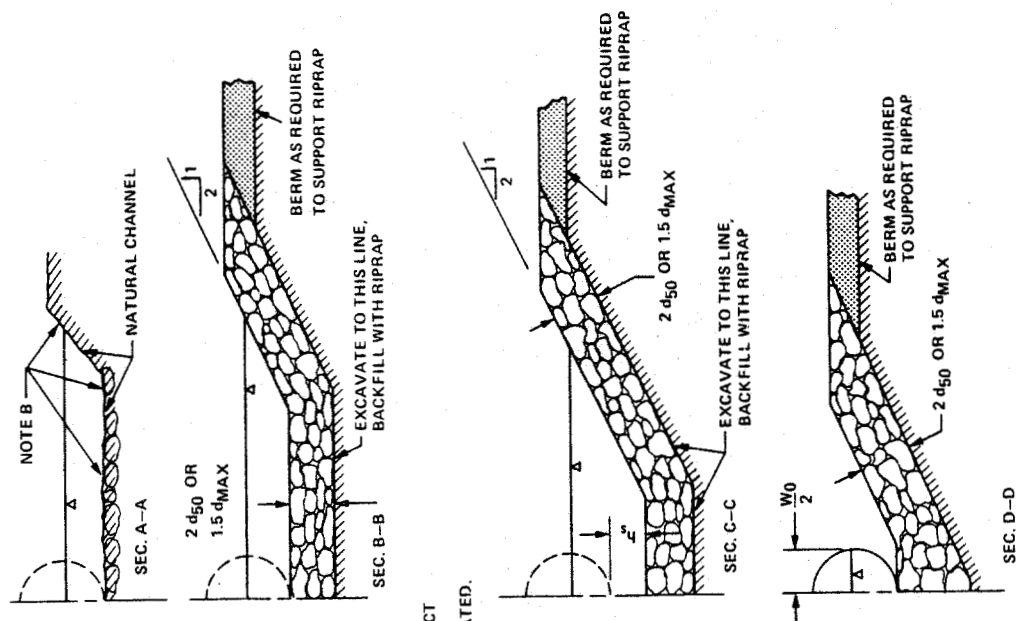


FIGURE XI-1. DETAILS OF RIPRAPPED CULVERT ENERGY BASIN

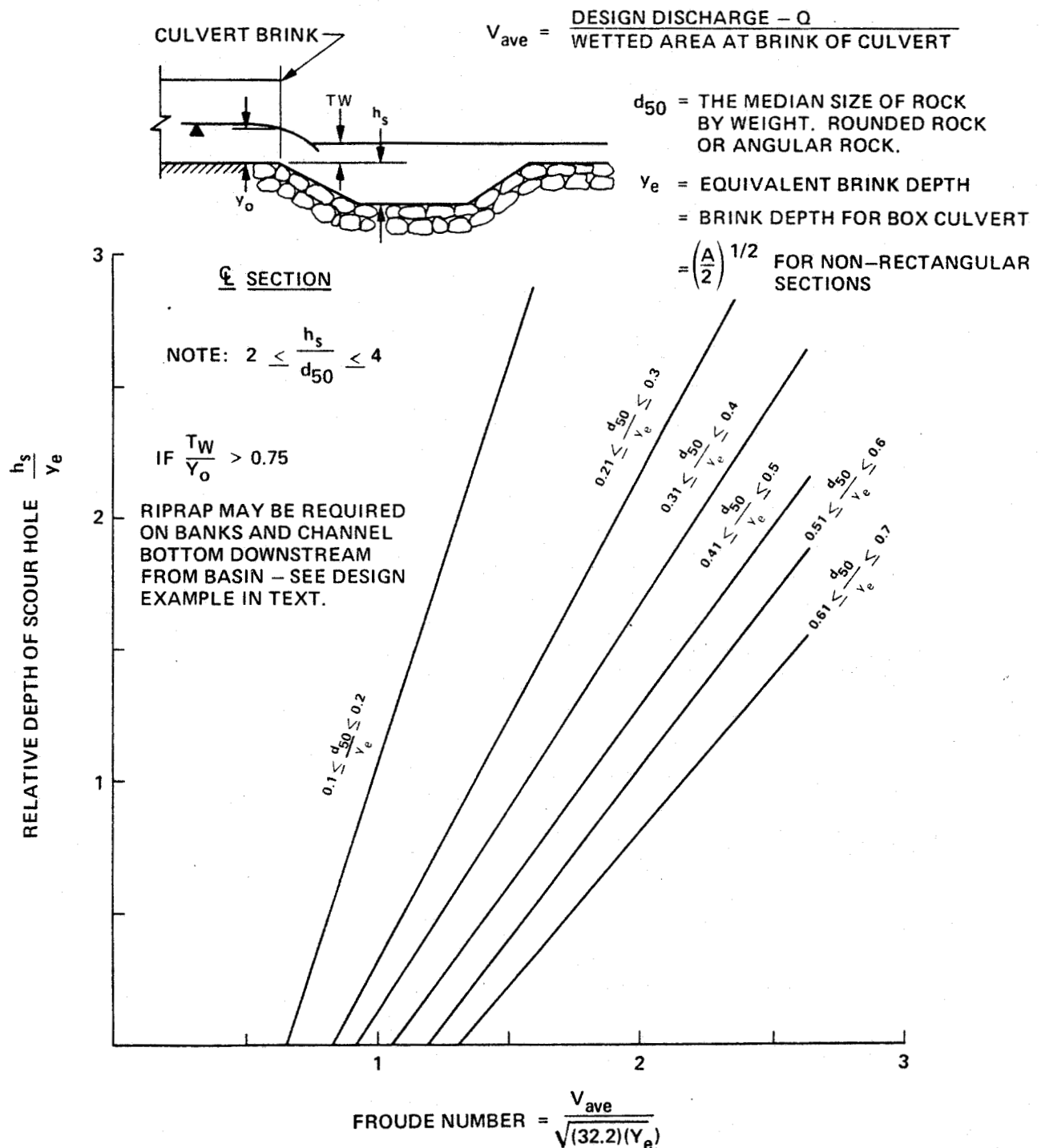


FIGURE X1-2. RELATIVE DEPTH OF SCOUR HOLE VERSUS FROUDE NUMBER AT BRINK OF CULVERT WITH RELATIVE SIZE OF RIPRAP AS A THIRD VARIABLE

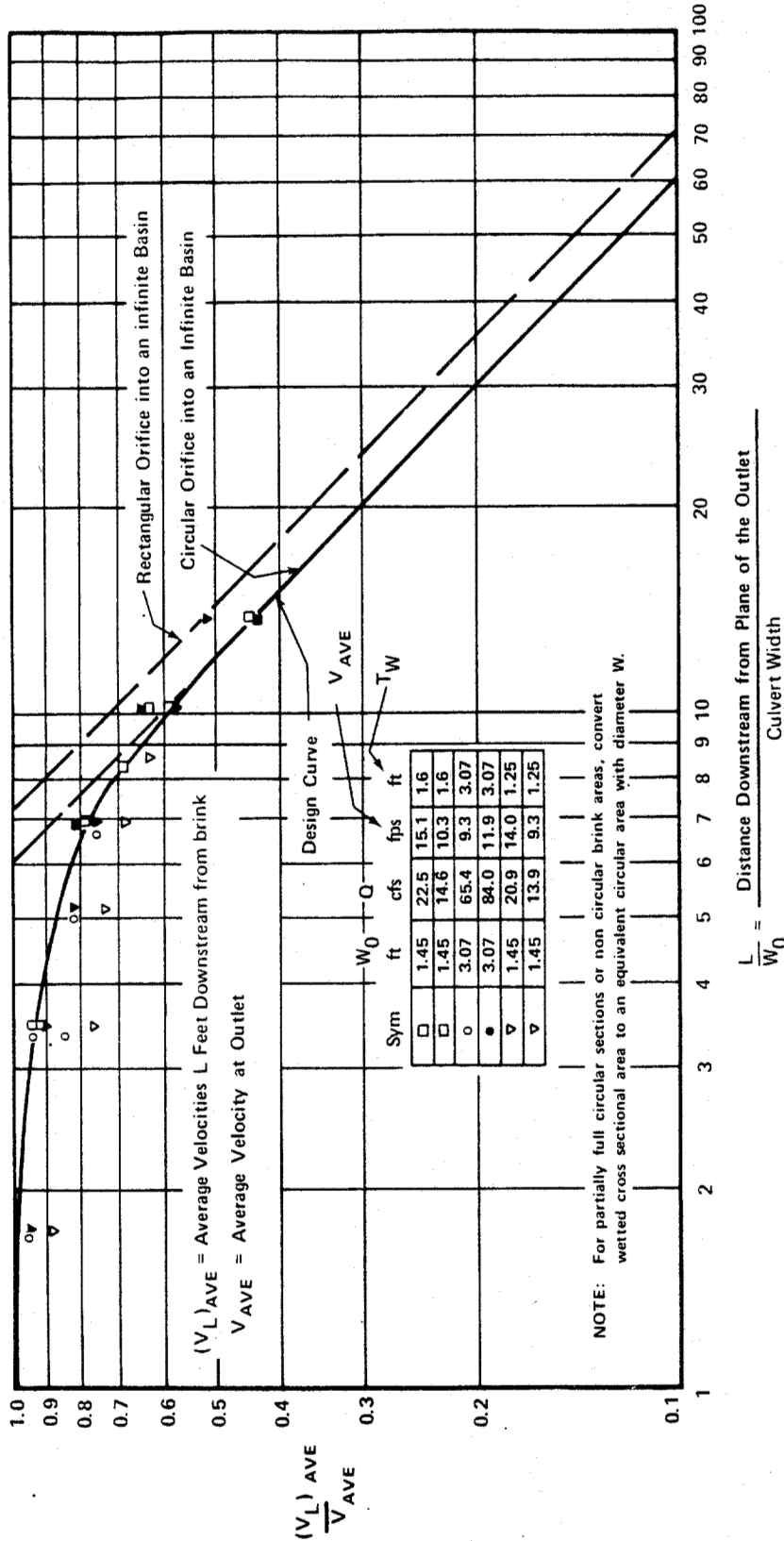
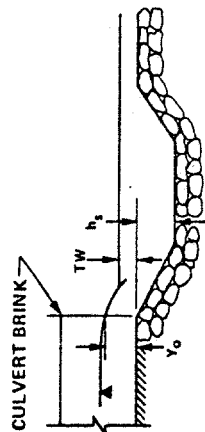


Figure XI - 3 Distribution of Centerline Velocity for Flow from Submerged Outlets from Reference XI - 2. to be used for Predicting Channel Velocities Downstream from Culvert Outlet where High Tailwater prevails. Velocities obtained from the use of this Chart can be used with Figure 2 of HEC No. 11 for sizing riprap (DO not use Figure 1 HEC No. 11, use Mean Velocity Values)

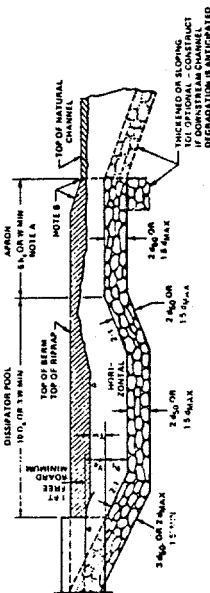
RIPRAP BASINS



NOTE A - IF EXISTING CHANNEL IS NOT DEEP ENOUGH TO MAINTAIN THE DESIRED FLOW, THE RIPRAP BASIN SHOULD BE DESIGNED TO MAINTAIN THE DESIRED FLOW AT THE SPECIFIED EXIT VELOCITY.

NOTE B - TRANSVERSE RIPRAP CHANNELS SHOULD BE DESIGNED TO MAINTAIN THE DESIRED FLOW AT THE SPECIFIED EXIT VELOCITY.

NOTE C - RIPRAP CHANNELS SHOULD BE DESIGNED TO MAINTAIN THE DESIRED FLOW AT THE SPECIFIED EXIT VELOCITY.



	TW	y_e	(1) TW/y_e	d_{50}/y_e	d_{50}	h_s/y_e	h_s	(2) h_s/d_{50}	
LOW TW $TW/y_e \leq 0.75$									
	V ALLOWABLE	L/d_e (3)	L	V_{ave}/V_L	V_L				
HIGH TW $TW/y_e > 0.75$									

Larger of
 Length of Pool = $10 h_s$ or $3W_o$ = _____ ft.
 Length of Apron = $5 h_s$ or W_o = _____ ft.
 Thickness of Approach = $3d_{50}$ or $2d_{max}$ = _____ ft.
 Thickness of Remainder = $2d_{50}$ or $1.5d_{max}$ = _____ ft.
 of Basin

(1) $TW/y_e \leq 0.75$ for Low TW Design
 (2) $2 < h_s/d_{50} < 4$
 (3) $D_e = [4A/\pi]^{1/2}$

Design Guide DG-3

NRCS, Engineering Field Handbook

Chapter 16

Streambank and Shoreline

Protection

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Chapter 16 Streambank and Shoreline Protection



Issued December 1996

Cover: Little Yellow Creek, Cumberland Gap National Park, Kentucky
(photograph by Robbin B. Sotir & Associates)

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Chapter 16, Streambank and Shoreline Protection, is one of 18 chapters of the U.S. Department of Agriculture, Natural Resources Conservation Service, Engineering Field Handbook, previously referred to as the Engineering Field Manual. Other chapters that are pertinent to, and should be referenced in use with, Chapter 16 are:

Chapter 1: Engineering Surveys
Chapter 2: Estimating Runoff
Chapter 3: Hydraulics
Chapter 4: Elementary Soils Engineering
Chapter 5: Preparation of Engineering Plans
Chapter 6: Structures
Chapter 7: Grassed Waterways and Outlets
Chapter 8: Terraces
Chapter 9: Diversions
Chapter 10: Gully Treatment
Chapter 11: Ponds and Reservoirs
Chapter 12: Springs and Wells
Chapter 13: Wetland Restoration, Enhancement, or Creation
Chapter 14: Drainage
Chapter 15: Irrigation
Chapter 17: Construction and Construction Materials
Chapter 18: Soil Bioengineering for Upland Slope Protection and Erosion Reduction

This is the second edition of chapter 16. Some techniques presented in this text are rapidly evolving and improving; therefore, additions to and modifications of chapter 16 will be made as necessary.

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Chapter 16

Streambank and Shoreline Protection

Contents:	650.1600	Introduction	16-1
		(a) Purpose and scope	16-1
		(b) Categories of protection	16-1
		(c) Selecting streambank and shoreline protection measures	16-1
	650.1601	Streambank protection	16-3
		(a) General	16-3
		(b) Planning and selecting stream-bank protection measures	16-3
		(c) Design considerations for streambank protection	16-6
		(d) Protective measures for streambanks	16-10
	650.1602	Shoreline protection	16-63
		(a) General	16-63
		(b) Design considerations for shoreline protection	16-63
		(c) Protective measures for shorelines	16-64
	650.1603	References	16-81
	Appendix A	Size Determination for Rock Riprap	16A-1
	Appendix B	Plants for Soil Bioengineering and Associated Systems	16B-1
Tables	Table 16-1	Live fascine spacing	16-16
	Table 16-2	Methods for rock riprap protection	16-49
Figures	Figure 16-1	Appropriate selection and application of streambank or shoreline protection measures should vary in response to specific objectives and site conditions	16-2
	Figure 16-2	Vegetative system along streambank	16-9

Figure 16-3a	Eroding bank, Winooski River, Vermont, June 1938	16-12
Figure 16-3b	Bank shaping prior to installing soil bioengineering practices, Winooski River, Vermont, September 1938	16-12
Figure 16-3c	Three years after installation of soil bioengineering practices, 1941	16-12
Figure 16-3d	Soil bioengineering system, Winooski River, Vermont, June 1993 (55 years after installation)	16-12
Figure 16-4	Live stake details	16-13
Figure 16-5	Prepared live stake	16-15
Figure 16-6	Growing live stake	16-15
Figure 16-7	Live fascine details	16-17
Figure 16-8	Preparation of a dead stout stake	16-18
Figure 16-9a	Placing live fascines	16-18
Figure 16-9b	Installing live stakes in live fascine system	16-18
Figure 16-9c	An established 2-year-old live fascine system	16-18
Figure 16-10	Branchpacking details	16-20
Figure 16-11a	Live branches installed in criss-cross configuration	16-21
Figure 16-11b	Each layer of branches is followed by a layer of compacted soil	16-21
Figure 16-11c	A growing branchpacking system	16-21
Figure 16-12	Vegetated geogrid details	16-23
Figure 16-13a	A vegetated geogrid during installation	16-24
Figure 16-13b	A vegetated geogrid immediately after installation	16-24
Figure 16-13c	Vegetated geogrid 2 years after installation	16-24
Figure 16-14	Live cribwall details	16-26
Figure 16-15a	Pre-construction streambank conditions	16-27
Figure 16-15b	A live cribwall during installation	16-27

Figure 16-15c	An established live cribwall system	16-27
Figure 16-16	Joint planting details	16-28
Figure 16-17a	Live stake tamped into rock joints	16-29
Figure 16-17b	An installed joint planting system	16-29
Figure 16-17c	An established joint planting system	16-29
Figure 16-18	Brushmattress details	16-31
Figure 16-19a	Brushmattress during installation	16-32
Figure 16-19b	An installed brushmattress system	16-32
Figure 16-19c	Brushmattress system 6 months after installation	16-32
Figure 16-19d	Brushmattress system 2 years after installation	16-32
Figure 16-20	Tree revetment details	16-34
Figure 16-21a	Tree revetment system with dormant posts	16-35
Figure 16-21b	Tree revetment system with dormant posts, 2 years after installation	16-35
Figure 16-22	Log, rootwad, and boulder revetment details	16-36
Figure 16-23	Rootwad, boulder, and willow transplant revetment system, Weminuche River, CO	16-37
Figure 16-24	Dormant post details	16-38
Figure 16-25a	Pre-construction streambank conditions	16-39
Figure 16-25b	Installing dormant posts	16-39
Figure 16-25c	Established dormant post system	16-39
Figure 16-26	Piling revetment details	16-41
Figure 16-27	Slotted board fence details (double fence option)	16-42
Figure 16-28	Slotted board fence system	16-43
Figure 16-29	Concrete jack details	16-44
Figure 16-30	Wooden jack field	16-45

Figure 16-31	Concrete jack system several years after installation	16-46
Figure 16-32	Rock riprap details	16-47
Figure 16-33	Rock riprap revetment system	16-48
Figure 16-34	Concrete cellular block details	16-50
Figure 16-35a	Concrete cellular block system before backfilling	16-51
Figure 16-35b	Concrete cellular block system several years after installation	16-51
Figure 16-36	Coconut fiber roll details	16-52
Figure 16-37a	Coconut fiber roll	16-53
Figure 16-37b	Coconut fiber roll system	16-53
Figure 16-38	Stream jetty details	16-55
Figure 16-39a	Stream jetty placed to protect railroad bridge	16-56
Figure 16-39b	Long-established vegetated stream jetty, with deposition in foreground	16-56
Figure 16-40	Stream barb details	16-58
Figure 16-41	Stream barb system	16-59
Figure 16-42	Vegetated rock gabion details	16-61
Figure 16-43	Vegetated rock gabion system	16-62
Figure 16-44	Timber groin details	16-65
Figure 16-45	Timber groin system	16-66
Figure 16-46	Timber bulkhead system	16-67
Figure 16-47	Timber bulkhead details	16-68
Figure 16-48	Concrete bulkhead details	16-69
Figure 16-49	Concrete bulkhead system	16-70
Figure 16-50	Concrete revetment (poured in place)	16-71
Figure 16-51	Rock riprap revetment	16-71

Figure 16-52	Live siltation construction details	16-74
Figure 16-53	Live siltation construction system	16-75
Figure 16-54	Reed clump details	16-77
Figure 16-55a	Installing dead stout stakes in reed clump system	16-78
Figure 16-55b	Completing installation of reed clump system	16-78
Figure 16-55c	Established reed clump system	16-78
Figure 16-56	Coconut fiber roll details	16-79
Figure 16-57	Coconut fiber roll system	16-80

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650.1600 Introduction**(a) Purpose and scope**

Streambank and shoreline protection consists of restoring and protecting banks of streams, lakes, estuaries, and excavated channels against scour and erosion by using vegetative plantings, soil bioengineering, and structural systems. These systems can be used alone or in combination. The information in chapter 16 does not apply to erosion problems on ocean fronts, large river and lake systems, or other areas of similar scale and complexity.

(b) Categories of protection

The two basic categories of protection measures are those that work by reducing the force of water against a streambank or shoreline and those that increase their resistance to erosive forces. These measures can be combined into a system.

Stormwater reduction or retention methods, grade reduction, and designs that reduce flow velocity fall into the first category of protection. Examples include permeable fence design, tree or brush revetments, jacks, groins, stream jetties, barbs, drop structures, increasing channel sinuosity, and log, rootwad, and boulder combinations. The second category includes channels lined with grass, concrete, riprap, gabions, cellular concrete, and other revetment designs. These measures can be used alone or in combination. Most designs that employ brushy vegetation, e.g., soil bioengineering, either alone or in combination with structures, protect from erosion in both ways.

Revetment designs do not reduce the energy of the flow significantly, so using revetments for spot protection may move erosion problems downstream or across the stream channel.

(c) Selecting streambank and shoreline protection measures

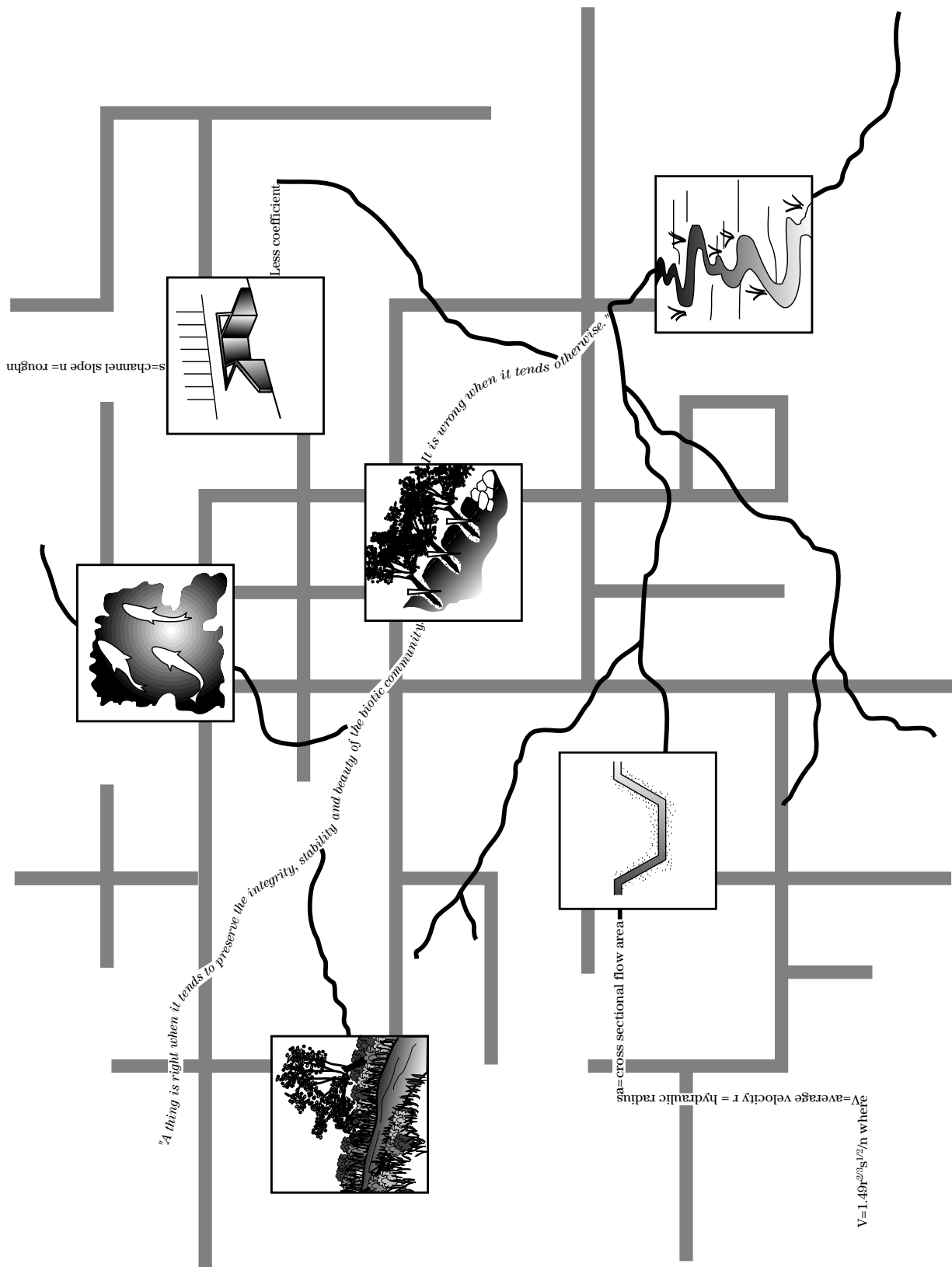
This document recognizes the need for intervention into stream corridors to affect rehabilitation; however, it is also acknowledged that this should be done on a selective basis. When selecting a site or stream reach for treatment, it is most effective to select areas within relatively healthy systems. Projects planned and installed in this context are more likely to be successful, and it is often critically important to prevent the decline of these healthier systems while an opportunity remains to preserve their biological diversity. Rehabilitation of highly degraded systems is also important, but these systems often require substantial investment of resources and may be so modified that partial success is often a realistic goal.

After deciding rehabilitation is needed, a variety of remedies are available to minimize the susceptibility of streambanks or shorelines to disturbance-caused erosive processes. They range from vegetation-oriented remedies, such as soil bioengineering, to engineered grade stabilization structures (fig. 16–1). In the recent past, many organizations involved in water resource management have given preference to engineered structures. Structures may still be viable options; however, in a growing effort to restore sustainability and ensure diversity, preference should be given to those methods that restore the ecological functions and values of stream or shoreline systems.

As a first priority consider those measures that

- are self sustaining or reduce requirements for future human support;
- use native, living materials for restoration;
- restore the physical, biological, and chemical functions and values of streams or shorelines;
- improve water quality through reduction of temperature and chronic sedimentation problems;
- provide opportunities to connect fragmented riparian areas; and
- retain or enhance the stream corridor or shoreline system.

Figure 16-1 Appropriate selection and application of streambank or shoreline protection measures should vary in response to specific objectives and site conditions (Aldo Leopold)



650.1601 Streambank protection

(a) General

The principal causes of streambank erosion may be classed as geologic, climatic, vegetative, and hydraulic. These causes may act independently, but normally work in an interrelated manner. Direct human activities, such as channel confinement or realignment and damage to or removal of vegetation, are major factors in streambank erosion.

Streambank erosion is a natural process that occurs when the forces exerted by flowing water exceed the resisting forces of bank materials and vegetation. Erosion occurs in many natural streams that have vegetated banks. However, land use changes or natural disturbances can cause the frequency and magnitude of water forces to increase. Loss of streamside vegetation can reduce resisting forces, thus streambanks become more susceptible to erosion. Channel realignment often increases stream power and may cause streambeds and banks to erode. In many cases streambed stabilization is a necessary prerequisite to the placement of streambank protection measures.

(b) Planning and selecting streambank protection measures

The list that follows, although not exhaustive, includes data commonly needed for planning purposes.

(1) Watershed data

When analyzing the source of erosion problems, consider the stream as a system that is affected by watershed conditions and what happens in other stream reaches. An analysis of stream and watershed conditions should include historical information on land use changes, hydrologic conditions, and natural disturbances that might influence stream behavior. It should anticipate the changes most likely to occur or that are planned for the near future:

- Climatic regime.
- Land use/land cover.
- History of land use, prior stream modifications, past stability problems, and previous treatments.

- Projected development over anticipated project life.

(2) Causes and extent of erosion problems

- If bank failure problems are the result of widespread bed degradation or headcutting, determine what triggered the problem.
- If bank erosion problems are localized, determine the cause of erosion at each site.

(3) Hydrologic/hydraulic data

- Flood frequency data (if not available, estimate using regional equations or other procedures).
- Estimates of stream-forming flow at 1- to 2-year recurrence interval and flow velocities.
- Estimates of width and depth at stream-forming flow conditions.
- Channel slope, width, depth, meander wavelength, and shape (width/depth, wetted perimeter).
- Sediment load (suspended and bedload).
- Water quality.

(4) Stream reach characteristics

- Soil and streambank materials at site.
- Potential streambank failures.
- Vegetative condition of banks.
- Channel alignment.
- Present stream width, depth, meander amplitude, belt width, wavelength, and sinuosity to determine stream classification.
- Identification of specific problems arising from flow deflection caused by sediment buildup, boulders, debris jams, bank irregularities, or constrictions.
- Bed material d_{50} based on a pebble count.
- Quality, amount, and types of terrestrial and aquatic habitat.
- Suspended load and bedload as needed, to determine if incoming sediment load can be transported through the restored reach.
- When selecting protective measures, analyze the needs of the entire watershed, the effects that stream protection may have on other reaches, surrounding wetlands, the riparian corridor, terrestrial habitat, aquatic habitat, water quality, and aesthetics. Reducing runoff and soil loss from the upland portions of the watershed using sound land treatment and management measures normally makes the streambank protection solution less expensive and more durable.

(5) Stream classification

Stream classification has evolved significantly over the past 100 years. William Davis (1899) first divided streams into three stages as youthful, mature and old age. Streams were later classified by their pattern as straight, meandering, or braided (Leopold & Wolman, 1957) or by stability and mode of sediment transport (Schumm, 1963 and 1977). Although all these systems served their intended purposes, they were not particularly helpful in establishing useful criteria for streambank protection and design. Rosgen (1985) developed a stream classification system that categorizes essentially all types of stream channels on the basis of measured morphological features. This system has been updated several times (Rosgen, 1992) and has broad applicability for communication among users and to predict a stream's behavior based on its appearance.

Predicting a stream's behavior based on appearance is also a feature of the Schumm, Harvey, and Watson (1984) channel evolution model developed for Oaklimeter Creek in Mississippi. This model discusses channel conditions extending from total disequilibrium to a new state of dynamic equilibrium. Such a model is useful in stream restoration work because streams can be observed in the field and their dominant process determined in the reach under consideration (i.e., active headcutting and transport of sediment, through aggradation and stabilization of alternate bars, and approaching a stage of dynamic equilibrium).

Rosgen's (1992) stream classification system goes beyond the channel evolution model as it is based on determining hydraulic geometry of stable stream reaches. This geometry is then extrapolated to unstable stream reaches to derive a template for potential channel design and reconstruction.

The present version of Rosgen's stream classification has several types (A, B, C, D, DA, E, F, and G), based on a hierarchical system. The first level of classification distinguishes between single or multiple thread channels. The streams are then separated based on degrees of entrenchment, width-to-depth ratio, and stream sinuosity. They are further subdivided by slope range and channel materials. Several stream subtypes are based on other criteria, such as average riparian vegetation, organic debris and channel blockages, flow regimes, stream size, depositional features, and meander pattern.

(6) Soils

A particular soil's resistance to erosion depends on its cohesiveness and particle size. Sandy soils have low cohesion, and their particles are small enough to be entrained by velocity flows of 2 or 3 feet per second. Lenses or layers of erodible material are frequent sources of erosion. Fines are selectively removed from soils that are heterogeneous mixtures of sand and gravel, leaving behind a layer of gravel that may protect or armor the streambed against further erosion. However, the hydraulic removal of fines and sand from a gravel matrix may cause it to collapse, resulting in sloughing of the streambank and its overlying material.

The resistance of cohesive soils depends on the physical and chemical properties of the soil as well as the chemical properties of the eroding fluid. Cohesive soils often contain montmorillonite, bentonite, or other expansive clays. Because unvegetated banks made up of expansive clays are subject to shrinkage during dry weather, tension cracks may develop parallel to and several feet below the top of the bank. These cracks may lead to slab failures on oversteepened banks, especially in places where bank support has been reduced by toe erosion. Tension cracks can also contribute to piping and related failures.

(7) Hydrologic, climatic, and vegetative conditions

Stream erosion is largely a function of the magnitude and frequency of flow events. Flow duration is of secondary importance except for flows that exceed stream-forming flow stage for extended periods. A streambank's position (outside curve or inside) can also be a major factor in determining its erosion potential.

Watershed changes that increase magnitude and frequency of flooding, such as urbanization, deforestation, and increased surface runoff, contribute to streambank erosion. Associated changes, such as loss of streamside vegetation from human or animal trampling, often compound the streambank erosion effect.

In cold climates where streams normally freeze or partly freeze during winter, erosion caused by ice is an additional problem. Streambanks are affected by ice scour in several ways:

- Streambanks and associated vegetation can be forcibly damaged during freezing or thawing action.

- Floating ice can cause gouging of streambanks.
- Acceleration of flow around and under ice rafts can cause damage to streambanks.

Erosion from ice may be minimized or reduced by vegetation for the following reasons:

- Streambank vegetation reduces damaging cycles of freeze-thaw by maintaining the temperature of bank materials, thus preventing ice from forming and encouraging faster thawing.
- Vegetation tends to be flexible and absorbs much of the momentum of drifting ice.
- Vegetation helps protect the bank from ice damage.
- Woody vegetation has deeply embedded roots that reinforce soils.
- Deeply rooted, woody vegetation helps to control erosion by adding strength to streambank materials, increasing flow resistance, reducing flow velocities in the vicinity of the bank, and retarding tension crack development.

(8) Hydraulic data

Stream power is a function of velocity, flow depth, and slope. Channelization projects that straighten or enlarge channels often increase one or more of these factors enough to cause widespread erosion and associated problems, especially if soils are easily erodible.

Headcuts often develop in the modified reach or at the transition from the modified reach to the unaltered reach. They move upstream, causing bed erosion and bank failure on the main stream and its tributaries. Returning the stream to its former meander geometry is generally the most reliable way to stop headcuts or prevent their development. Installing grade control structures that completely cross a stream and act as a very low head dam may initiate other channel instabilities by:

- inducing bank erosion around the ends of the structure;
- raising flood levels and causing out-of-bank flows to erode new channels;
- trapping sediment, thus decreasing channel capacity, inducing bank erosion and flood plain scour; and
- increasing width-to-depth ratio with subsequent lateral migration, increased bank erosion, and increased bar deposition or formation.

Grade control structures should be designed to maintain low channel width-to-depth ratios, maintain the sediment transport capacity of the channel, and provide for passing a wide range of flow velocities without creating backwater and causing sediment deposition. Vortex rock weirs, "W" rock weirs, and other rock/boulder structures that protect the channel without creating backwater should be considered instead of small rock and log dams.

Local obstructions to flow, channel constrictions, and bank irregularities cause local increases in the energy slope and create secondary currents that produce accelerations in velocity sufficient to cause localized streambank erosion problems. These localized problems often are treated best by eliminating the source of the problem and providing remedial bank protection. However, secondary cross currents are also a natural feature around the outside curves of meanders, and structural features may be required to modify these cross currents.

Streamflows that transport sustained heavy loads of sediment are less erosive than clear flows. This can easily be seen where dams are constructed on large sediment-laden streams. Once a dam is operational, the sediment drops out into the reservoir pool, so the water leaving the structure is clear. Several feet of degradation commonly occurs in the reach below the dam before an armor layer develops or hydraulic parameters are sufficiently altered to a stable grade. In watersheds that have high sediment yields, conservation treatments that significantly reduce sediment loads can trigger stream erosion problems unless runoff is also reduced.

(9) Habitat characteristics

The least-understood aspect of designing and analyzing streambank protection measures is often the impact of the protective measures on instream and riparian habitats. Commonly, each stage of the life cycle of aquatic species requires different habitats, each having specific characteristics. These diverse habitats are needed to meet the unique demands imposed by spawning and incubation, summer rearing, and overwintering. The productivity of most aquatic systems is directly related to the diversity and complexity of available habitats.

Fish habitat structures are commonly an integral part of stream protection measures, but applicability of habitat structures varies by classified stream type. Work by Rosgen and Fittante (1992) resulted in a guide for evaluating suitability of various proposed fish habitat structures for a wide range of morphological stream types. They divide structures into those for rearing habitat enhancement and those for spawning habitat enhancement. The structures for rearing habitat enhancement include low stage check dam, medium stage check dam, boulder placement, bank-placed materials, single wing deflector, channel constrictor, bank cover, floating log cover, submerged shelter, half log cover, and migration barrier. U-shaped gravel traps, log sill gravel traps, and gravel placement are for spawning habitat enhancement.

Since a multitude of interrelated factors influence the productivity of streams, the response of fish and wildlife populations to changes in habitat is often difficult to predict with confidence.

(10) Environmental data

Environmental goals should be set early in the planning process to ensure that full consideration is given to ecological stability and productivity during the selection and design of streambank protection measures. Special care should be given to consideration of terrestrial and aquatic habitat benefits of alternative types of protection and to maintenance needs on a site specific basis.

In general, the least disturbance to the existing stream system during construction and maintenance produces the greatest environmental benefits. Damages to the environment can be limited by:

- Using small equipment and hand labor.
- Limiting access.
- Locating staging areas outside work area boundaries.
- Avoiding or altering construction procedures during critical times, such as fish spawning or bird nesting periods.
- Coordinating construction on a stream that involves more than one job or ownership.
- Adopting maintenance plans that maximize riparian vegetation and allow wide, woody vegetative buffers.
- Scheduling construction activities to avoid expected peak flood season(s).

(11) Social and economic factors

Initial installation cost and long-term maintenance are factors to be considered when planning streambank and shoreline protection. Other factors include the suitability of construction material for the use intended, the cost of labor and machinery, access for equipment and crews at the site, and adaptations needed to adjust designs to special conditions and the local environment.

Some protection measures seem to have apparent advantages, such as low cost or ease of construction, but a more expensive alternative might best meet planned objectives when maintenance, durability of material, and replacement costs are considered. Effect upon resources and environmental values, such as aesthetics, wildlife habitat, and aquatic requirements, are also integral factors.

The need for access to the stream or shoreline and the effects of protection measures upon adjacent property and land uses should be analyzed.

Minor protective measures can be installed without using contract labor or heavy equipment. However, many of the protective measures presented in this chapter require evaluation, design, and implementation to be done by a knowledgeable interdisciplinary team because precise construction techniques and costly construction materials may be required.

(c) Design considerations for streambank protection

(1) Channel grade

The channel grade may need to be controlled before any permanent type of bank protection can be considered feasible unless the protection can be safely and economically constructed to a depth well below the anticipated lowest depth of bed scour. Control can be by natural or artificial means. Reconstructing stream channels to their historical stream type (i.e., stream geometry) has been successfully used to achieve grade control. Artificial measures typically include rock, gabions and reinforced concrete grade control structures.

(2) Discharge frequency

Maximum floods are rarely used for design of streambank protection measures. The design flood frequency should be compatible with the value or safety of the property or improvements being protected, the repair cost of the streambank protection, and the sensitivity and value of ecological systems within the planning unit. Bankfull discharge (stream-forming flow) of natural streams tends to have a recurrence interval of 1 to 2 years based on the annual flood series (Leopold and Rosgen, 1991). The discharge at this frequency is commonly used as a design discharge for stream restoration (Rosgen, 1992). For modified streams, the 1- to 2-year frequency discharge is also useful for design discharge because it is the flow that has the most impact upon the stability of the stream channel.

(3) Discharge velocities

Where the flow entering the section to be protected carries only clay, silt, and fine sand in suspension, the maximum velocity should be limited to that which is nonscouring on the least resistant material occurring in any appreciable quantity in the streambed and bank. The minimum velocity should be that required to transport the suspended material. The depth-area-velocity relationship of the upstream channel should be maintained through the protected reach. Where the flow entering the section is transporting bedload, the minimum velocity should be that which will transport the entering bedload material through the section.

The minimum design velocity should also be compatible with the needs of the various fish species present or those targeted for recovery. Velocity changes can reduce available habitat or create physical barriers that restrict fish passage. Further information on fish habitat is available in publications cited in the reference section.

Streambank protection measures on large, wide channels most likely will not significantly change streamflow velocity. On smaller streams, however, the protective measures can influence the velocity throughout the reach.

In calculating these velocities, the Manning's n values selected should represent the stream condition after the channel has matured, which normally requires several years. Erosion or sedimentation may occur if this is not anticipated.

(4) Freeboard

Freeboard should be provided to prevent overtopping of the revetment at curves and other points where high velocity flow contacts the revetment. In these areas a potential supercritical velocity can set up waves, and the climb on sloping revetments may be appreciable. Because an accurate method to determine freeboard requirements is not available for sloping revetments in critical zones, the allowance for freeboard should be based on sound judgment and experience. Under similar conditions, the freeboard required for a sloping revetment is always greater than that for a vertical revetment.

(5) Alignment

Changes in channel alignment affect the flow characteristics through, above, and below the changed reach. Straightening without extensive channel hardening does not eliminate a stream's tendency to meander. An erosion hazard may often develop at both ends of the channel because of velocity increases, bar formations, and current direction changes. Changes in channel alignment are not recommended unless the change is to reconstruct the channel to its former meander geometry.

Alignment of the reach must also be carefully considered in designing protective measures. Because of major changes in hydraulic characteristics, streambanks for channels having straight alignment generally require a continuous scour-resistant lining or revetment. To prevent scour by streamflow as the stream attempts to recreate its natural meander pattern, most banks must be sloped to a stable grade before the lining is applied. For nonrigid lining, the slope must be flat enough to prevent the lining material from sliding.

Curved revetments are subjected to increased forces because of the secondary currents acting against them. More substantial and permanent types of construction may be needed on curved channel sections because streambank failures at these vulnerable points could result in much greater damage than that along unobstructed straight reaches of channel.

(6) Stream type and hydraulic geometry

Stream rehabilitation should be considered in the context of the historically stable stream type and its geometry. If stream modification has caused shortened meander wavelength, amplitude, and radius of curvature, the stream being treated might be best stabilized by restoring the historical geometry. The width-to-depth ratio of the stream being treated may be too high to transport the sediment load, and a lower ratio may be needed in the design channel.

(7) Sediment load and bed material

To determine the potential for stream aggradation, the sediment load (bedload and suspended) for storm and snowmelt runoff periods must frequently be determined before reconstruction. The size distribution of the streambed and bar material also should be determined. These measurements are important above and below the reconstruction reach under consideration as well as in the main tributary streams above the reach. This information is used with appropriate shear stress equations to determine the size of material that would be entrained at bankfull discharge (stream-forming flow) for both the tributary streams and in the restored reach. The sediment transport rate must be sufficient to prevent aggradation of the newly restored channel. As shown by studies in Colorado (Andrews, 1983) on gravelbed rivers, it is anticipated that particles as large as the median diameter of the bed surface will be entrained by discharge equal to the bankfull stage (stream-forming flow) or less.

(8) Protection against failure

Measures should be designed to provide against loss of support at the revetment's boundaries. This includes upstream and downstream ends, its base or toe, and the crest or top.

(9) Undermining

Undermining or scouring of the foundation material by high velocity currents is a major cause of bank protection failure. In addition to protecting the lowest expected stable grade, additional depth must be provided to reach a footing that most likely will not be scoured out during floods or lose its stability through saturation. Deep scour can be expected where construction is on an erodible streambed and high velocity currents flow adjacent to it.

Methods used to provide protection against undermining at the toe are:

- Extending the toe trench down to a depth below the anticipated scour and backfilling with heavy rock.
- Anchoring a heavy, flexible mattress to the bottom of the revetment, which at the time of installation will extend some distance out into the channel. This mattress will settle progressively as scour takes place, protecting the revetment foundation.
- Installing a massive toe of heavy rock where excavation for a deep toe is not practical. This allows the rock forming the toe to settle in place if scour occurs. However, because of the forces of flow, the settlement direction of the rock is not always straight down.
- Driving sheet piling to form a continuous protection for the revetment foundation. Such piling should be securely anchored against lateral pressures. To provide for a remaining embedment after scour, piling should be driven to a depth equal to about twice the exposed height.
- Installing toe deflector groins to deflect high velocity currents away from the toe of the revetment.
- Installing submerged vanes to control secondary currents.

Since most of these measures have direct impacts on aquatic habitat and other stream functions and values, their use should be considered carefully when planning a streambank protection project.

(10) Ends of revetment

The location of the upstream and downstream ends of revetments must be selected carefully to avoid flanking by erosion. Wherever possible, the revetment should tie into stable anchorage points, such as bridge abutments, rock outcrops, or well-vegetated stable sections. If this is not practical, the upstream and downstream ends of the revetment must be positioned well into a slack water area along the bank where bank erosion is not a problem.

(11) Debris removal

Streambank protection may require the selective removal or repositioning of debris, such as fallen trees, sediment bars, or other obstructions. Because logs and other woody debris are the major habitat-forming components in many stream systems, a plan for debris removal should be developed in consultation with qualified fish and wildlife specialists. Small accumulations of debris and sediment generally do not cause problems and should be left undisturbed.

When planning streambank stabilization work, select access routes for equipment that minimize disturbance to the flood plain and riparian areas. All debris removal, grading, and material delivery and placement should be accomplished in a manner that uses the smallest equipment feasible and minimizes disturbance of riparian vegetation. Excavated material should be disposed of in such a way that it does not interfere with overbank flooding, flood plain drainage, or associated wetland hydrology. In high velocity streams it may be necessary to remove floating debris selectively from flood-prone areas or anchor it so that it will not float back into the channel.

Sediment bars, snags, trees, and other debris drifts that create secondary currents or deflect flow toward the banks may require selective removal or relocation in the stream channel. The entire plant structure does not always need to be dislodged when considering the removal of trees and snags; rooted stumps should be left in place to prevent erosion. Isolated or single logs that are embedded, lodged, or rooted in the channel and not causing flow problems should not be disturbed. Fallen trees may be used to construct bank protection systems. Trees and other large vegetation are important to aquatic, aesthetic and riparian habitat systems, and removal should be done judiciously and with great care.

(12) Vegetative systems

Vegetative systems provide many benefits to fish and wildlife populations as well as increasing the streambank's resistance to erosive forces. Vegetation near the channel provides shade to help maintain suitable water temperature for fish, provides habitat for wildlife and protection from predators, and contributes to aesthetic quality. Leaves, twigs, and insects drop into the stream, providing nutrients for aquatic life (fig. 16-2).

Figure 16-2 Vegetative system along streambank



Although woody brush is preferable for habitat reasons, suitable herbaceous ground cover can provide desirable bank protection in areas of marginal erosion. Perennial grasses and forbes, preferably those native to the area, should be used rather than annual grasses. Woody vegetation may also be used to control undesirable access to the stream.

Associated emergent aquatic plants serve multiple functions, including the protection of woody streambank or shoreline vegetation from wave or current wave action, which tend to undercut them.

Vegetation protects streambanks in several ways:

- Root systems help hold the soil particles together increasing bank stability.
- Vegetation may increase the hydraulic resistance to flow and reduce local velocities in small channels.
- Vegetation acts as a buffer against the hydraulic forces and abrasive effect of transported materials.
- Dense vegetation on streambanks can induce sediment deposition.
- Vegetation can redirect flow away from the bank.

(d) Protective measures for streambanks

Protective measures for streambanks can be grouped into three categories: vegetative plantings, soil bioengineering systems, and structural measures. They are often used in combination.

(1) Vegetative plantings

Conventional plantings of vegetation may be used alone for bank protection on small streams and on locations having only marginal erosion, or it may be used in combination with structural measures in other situations. Considerations in using vegetation alone for protection include:

- Conventional plantings require establishment time, and bank protection is not immediate.
- Maintenance may be needed to replace dead plants, control disease, or otherwise ensure that materials become established and self-sustaining.
- Establishing plants to prevent undercutting and bank sloughing in a section of bank below baseflow is often difficult.
- Establishing plants in coarse gravelly material may be difficult.

- Protection and maintenance requirements are often high during plant establishment.

Woody vegetation, which is seeded or planted as rooted stock, is used most successfully above baseflow on properly sloped banks and on the flood plain adjacent to the banks. Vegetation should always be used behind revetments and jetties in the area where sediment deposition occurs, on the banks above baseflow, and on slopes protected by cellular blocks or similar type materials.

Many species of plants are suitable for streambank protection (see appendix 16B). Use locally collected native species as a first priority. Exotic or introduced species should be used only if there is no alternative. They should never be invasive species. Locally available erosion-resistant species that are suited to the soil, moisture, and climatic conditions of a particular site are desirable. Aesthetics may also play an important role in selecting plants for certain areas.

In many instances streambank erosion is accelerated by overgrazing, cultivating too close to the banks, or by overuse. In either case the treated area should be protected by adequate streamside buffers and appropriate management practices. If the stream is the source of livestock drinking water, access can be provided by establishing a ramp down to the water. Such ramps should be located where the bank is not steep and, preferably, in straighter sections or at the inside of curves in the channel where velocities are low. Providing watering facilities out of the channel (i.e., on the flood plain or terrace) for the livestock is often a preferred alternative to using ramps.

The visual impact, habitat value, and other environmental effects of material removal or relocation must also be considered before performing any work.

Protective measures reduce streambank erosion and prevent land losses and sediment damages, but do not directly stabilize the channel grade. However, if the channel is restored to a stable stream type, vegetative protective measures, such as soil bioengineering, can be used to stabilize the streambanks. Vegetation assists in bank stabilization by trapping sediment, reducing tractive stresses acting on the bank, redirecting the flow, and holding soil. The boundary shear stress provided by vegetation, however, is much less than that provided by structural elements.

(2) Soil bioengineering systems

Properly designed and constructed soil bioengineering systems have been used successfully to stabilize streambanks (figs. 16–3a, 16–3b, 16–3c, and 16–3d).

Soil bioengineering is a system of living plant materials used as structural components. Adapted types of woody vegetation (shrubs and trees) are initially installed in specified configurations that offer immediate soil protection and reinforcement. In addition, soil bioengineering systems create resistance to sliding or shear displacement in a streambank as they develop roots or fibrous inclusions. Environmental benefits derived from woody vegetation include diverse and productive riparian habitats, shade, organic additions to the stream, cover for fish, and improvements in aesthetic value and water quality.

Under certain conditions, soil bioengineering installations work well in conjunction with structures to provide more permanent protection and healthy function, enhance aesthetics, and create a more environmentally acceptable product. Soil bioengineering systems normally use unrooted plant parts in the form of cut branches and rooted plants. For streambanks, living systems include brushmattresses, live stakes, joint plantings, vegetated geogrids, branchpacking, and live fascines.

Major attractions of soil bioengineering systems are their natural appearance and function and the economy with which they can often be constructed. As discussed in chapter 18 of this Engineering Field Handbook, the work is normally done in the dormant months, generally September to March, which is the off season for many laborers. The main construction materials are live cuttings from suitable plant species. Species must be appropriate for the intended use and adapted to the site's climate and soil conditions.

Consult a plant materials specialist for guidance on plant selection. Ideally plant materials should come from local ecotypes and genetic stock similar to that within the vicinity of the stream. Species that root easily, such as willow, are required for measures, such as live fascines and live staking, or where unrooted cuttings are used with structural measures. Suitable plant materials are listed in appendix 16B. They may also be identified in Field Office Technical Guides for specific site conditions or by contacting Plant Materials Centers.

Many sites require some earthwork before soil bioengineering systems are installed. A steep undercut or slumping bank, for example, may require grading to a 3:1 or flatter slope. Although soil bioengineering systems are suitable for most sites, they are most successful where installed in sunny locations and constructed during the dormant season.

Rooted seedlings and rooted cuttings are excellent additions to soil bioengineering projects. They should be installed for species diversification and to provide habitat cover and food for fish and wildlife. Optimum establishment is usually achieved shortly after earth work, preferably in the spring.

Some of the most common and useful soil bioengineering structures for restoration and protection of streambanks are described in the following sections.

Figure 16-3a Eroding bank, Winooski River, Vermont, June 1938



Figure 16-3b Bank shaping prior to installing soil bioengineering practices, Winooski River, Vermont, September 1938



Figure 16-3c Three years after installation of soil bioengineering practices, 1941



Figure 16-3d Soil bioengineering system, Winooski River, Vermont, June 1993 (55 years after installation)



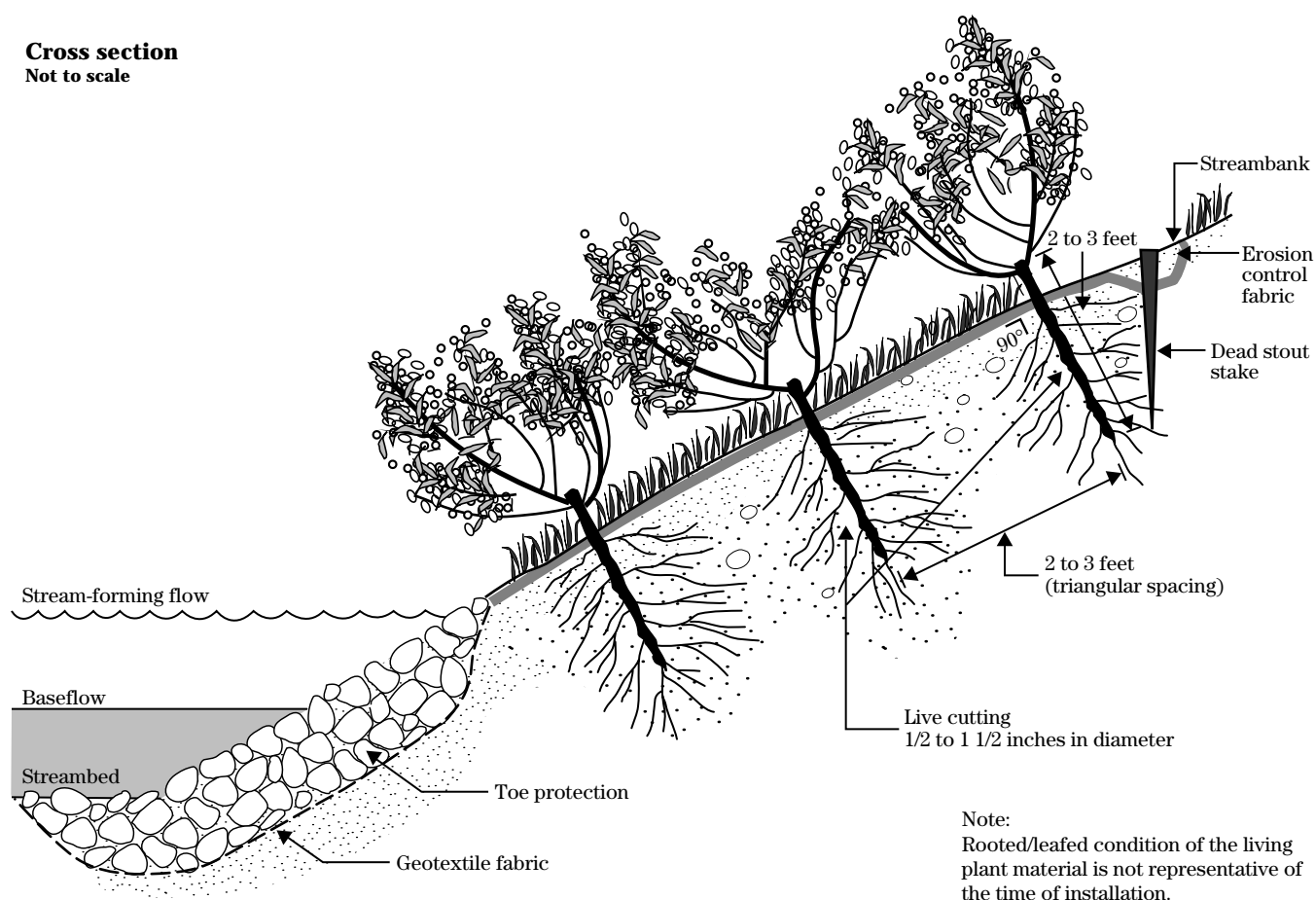
(i) Live stakes—Live staking involves the insertion and tamping of live, rootable vegetative cuttings into the ground (figs. 16–4 and 16–5). If correctly prepared, handled, and placed, the live stake will root and grow (fig. 16–6).

A system of stakes creates a living root mat that stabilizes the soil by reinforcing and binding soil particles together and by extracting excess soil moisture. Most willow species root rapidly and begin to dry out a bank soon after installation.

Applications and effectiveness

- Effective streambank protection technique where site conditions are uncomplicated, construction time is limited, and an inexpensive method is needed.
- Appropriate technique for repair of small earth slips and slumps that frequently are wet.
- Can be used to peg down and enhance the performance of surface erosion control materials.
- Enhance conditions for natural colonization of vegetation from the surrounding plant community.
- Stabilize intervening areas between other soil bioengineering techniques, such as live fascines.
- Produce streamside habitat.

Figure 16–4 Live stake details



Construction guidelines

Live material sizes—The stakes generally are 0.5 to 1.5 inches in diameter and 2 to 3 feet long. The specific site requirements and available cutting source determine sizes.

Live material preparation

- The materials must have side branches cleanly removed with the bark intact.
- The basal ends should be cut at an angle or point for easy insertion into the soil. The top should be cut square.
- Materials should be installed the same day that they are prepared.

Installation

- Erosion control fabric should be placed on slopes subject to erosive inundation.
- Tamp the live stake into the ground at right angles to the slope and diverted downstream. The installation may be started at any point on the slope face.
- The live stakes should be installed 2 to 3 feet apart using triangular spacing. The density of the installation will range from 2 to 4 stakes per square yard. Site variations may require slightly different spacing.

- Placement may vary by species. For example, along many western streams, tree-type willow species are placed on the inside curves of point bars where more inundation occurs, while shrub willow species are planted on outside curves where the inundation period is minimal.
- The buds should be oriented up.
- Four-fifths of the length of the live stake should be installed into the ground, and soil should be firmly packed around it after installation.
- Do not split the stakes during installation. Stakes that split should be removed and replaced.
- An iron bar can be used to make a pilot hole in firm soil.
- Tamp the stake into the ground with a dead blow hammer (hammer head filled with shot or sand).

Figure 16-5 Prepared live stake (Robbin B. Sotir & Associates photo)



Figure 16-6 Growing live stake



(ii) Live fascines—Live fascines are long bundles of branch cuttings bound together in cylindrical structures (fig. 16–7). They should be placed in shallow contour trenches on dry slopes and at an angle on wet slopes to reduce erosion and shallow sliding.

Applications and effectiveness

- Apply typically above bankfull discharge (stream-forming flow) except on very small drainage area sites (generally less than 2,000 acres).
- Effective stabilization technique for streambanks. When properly installed, this system does not cause much site disturbance.
- Protect slopes from shallow slides (1 to 2 foot depth).
- Offer immediate protection from surface erosion.
- Capable of trapping and holding soil on a streambank by creating small dam-like structures, thus reducing the slope length into a series of shorter slopes.
- Serve to facilitate drainage where installed at an angle on the slope.
- Enhance conditions for colonization of native vegetation by creating surface stabilization and a microclimate conducive to plant growth.

Construction guidelines

Live materials—Cuttings must be from species, such as young willows or shrub dogwoods, that root easily and have long, straight branches.

Live material sizes and preparation

- Cuttings tied together to form live fascine bundles normally vary in length from 5 to 10 feet or longer, depending on site conditions and limitations in handling.
- The completed bundles should be 6 to 8 inches in diameter, with all of the growing tips oriented in the same direction. Stagger the cuttings in the bundles so that tops are evenly distributed throughout the length of the uniformly sized live fascine.
- Live stakes should be 2.5 feet long.

Inert materials—String used for bundling should be untreated twine.

Dead stout stakes used to secure the live fascines should be 2.5-foot long, untreated, 2 by 4 lumber. Each length should be cut again diagonally across the 4-inch face to make two stakes from each length (fig 16–8). Only new, sound lumber should be used, and any stakes that shatter upon installation should be discarded.

Installation

- Prepare the live fascine bundle and live stakes immediately before installation.
- Beginning at the base of the slope, dig a trench on the contour approximately 10 inches wide and deep.
- Excavate trenches up the slope at intervals specified in table 16–1. Where possible, place one or two rows over the top of the slope.
- Place long straw and annual grasses between rows.
- Install jute mesh, coconut netting, or other acceptable erosion control fabric. Secure the fabric.
- Place the live fascine into the trench (fig. 16–9a).
- Drive the dead stout stakes directly through the live fascine. Extra stakes should be used at connections or bundle overlaps. Leave the top of the dead stout stakes flush with the installed bundle.
- Live stakes are generally installed on the downslope side of the bundle. Tamp the live stakes below and against the bundle between the previously installed dead stout stakes, leaving 3 inches to protrude above the top of the ground (fig. 16–9b). Place moist soil along the sides of the bundles. The top of the live fascine should be slightly visible when the installation is completed. Figure 16–9c shows an established live fascine system 2 years after installation is completed.

Table 16–1 Live fascine spacing

Slope steepness	Soils -----		
	Erosive (feet)	Non-erosive (feet)	Fill (feet)
3:1 or flatter	3 – 5	5 – 7	3 – 5 ^{1/}
Steeper than 3:1 (up to 1:1)	3 ^{1/}	3 – 5	^{2/}

^{1/} Not recommended alone.
^{2/} Not a recommended system.

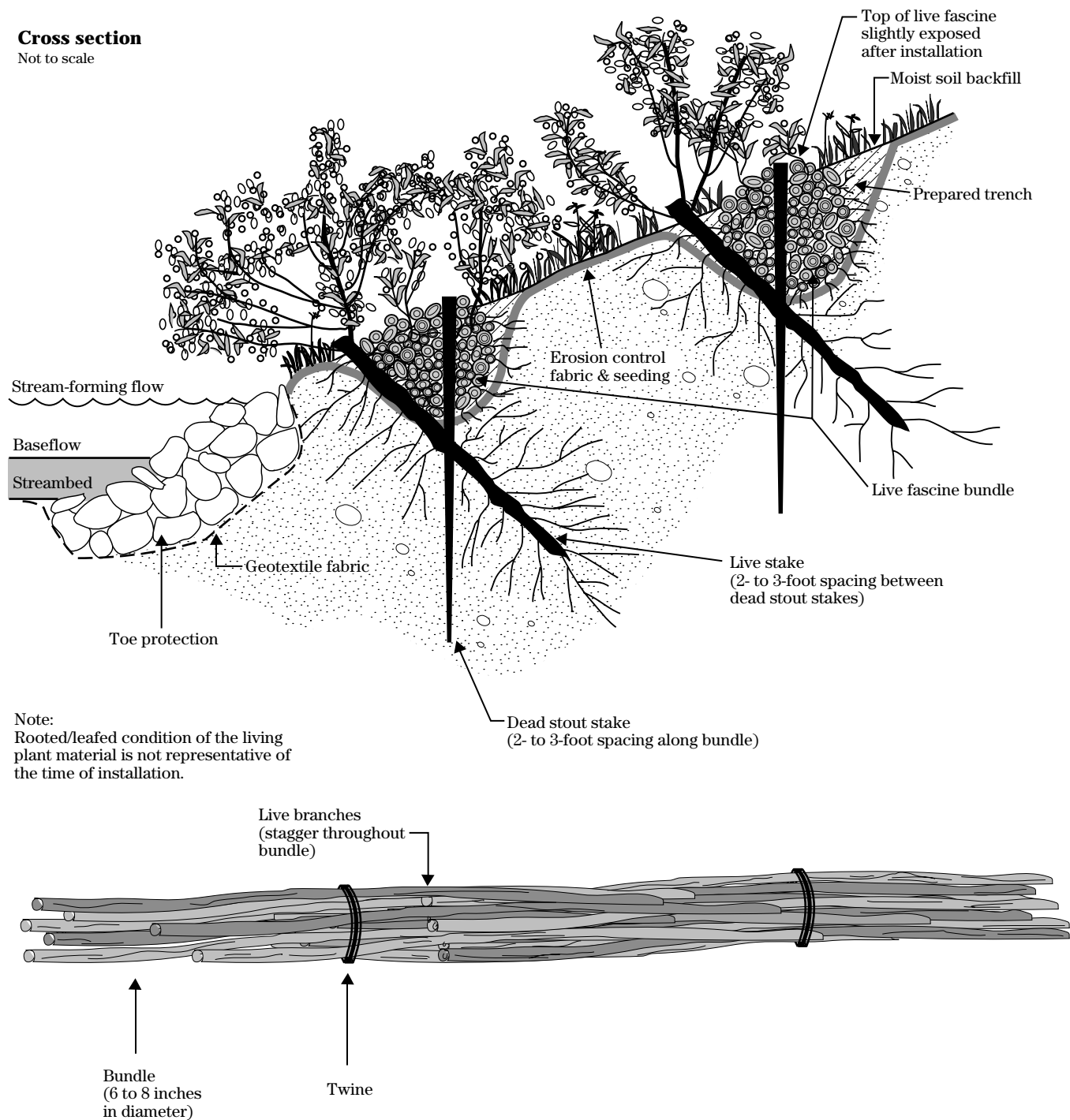
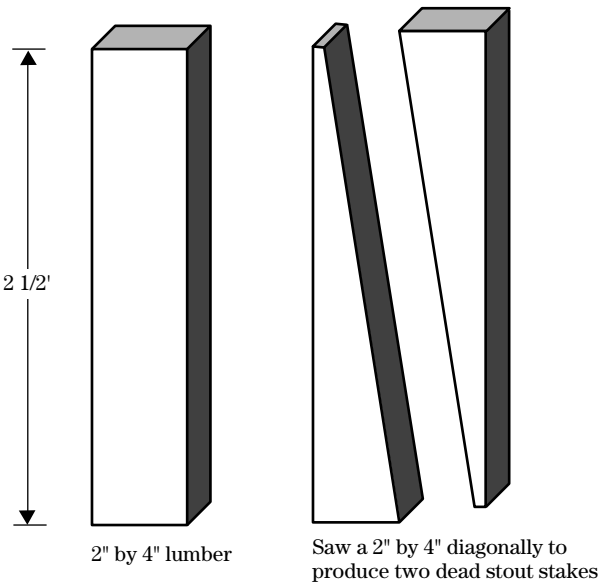
Figure 16-7 Live fascine details

Figure 16-8 Preparation of a dead stout stake



Not to scale

Figure 16-9b Installing live stakes in live fascine system (Robbin B. Sotir & Associates photo)



Figure 16-9c An established 2-year-old live fascine system (Robbin B. Sotir & Associates photo)



Figure 16-9a Placing live fascines (Robbin B. Sotir & Associates photo)



(iii) Branchpacking—Branchpacking consists of alternating layers of live branches and compacted backfill to repair small localized slumps and holes in streambanks (figs. 16–10, 16–11a, 16–11b, and 16–11c).

Applications and effectiveness

- Effective and inexpensive method to repair holes in streambanks that range from 2 to 4 feet in height and depth.
- Produces a filter barrier that prevents erosion and scouring from streambank or overbank flow.
- Rapidly establishes a vegetated streambank.
- Enhances conditions for colonization of native vegetation.
- Provides immediate soil reinforcement.
- Live branches serve as tensile inclusions for reinforcement once installed. As plant tops begin to grow, the branchpacking system becomes increasingly effective in retarding runoff and reducing surface erosion. Trapped sediment refills the localized slumps or hole, while roots spread throughout the backfill and surrounding earth to form a unified mass.
- Typically branchpacking is not effective in slump areas greater than 4 feet deep or 4 feet wide.

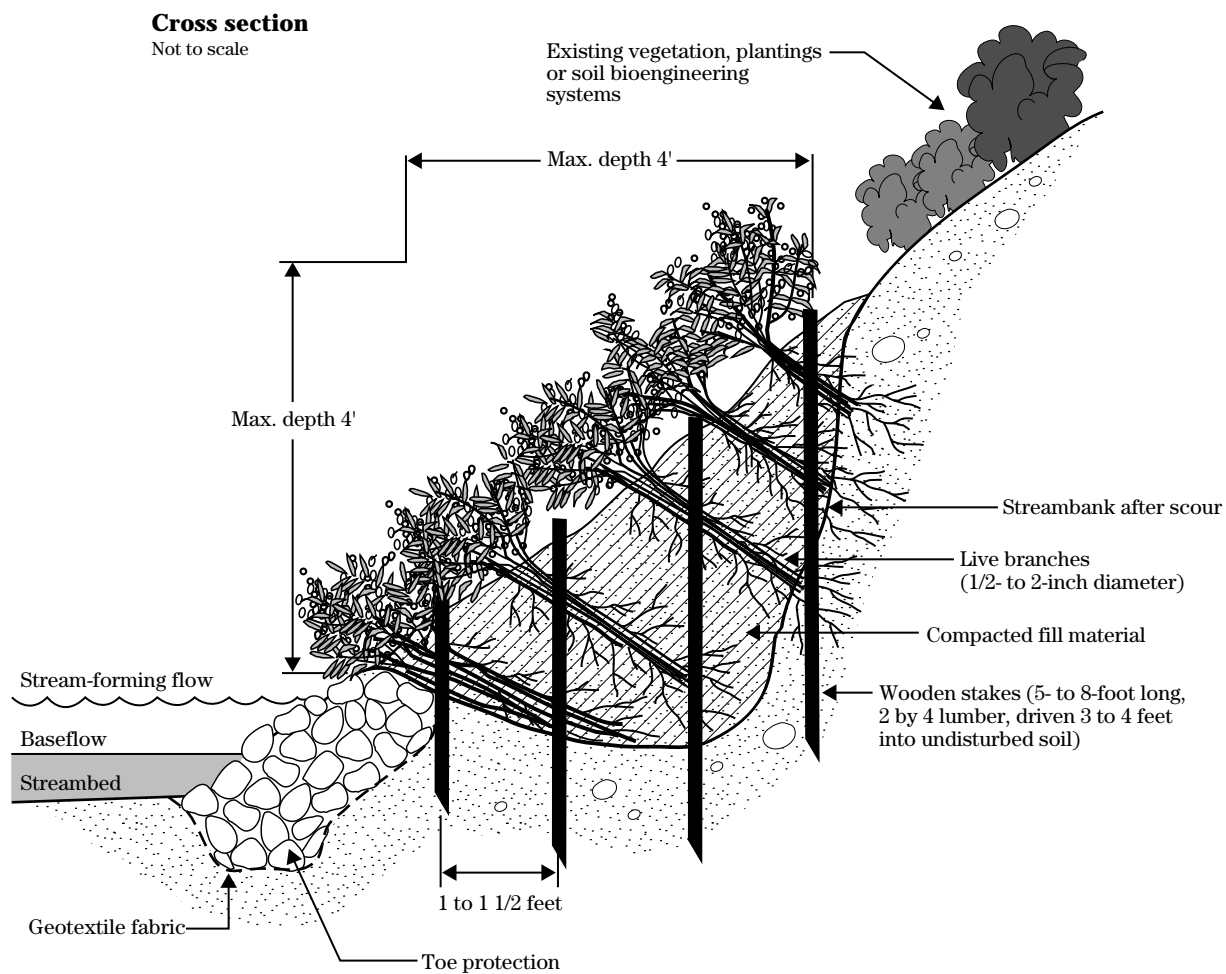
Construction guidelines

Live materials—Live branches may range from 0.5 to 2 inches in diameter. They should be long enough to touch the undisturbed soil of the back of the trench and extend slightly from the rebuilt streambank.

Inert materials—Wooden stakes should be 5 to 8 feet long and made from 3- to 4-inch diameter poles or 2 by 4 lumber, depending upon the depth of the particular slump or hole being repaired.

Installation

- Starting at the lowest point, drive the wooden stakes vertically 3 to 4 feet into the ground. Set them 1 to 1.5 feet apart.
- Place an initial layer of living branches 4 to 6 inches thick in the bottom of the hole between the vertical stakes, and perpendicular to the slope face (fig. 16–10). They should be placed in a criss-cross configuration with the growing tips generally oriented toward the slope face. Some of the basal ends of the branches should touch the undisturbed soil at the back of the hole.
- Subsequent layers of branches are installed with the basal ends lower than the growing tips of the branches.
- Each layer of branches must be followed by a layer of compacted soil to ensure soil contact with the branches.
- The final installation should conform to the existing slope. Branches should protrude only slightly from the filled installation.
- Water must be controlled or diverted if the original streambank damage was caused by water flowing over the bank. If this is not done, erosion will most likely occur on either or both sides of the new branchpacking installation.

Figure 16-10 Branchpacking details

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

Figure 16-11a Live branches installed in criss-cross configuration (Robbin B. Sotir & Associates photo)



Figure 16-11b Each layer of branches is followed by a layer of compacted soil (Robbin B. Sotir & Associates photo)



Figure 16-11c A growing branchpacking system (Robbin B. Sotir & Associates photo)



(iv) Vegetated geogrids—Vegetated geogrids are similar to branchpacking except that natural or synthetic geotextile materials are wrapped around each soil lift between the layers of live branch cuttings (figs. 16–12, 16–13a, 16–13b, and 16–13c).

Applications and effectiveness

- Used above and below stream-forming flow conditions.
- Drainage areas should be relatively small (generally less than 2,000 acres) with stable streambeds.
- The system must be built during low flow conditions.
- Can be complex and expensive.
- Produce a newly constructed, well-reinforced streambank.
- Useful in restoring outside bends where erosion is a problem.
- Capture sediment, which rapidly rebuilds to further stabilize the toe of the streambank.
- Function immediately after high water to rebuild the bank.
- Produce rapid vegetative growth.
- Enhance conditions for colonization of native vegetation.
- Benefits are similar to those of branchpacking, but a vegetated geogrid can be placed on a 1:1 or steeper slope.

Construction guidelines

Live materials—Live branch cuttings that are brushy and root readily are required. They should be 4 to 6 feet long.

Inert materials—Natural or synthetic geotextile material is required.

Installation

- Excavate a trench that is 2 to 3 feet below streambed elevation and 3 to 4 feet wide. Place the geotextile in the trench, leaving a foot or two overhanging on the streamside face. Fill this area with rocks 2 to 3 inches in diameter.
- Beginning at the stream-forming flow level, place a 6- to 8-inch layer of live branch cuttings on top of the rock-filled geogrid with the growing tips at right angles to the streamflow. The basal ends of branch cuttings should touch the back of the excavated slope.
- Cover this layer of cuttings with geotextile leaving an overhang. Place a 12-inch layer of soil suitable for plant growth on top of the geotextile before compacting it to ensure good soil contact with the branches. Wrap the overhanging portion of the geotextile over the compacted soil to form the completed geotextile wrap.
- Continue this process of excavated trenches with alternating layers of cuttings and geotextile wraps until the bank is restored to its original height.
- This system should be limited to a maximum of 8 feet in total height, including the 2 to 3 feet below the bed. The length should not exceed 20 feet for any one unit along the stream. An engineering analysis should determine appropriate dimensions of the system.
- The final installation should match the existing slope. Branch cuttings should protrude only slightly from the geotextile wraps.

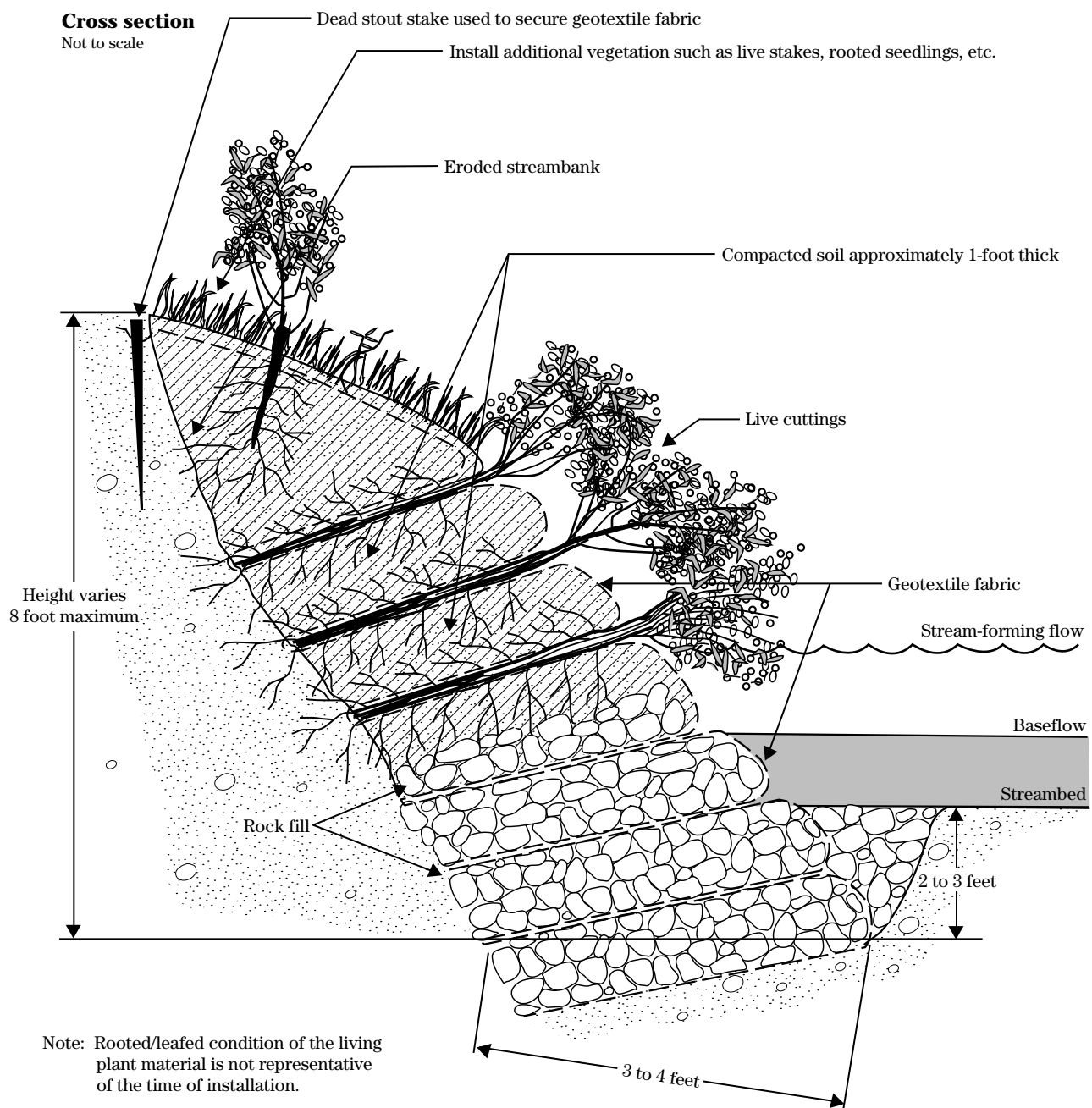
Figure 16-12 Vegetated geogrid details

Figure 16-13a A vegetated geogrid during installation (Robbin B. Sotir & Associates photo)



Figure 16-13b A vegetated geogrid immediately after installation (Robbin B. Sotir & Associates photo)



Figure 16-13c Vegetated geogrid 2 years after installation (Robbin B. Sotir & Associates photo)



(v) Live cribwall—A live cribwall consists of a box-like interlocking arrangement of untreated log or timber members. The structure is filled with suitable backfill material and layers of live branch cuttings that root inside the crib structure and extend into the slope. Once the live cuttings root and become established, the subsequent vegetation gradually takes over the structural functions of the wood members (fig. 16–14).

Applications and effectiveness

- Effective on outside bends of streams where strong currents are present.
- 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.
- Appropriate above and below water level where stable streambeds exist.
- Useful where space is limited and a more vertical structure is required.
- Effective in locations where an eroding bank may eventually form a split channel.
- Maintains a natural streambank appearance.
- Provides excellent habitat.
- Provides immediate protection from erosion, while established vegetation provides long-term stability.
- Supplies effective bank erosion control on fast flowing streams.
- Should be tilted back or battered if the system is built on a smooth, evenly sloped surface.
- Can be complex and expensive.

Construction guidelines

Live materials—Live branch cuttings should be 0.5 to 2.5 inches in diameter and long enough to reach the back of the wooden crib structure.

Inert materials—Logs or timbers should range from 4 to 6 inches in diameter or dimension. The lengths will vary with the size of the crib structure.

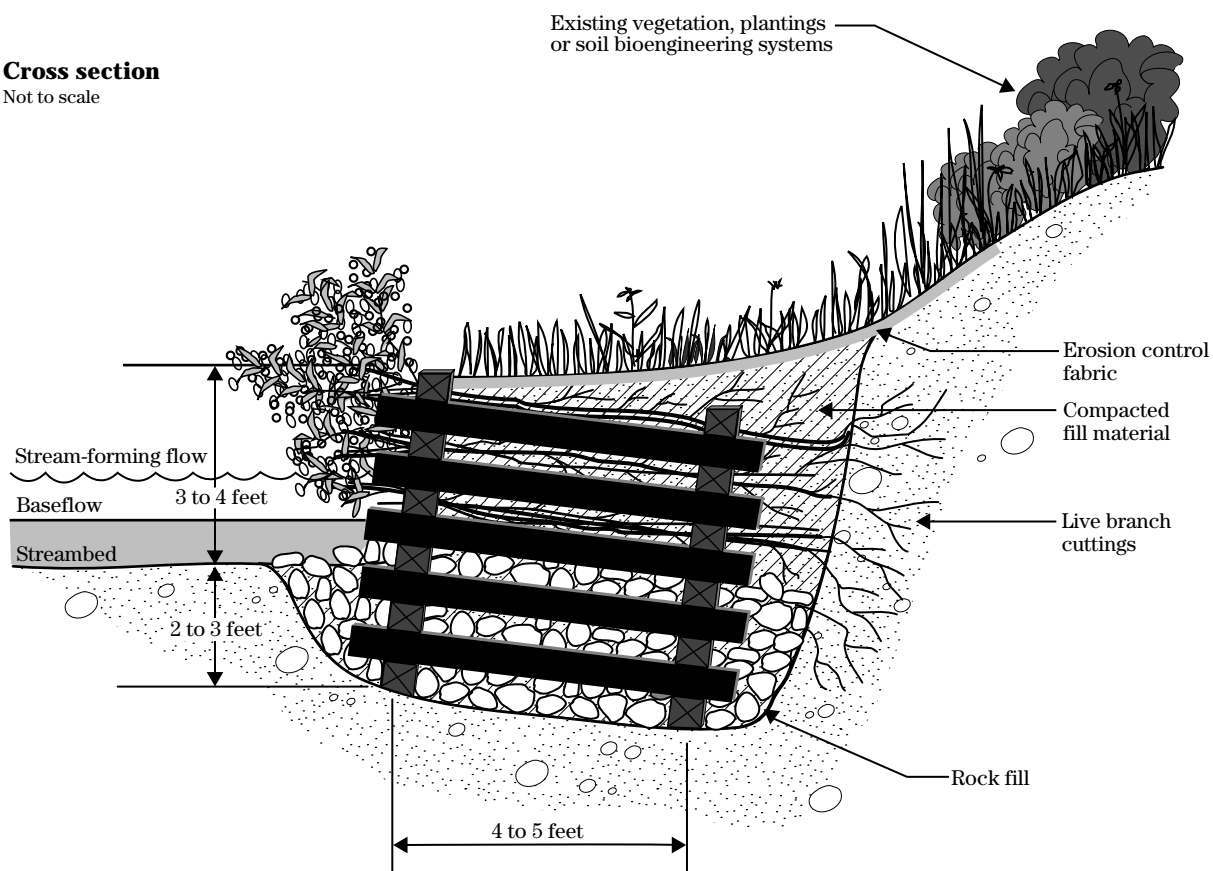
Large nails or rebar are required to secure the logs or timbers together.

Installation

- Starting at the base of the streambank to be treated, excavate 2 to 3 feet below the existing streambed until a stable foundation 5 to 6 feet wide is reached.
- Excavate the back of the stable foundation (closest to the slope) 6 to 12 inches lower than the front to add stability to the structure.
- Place the first course of logs or timbers at the front and back of the excavated foundation, approximately 4 to 5 feet apart and parallel to the slope contour.
- Place the next course of logs or timbers at right angles (perpendicular to the slope) on top of the previous course to overhang the front and back of the previous course by 3 to 6 inches. Each course of the live cribwall is placed in the same manner and secured to the preceding course with nails or reinforcement bars.
- Place rock fill in the openings in the bottom of the crib structure until it reaches the approximate existing elevation of the streambed. In some cases it is necessary to place rocks in front of the structure for added toe support, especially in outside stream meanders.
- Place the first layer of cuttings on top of the rock material at the baseflow water level, and change the rock fill to soil fill capable of supporting plant growth at this point. Ensure that the basal ends of some of the cuttings contact undisturbed soil at the back of the cribwall.
- When the cribwall structure reaches the existing ground elevation, place live branch cuttings on the backfill perpendicular to the slope; then cover the cuttings with backfill and compact.
- Live branch cuttings should be placed at each course to the top of the cribwall structure with growing tips oriented toward the slope face. Follow each layer of branches with a layer of compacted soil. Place the basal ends of the remaining live branch cuttings so that they reach to undisturbed soil at the back of the cribwall with growing tips protruding slightly beyond the front of the cribwall (figs. 16–15a, 16–15b, and 16–15c).
- The live cribwall structure, including the section below the streambed, should not exceed a maximum height of 7 feet. An engineering analysis should determine appropriate dimensions of the system.
- The length of any single constructed unit should not exceed 20 feet.

Figure 16-14 Live cribwall details**Cross section**

Not to scale



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

Figure 16-15a Pre-construction streambank conditions



Figure 16-15b A live cribwall during installation



Figure 16-15c An established live cribwall system



(vi) Joint planting—Joint planting or vegetated riprap involves tamping live stakes into joints or open spaces in rocks that have been previously placed on a slope (fig 16-16). Alternatively, the stakes can be tamped into place at the same time that rock is being placed on the slope face.

Applications and effectiveness

- Useful where rock riprap is required or already in place.
- Roots improve drainage by removing soil moisture.
- Over time, joint plantings create a living root mat in the soil base upon which the rock has been placed. These root systems bind or reinforce the soil and prevent washout of fines between and below the rock.
- Provides immediate protection and is effective in reducing erosion on actively eroding banks.
- Dissipates some of the energy along the streambank.

Construction guidelines

Live material sizes—The stakes must have side branches removed and bark intact. They should be 1.5 inches or larger in diameter and sufficiently long to extend well into soil below the rock surface.

Installation

- Tamp live stakes into the openings of the rock during or after placement of riprap. The basal ends of the material must extend into the backfill or undisturbed soil behind the riprap. A steel rod or hydraulic probe may be used to prepare a hole through the riprap.
- Orient the live stakes perpendicular to the slope with growing tips protruding slightly from the finished face of the rock (figs. 16-17a, 16-17b, and 16-17c).
- Place the stakes in a random configuration.

Figure 16-16 Joint planting details

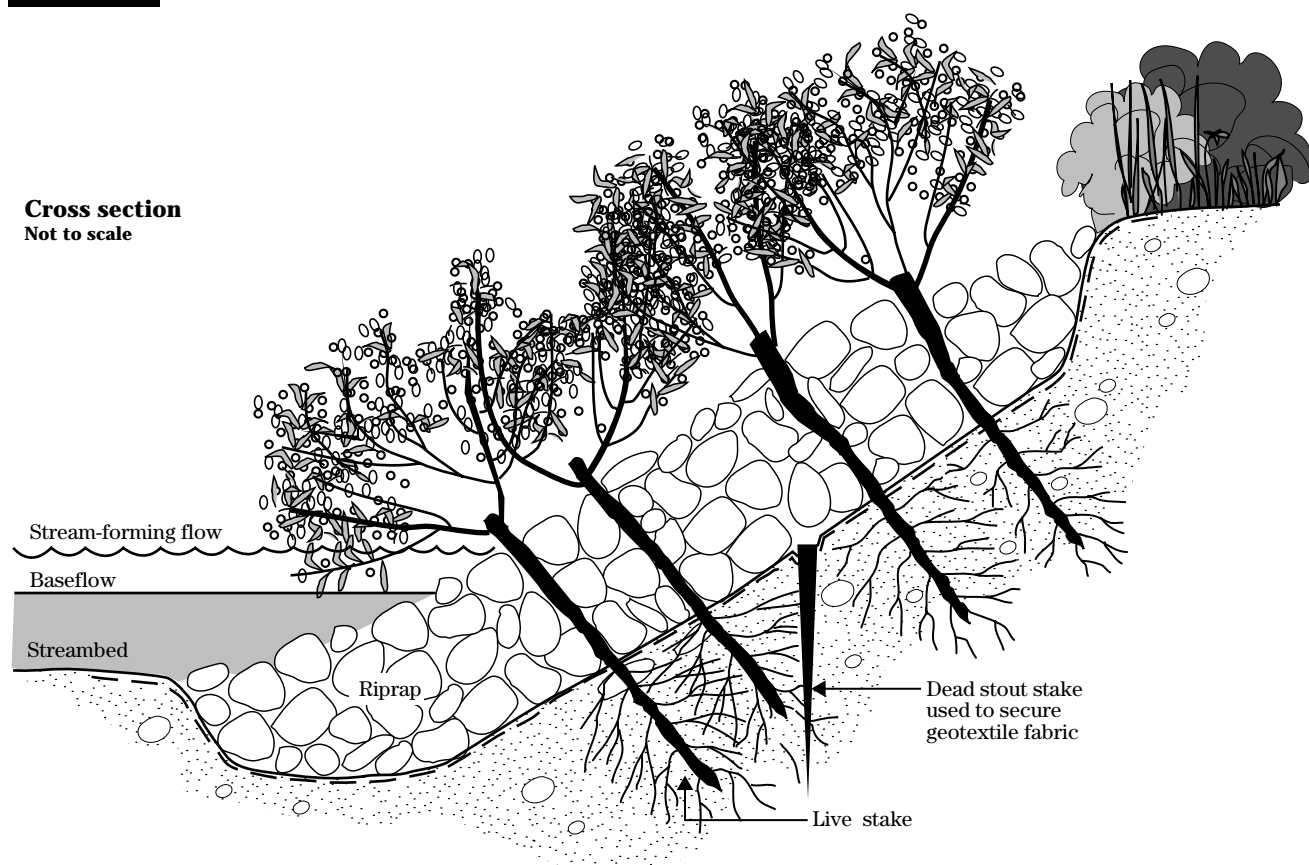


Figure 16-17a Live stake tamped into rock joints (joint planting) (Robbin B. Sotir & Associates photo)

Figure 16-17b An installed joint planting system (Robbin B. Sotir & Associates photo)

Figure 16-17c An established joint planting system (Robbin B. Sotir & Associates photo)

(vii) Brushmattress—A brushmattress is a combination of live stakes, live fascines, and branch cuttings installed to cover and stabilize streambanks (figs. 16–18, 16–19a through 16–19d). Application typically starts above stream-forming flow conditions and moves up the slope.

Applications and effectiveness

- Forms an immediate, protective cover over the streambank.
- Useful on steep, fast-flowing streams.
- Captures sediment during flood conditions.
- Rapidly restores riparian vegetation and stream-side habitat.
- Enhances conditions for colonization of native vegetation.

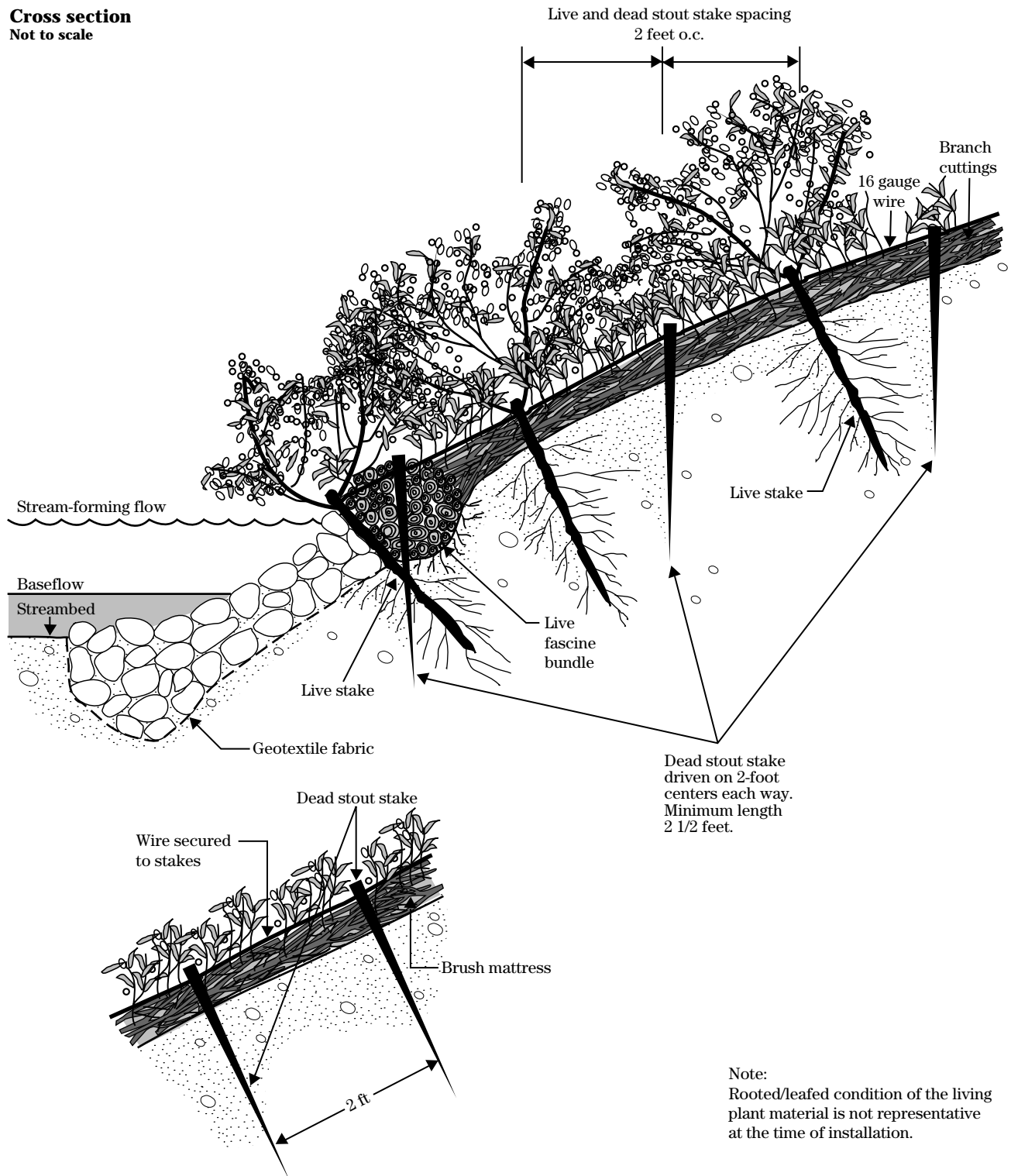
Construction guidelines

Live materials—Branches 6 to 9 feet long and approximately 1 inch in diameter are required. They must be flexible to enable installations that conform to variations in the slope face. Live stakes and live fascines are previously described in this chapter.

Inert materials—Untreated twine for bundling the live fascines and number 16 smooth wire are needed to tie down the branch mattress. Dead stout stakes to secure the live fascines and brushmattress in place.

Installation

- Grade the unstable area of the streambank uniformly to a maximum steepness of 3:1.
- Prepare live stakes and live fascine bundles immediately before installation, as previously described in this chapter.
- Beginning at the base of slope, near the stream-forming flow stage, excavate a trench on the contour large enough to accommodate a live fascine and the basal ends of the branches.
- Install an even mix of live and dead stout stakes at 1-foot depth over the face of the graded area using 2-foot square spacing.
- Place branches in a layer 1 to 2 branches thick vertically on the prepared slope with basal ends located in the previously excavated trench.
- Stretch No. 16 smooth wire diagonally from one dead stout stake to another by tightly wrapping wire around each stake no closer than 6 inches from its top.
- Tamp and drive the live and dead stout stakes into the ground until branches are tightly secured to the slope.
- Place live fascines in the prepared trench over the basal ends of the branches.
- Drive dead stout stakes directly through into soil below the live fascine every 2 feet along its length.
- Fill voids between brushmattress and live fascine cuttings with thin layers of soil to promote rooting, but leave the top surface of the brushmattress and live fascine installation slightly exposed.

Figure 16-18 Brushmattress details**Cross section**
Not to scale

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

Figure 16-19a Brushmattress during installation
(Robbin B. Sotir & Associates photo)



Figure 16-19b An installed brushmattress system
(Robbin B. Sotir & Associates photo)



Figure 16-19c Brushmattress system 6 months after installation
(Robbin B. Sotir & Associates photo)



Figure 16-19d Brushmattress system 2 years after installation
(Robbin B. Sotir & Associates photo)



(4) Structural measures

Structural measures include tree revetments; log, rootwad and boulder revetments; dormant post plantings; piling revetments with wire or geotextile fencing; piling revetments with slotted fencing; jacks or jack fields; rock riprap; stream jetties; stream barbs; and gabions.

(i) Tree revetment—A tree revetment is constructed from whole trees (except rootwads) that are usually cabled together and anchored by earth anchors, which are buried in the bank (figs. 16–20, 16–21a, and 16–21b).

Applications and effectiveness

- Uses inexpensive, readily available materials to form semi-permanent protection.
- Captures sediment and enhances conditions for colonization of native species.
- Has self-repairing abilities following damage after flood events if used in combination with soil bioengineering techniques.
- Not appropriate near bridges or other structures where there is high potential for downstream damage if the revetment dislodges during flood events.
- 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 periodic maintenance to replace damaged or deteriorating trees.

Construction guidelines

- Lay the cabled trees along the bank with the basal ends 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 custom designed 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 inundation should be staked in openings in the revetment below stream-forming flow stage.

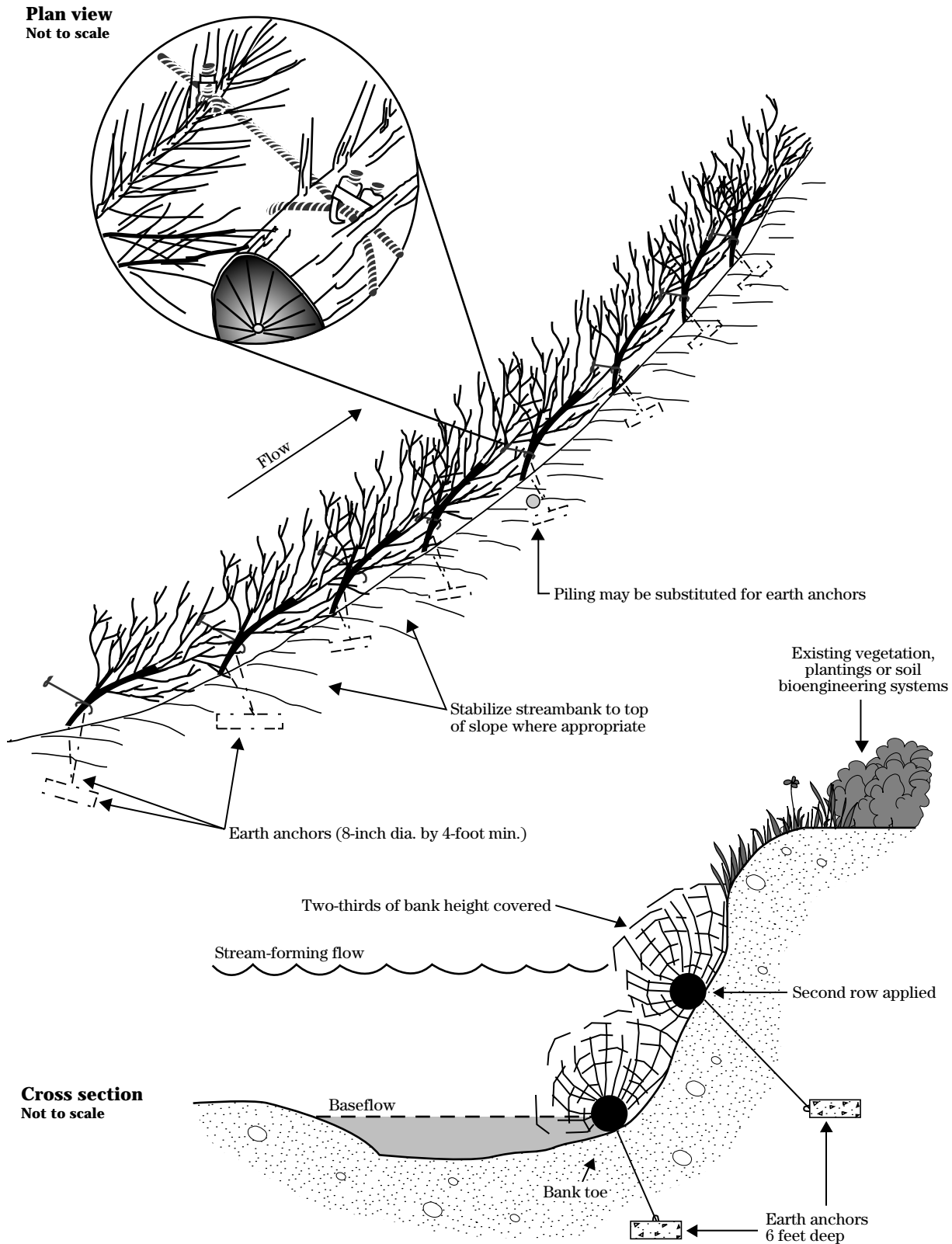
Figure 16-20 Tree revetment details

Figure 16-21a Tree revetment system with dormant posts



Figure 16-21b Tree revetment system with dormant posts, 2 years after installation



(ii) Log, rootwad and boulder revetments—

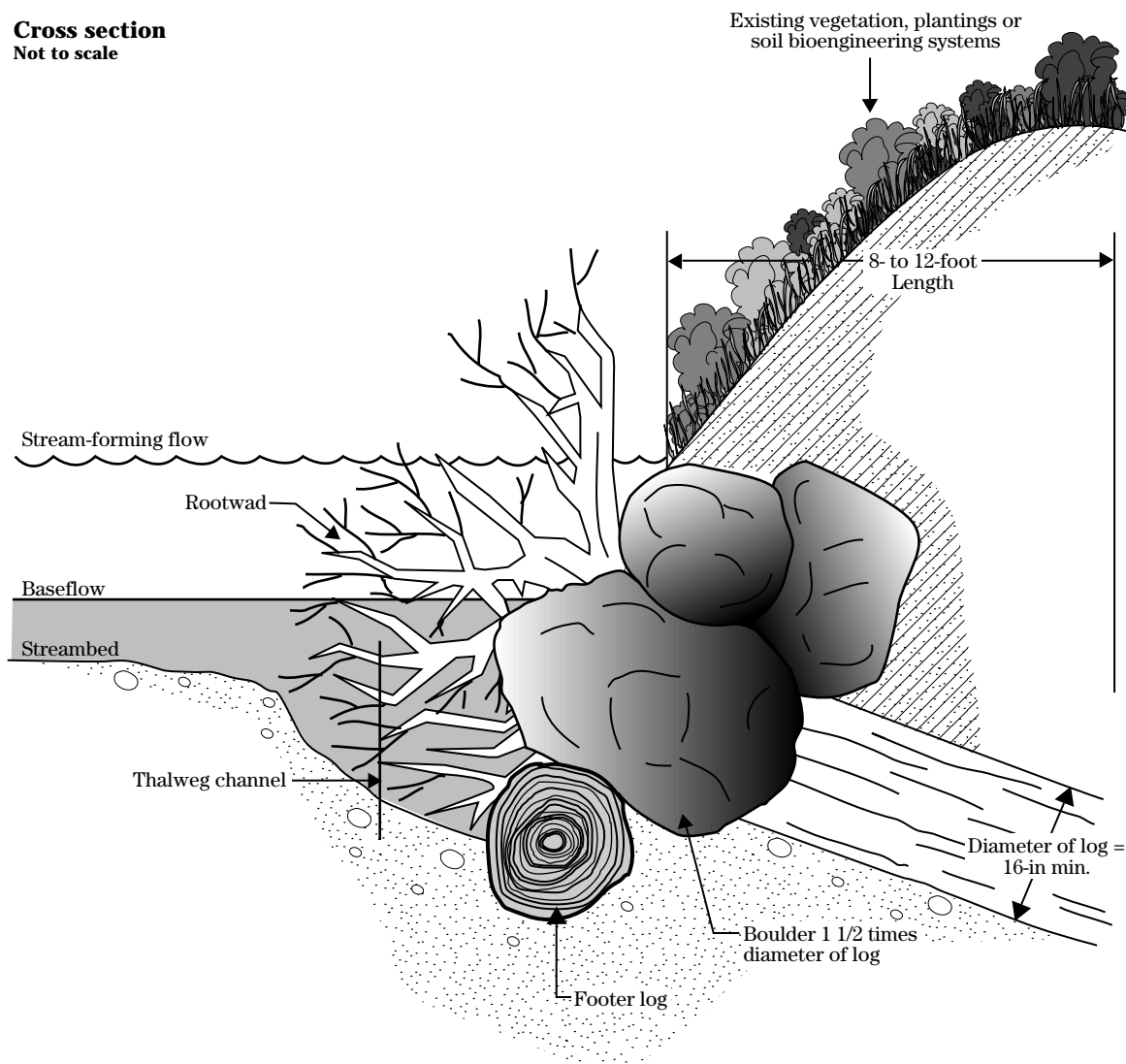
These revetments are systems composed of logs, rootwads, and boulders selectively placed in and on streambanks (figs. 16–22 and 16–23). These revetments can provide excellent overhead cover, resting areas, shelters for insects and other fish food organisms, substrate for aquatic organisms, and increased stream velocity that results in sediment flushing and deeper scour pools. Several of these combinations are described in Flosi and Reynolds (1991), Rosgen (1992) and Berger (1991).

Applications and effectiveness

- Used for stabilization and to create instream structures for improved fish rearing and spawning habitat
- Effective on meandering streams with out-of-bank flow conditions.
- Will tolerate high boundary shear stress if logs and rootwads are well anchored.
- Suited to streams where fish habitat deficiencies exist.
- Should be used in combination with soil bioengineering systems or vegetative plantings to stabilize

Figure 16–22 Log, rootwad, and boulder revetment details (adapted from Rosgen 1993—Applied fluvial geomorphology short course)

Cross section
Not to scale



lize the upper bank and ensure a regenerative source of streambank vegetation.

- Enhance diversity of riparian corridor when used in combination with soil bioengineering systems.
- Have limited life depending on climate and tree species used. Some species, such as cottonwood or willow, often sprout and accelerate natural colonization. Revetments may need eventual replacement if natural colonization does not take place or soil bioengineering methods are not used in combination.

Construction guidelines

Numerous individual organic revetments exist and many are detailed in the U.S. Forest Service publication, *Stream Habitat Improvement Handbook*. Chapter 16 only presents construction guidelines for a combination log, rootwad, and boulder revetment.

- Use logs over 16 inches in diameter that are crooked and have an irregular surface.
- Use rootwads with numerous root protrusions and 8- to 12-foot long boles.
- Boulders should be as large as possible, but at a minimum one and one-half the log diameter. They should have an irregular surface.

- Install a footer log at the toe of the eroding bank by excavating trenches or driving them into the bank to stabilize the slope and provide a stable foundation for the rootwad.
- Place the footer log to the expected scour depth at a slight angle away from the direction of the stream flow.
- Use boulders to anchor the footer log against flotation. If boulders are not available, logs can be pinned into gravel and rubble substrate with 3/4-inch rebar 54 inches or longer. Anchor rebar to provide maximum pull out resistance. Cable and anchors may also be used in combination with boulders and rebar.
- Drive or trench and place rootwads into the streambank so that the tree's primary brace roots are flush with the streambank. Place the rootwads at a slight angle toward the direction of the streamflow.
- Backfill and combine vegetative plantings or soil bioengineering systems behind and above rootwad. They can include live stakes and dormant post plantings in the openings of the revetment below stream-forming flow stage, live stakes, bare root, or other upland methods at the top of the bank.

Figure 16-23 Rootwad, boulder, and willow transplant revetment system, Weminuche River, CO (Rosgen, Wildland hydrology)



(iii) Dormant post plantings—Dormant post plantings form a permeable revetment that is constructed from rootable vegetative material placed along streambanks in a square or triangular pattern (figs. 16-24, 16-25a, 16-25b, 16-25c).

Applications and effectiveness

- Well suited to smaller, non-gravelly streams where ice damage is not a problem.
- Quickly re-establishes riparian vegetation.
- Reduce stream velocities and causes sediment deposition in the treated area.
- Enhance conditions for colonization of native species.
- Are self-repairing. For example, posts damaged by beaver often develop multiple stems.
- Can be used in combination with soil bioengineering systems.
- Can be installed by a variety of methods including water jetting or mechanized stingers to form planting holes or driving the posts directly with machine mounted rams.
- Unsuccessfully rooted posts at spacings of about 4 feet can provide some benefits by deflecting higher streamflows and trapping sediment.

Construction guidelines

- Select a plant species appropriate to the site conditions. Willows and poplars have demonstrated high success rates.
- Cut live posts approximately 7 to 9 feet long and 3 to 5 inches in diameter. Taper the basal end of the post for easier insertion into the ground.
- Install posts into the eroding bank at or just above the normal waterline. Make sure posts are installed pointing up.
- Insert one-half to two-thirds of the length of post below the ground line. At least the bottom 12 inches of the post should be set into a saturated soil layer.
- Avoid excessive damage to the bark of the posts.
- Place two or more rows of posts spaced 2 to 4 feet apart using square or triangular spacing.
- Supplement the installation with appropriate soil bioengineering systems or, where appropriate, rooted plants.

Figure 16-24 Dormant post details

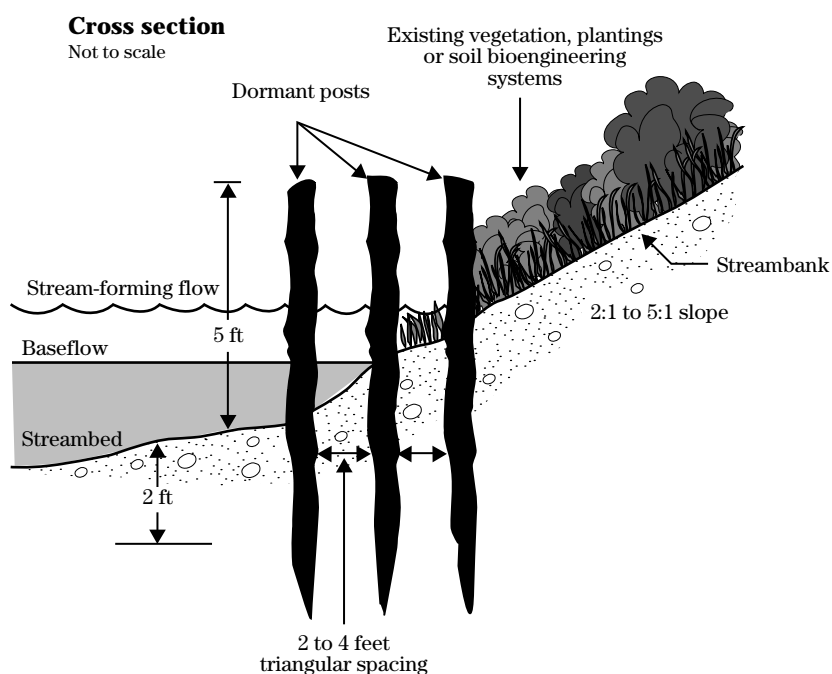


Figure 16-25a Pre-construction streambank conditions
(Don Roseboom photo)



Figure 16-25b Installing dormant posts
(Don Roseboom photo)



Figure 16-25c Established dormant post system (Don Roseboom photo)



(iv) Piling revetment with wire or geotextile fencing—Piling revetment is a continuous single or double row of pilings with a facing of woven wire or geogrid material (fig. 16–26). The space between double rows of pilings is filled with rock and brush.

Applications and effectiveness

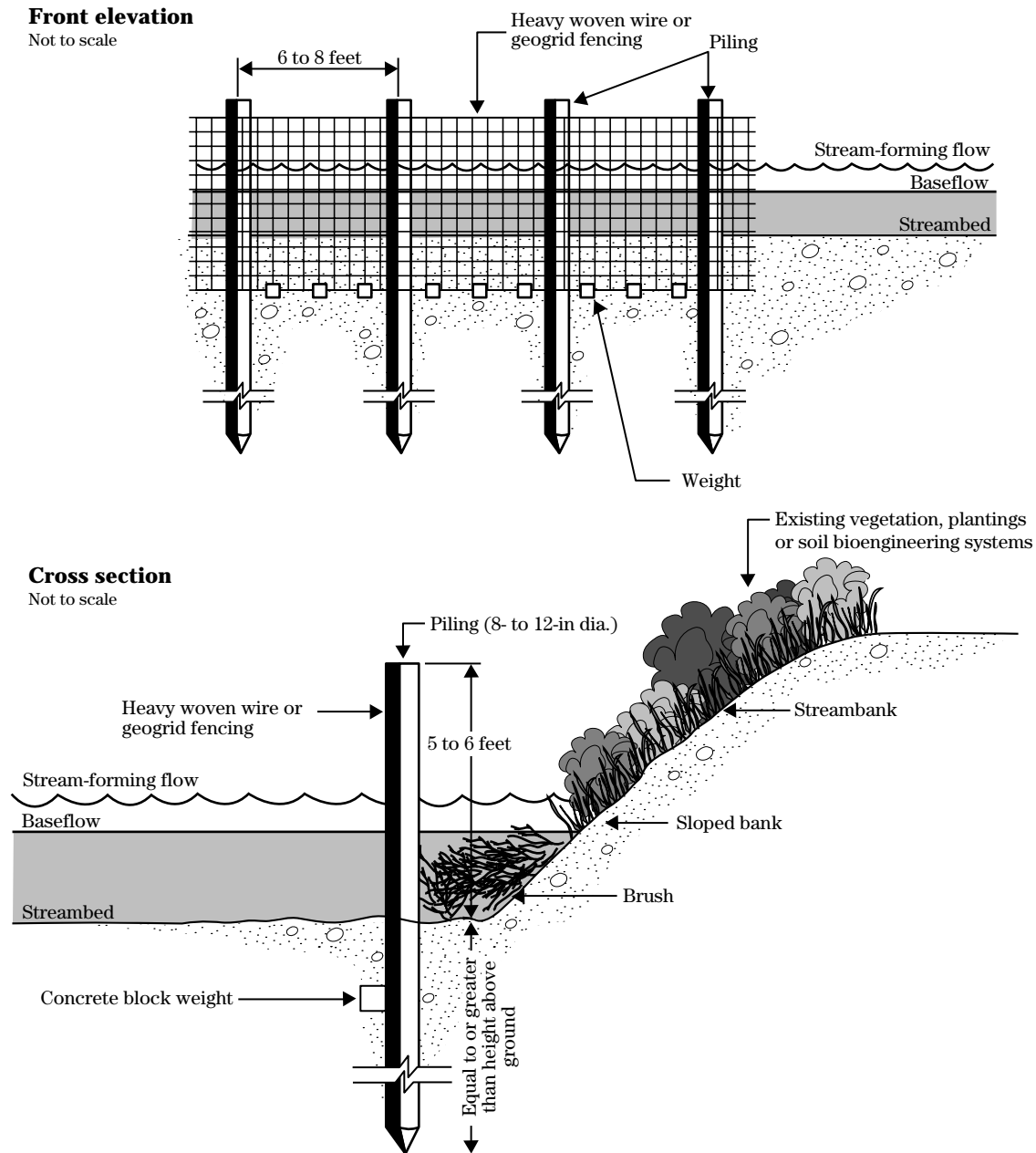
- Particularly suited to streams where water next to the bank is more than 3 feet deep.
- Application is limited to a flow depth (and height of piling) of 6 feet.
- More economical than riprap construction in deep water because it eliminates the need to build a stable foundation under water for holding the riprap in place.
- Is easily damaged by ice flows or heavy flood debris and should not be used where these conditions occur.
- Do not use where the stream has fish or an abundance of riparian wildlife.
- Do not use without careful analysis of its long-term effects upon aesthetics, changes in flows where large amounts of debris will be collected, habitat damage caused by driving or installing pilings with water jets, and possible dangers for recreational uses (boating, rafting, swimming, or wading).

Construction guidelines

Inert materials—Used material, such as timbers, logs, railroad rails, or pipe, may be used for pilings. Logs should have a diameter sufficiently large to permit driving to the required depth. Avoid material that may produce toxicity effects in aquatic ecosystems.

Installation

- Beginning at the base of the streambank, near stream-forming flow stage, drive pilings 6 to 8 feet apart to a depth approximately half their length and below the point of maximum scour. If the streambed is firm and not subject to appreciable scour, the piling should be driven to refusal or to a depth of at least half the length of the piling.
- Additional rows of pilings may be installed at higher elevations on the streambank if required to protect the bank and if using vegetation or other methods is not practical.
- Fasten a heavy gauge of woven wire or geotextile material to the stream side of the pilings to form a fence. The purpose of this material is to collect debris while serving as a permeable wall to reduce velocities on the streambank.
- Double row piling revetment is typically constructed with 5 feet between rows. Fill the row space with rock and brush.
- If the streambed is subject to scour, extend the woven wire or geotextile material horizontally toward the center of the streambed for a distance at least equal to the anticipated depth of scour. Attach concrete blocks or other suitable weights at regular intervals to cause the fence to settle in a vertical position along the face of the pilings after scouring occurs.
- Place brush behind the piling to increase the system's effectiveness. Where piling revetments extend for several hundred feet in length, install permeable groins or tiebacks of brush and rock at right angles to the revetment at 50 foot intervals. This reduces currents developing between the streambank and the revetment.

Figure 16-26 Piling revetment details

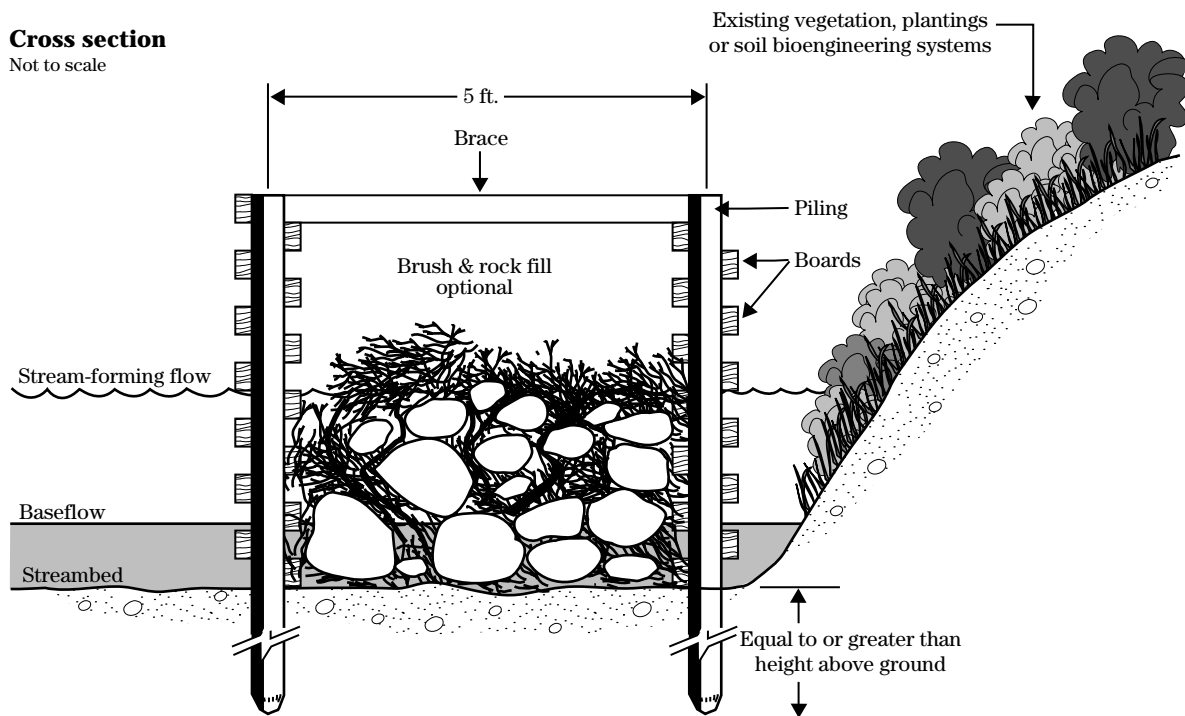
(v) Piling revetment with slotted board fencing

—This type of revetment consists of slotted board fencing made of wood pilings and horizontal wood timbers (figs. 16–27 and 16–28). Variations include different fence heights, double rows of slotted fence, and use of woven wire in place of timber boards. The size and spacing of pilings, cross members, and vertical fence boards depend on height of fence, stream velocity, and sediment load.

Applications and effectiveness

- Most variations of slotted fencing include some bracing or tieback into the streambank to increase strength, reduce velocity against the streambank, and to trap sediment.
- Should not be constructed higher than 3 feet without an engineering analysis to determine sizes of the structural members.
- May be vulnerable to damage by ice or heavy flood debris; should not be used where these conditions occur.
- Usually complex and expensive.
- Most effective on streams that have a heavy sediment load of sand and silt.
- Can withstand a relatively high velocity attack force and, therefore, can be installed in sharper curves than jacks or other systems.
- Useful in deeper stream channels with large flow depths.
- Low slotted board fences, which do not control the entire flood flow, can be very effective for streambank toe protection where the toe is the weak part of the streambank.
- May not be appropriate where unusually hard materials are encountered in the channel bottom.

Figure 16–27 Slotted board fence details (double fence option)



- Should not be used without careful consideration of its long-term effects upon aesthetics, changes in flows where large amounts of debris are collected, habitat damage caused by driving or installing pilings with water jets, and possible dangers for recreational uses (boating, rafting, swimming, or wading).

Construction guidelines

Inert materials—Slotted fencing is constructed of wood boards, wood pilings, and woven wire. Avoid materials that may produce toxicity effects in aquatic ecosystems.

Installation

- See (iv) *Piling revetment with wire or geotextile fencing* for general construction guidelines.
- Drive the timber piling to a depth below the channel bottom that is equal to the height of the slotted fence above the expected scour line when stream soils have a standard penetration resistance of 10 or more blows per foot. Increase the piling depth when penetration resistance is less than 10 blows per foot.
- Take great care during layout to tie in the upstream end adequately to prevent flanking and unraveling.

Figure 16-28 Slotted board fence system



(vi) Jacks or jack fields—Jacks are individual structures made of wood, concrete, or steel. The jacks are placed in rows parallel to the eroding streambank and function by trapping debris and sediment. They are often constructed in groups called jack fields (figs. 16-29, 16-30, and 16-31).

Applications and effectiveness

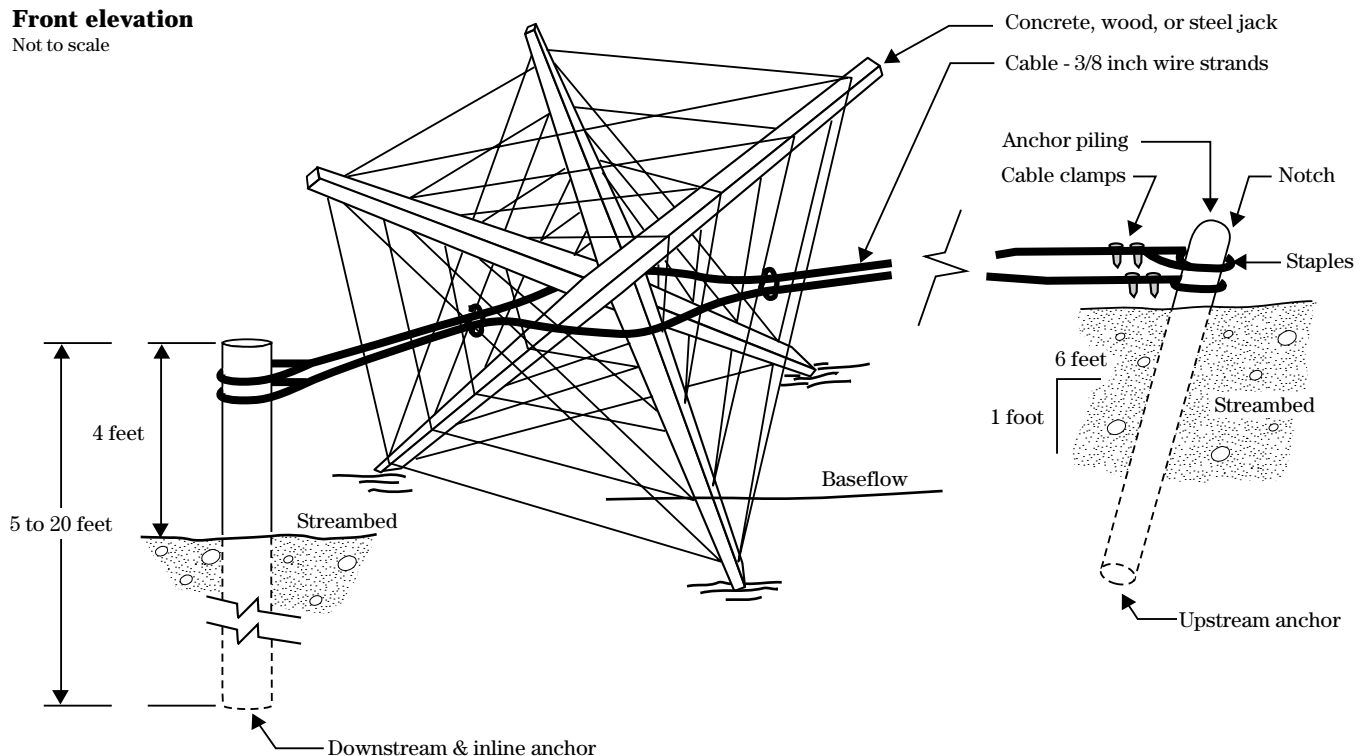
- May be an effective means of controlling bank erosion on sinuous streams carrying heavy bedloads of sand and silt during flood flows. This condition is generally indicated by the presence of extensive sandbar formations on the bed at low flow.
- Are complex systems requiring proper design and installation for effective results.
- Collect coarse and fine sediment, when functioning properly, and naturally revegetate as the systems, including cable, become embedded in the streambank.

- Do not use on high velocity, debris-laden streams.
- Somewhat flexible because of their physical configuration and installation techniques that allow them to adjust to slight changes in the channel grade.
- Most effective on long, radius curves.
- Not an effective alternative for redirecting flow away from the streambank.
- Do not use without careful analysis of its long-term effects upon aesthetics, changes in flows where large amounts of debris are collected, fish habitat damage, and possible dangers for recreational uses (boating, rafting, swimming, or wading).

Figure 16-29 Concrete jack details

Front elevation

Not to scale

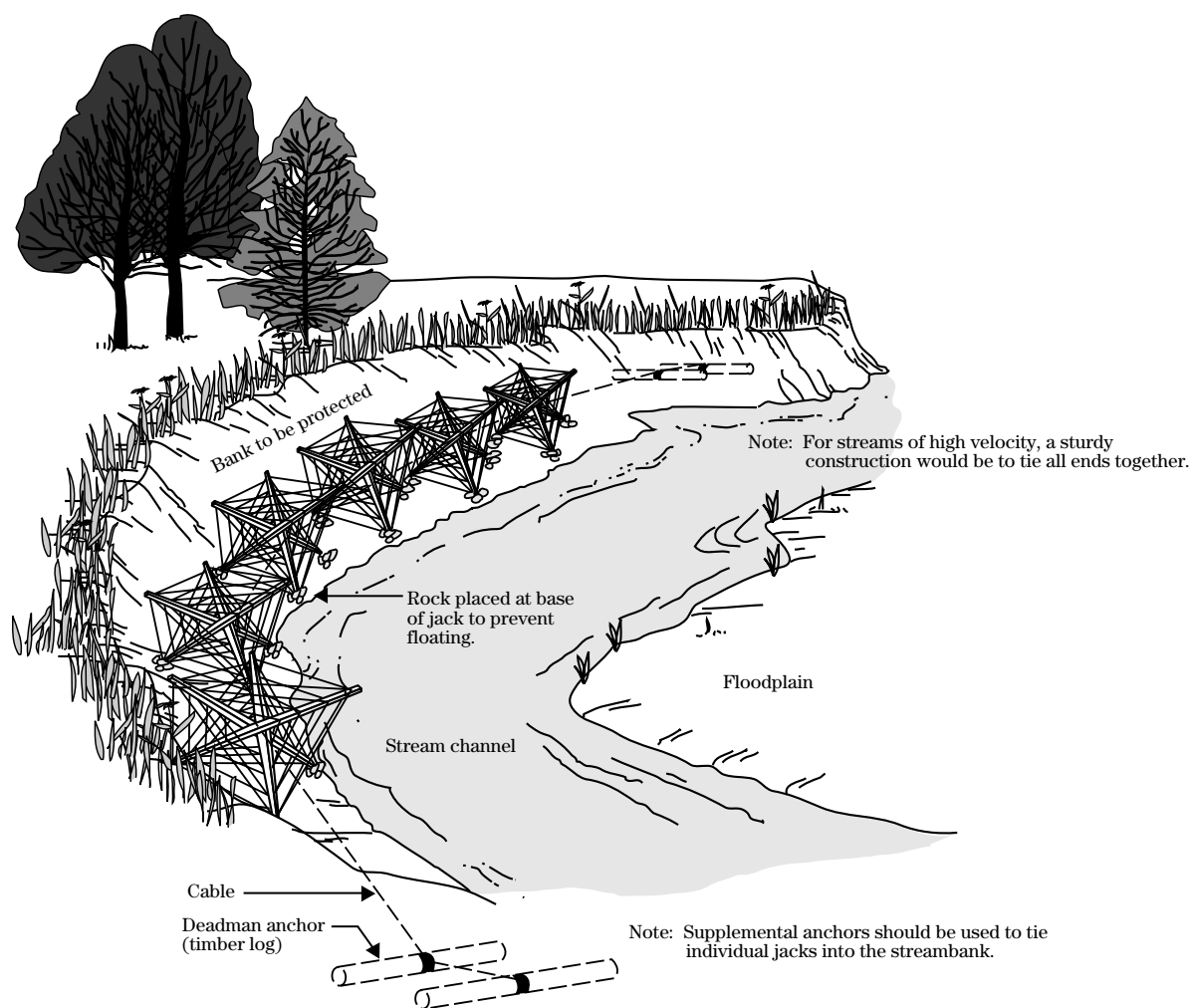


Construction guidelines

Inert materials—Jacks may be constructed of wood, steel, or concrete. Wooden jacks are constructed from three poles 10 to 16 feet long. They are crossed and wired together at the ends and midpoints with No. 9 galvanized wire. Cables used to anchor the wood jack systems should be 3/8-inch diameter or larger with a minimum breaking strength of 15,400 pounds. Wooden jack systems dimensioned in this chapter are limited to shallow flow depths of 12 feet or less.

Steel jacks are used in a manner similar to that of wood jacks; however, leg assemblies, cable size, anchor blocks, and anchor placement details vary. Concrete beams may be substituted for steel, but engineering design is required to determine different attachment methods, anchoring systems, and assembly configurations.

Figure 16-30 Wooden jack field



Installation

- Jack rows can be placed on a shelf 14 feet wide for one line and on two shelves, each 14 feet wide, for a double jack row. Grade the shelf to slope from 1 foot above the streambed at the side nearest the stream to 3 feet above the streambed at the side nearest the slope. This encourages a dry surface for construction and provides some additional elevation for protection from greater depths of flow. Alternatively, jacks can be constructed on the streambed or on the top of the bank and moved into place.
- Space jacks closely together with a maximum of one jack dimension between them to provide an almost continuous line of revetment.
- Anchor the jacks in place by a cable strung through and tied to the center of the jacks with cable clamps. The cable should be tied to a buried anchor or pilings, thereby securing all the jacks as a unit. Wooden jacks are weighted by rocks, which should be wired onto the jack poles. The first two pilings at the upstream end of the jack line should be driven no more than 12 feet apart to reduce the effect of increased water force from trash buildup.
- Bury anchors or drive anchor pilings to the design depth determined by an engineer. Depths may vary from 5 to 20 feet and must be specified based on individual site characteristics.
- On long curves, anchor jack rows at intermediate points along the curve to isolate damages to the jack row. Two 3/8-inch diameter wire cables tied to timber or steel pilings provide adequate anchors. Place anchors up the streambank rather than in the streambed.
- Consider pilings if streambed anchors are required. Space pilings 75 to 125 feet apart along the jack row, with closer spacing on shorter curves.
- Attach an anchored 3/8-inch diameter wire cable to one leg of each jack to prevent rotation and improve stability.
- Place jack rows perpendicular to the bank at regular intervals where jack rows are not close to existing banks. This prevents local scour. Extend bank protection far enough to prevent flanking action. Ensure the jack row is anchored to a hardpoint at the upstream end.
- Supplement the jack string or field with vegetative plantings. Dormant posts offer a compatible component in the system.

Figure 16-31 Concrete jack system several years after installation



(vii) Rock riprap—Rock riprap, properly designed and placed, is an effective method of streambank protection (figs. 16–32 and 16–33). The cost of quarrying, transporting, and placing the stone and the large quantity of stone that may be needed must be considered. Gabion baskets, concrete cellular blocks, or similar systems (figs. 16–34, 16–35a, 16–35b; and 16–42, 16–43) can be an alternative to rock riprap under many circumstances.

Applications and effectiveness

- Provides long-term stability.
- Has structural flexibility. It can be designed to self-adjust to eroding foundations.
- Has a long life and seldom needs replacement.
- Is inert so does not depend on specific environmental or climatic conditions for success.
- May be designed for high velocity flow conditions.

Construction guidelines

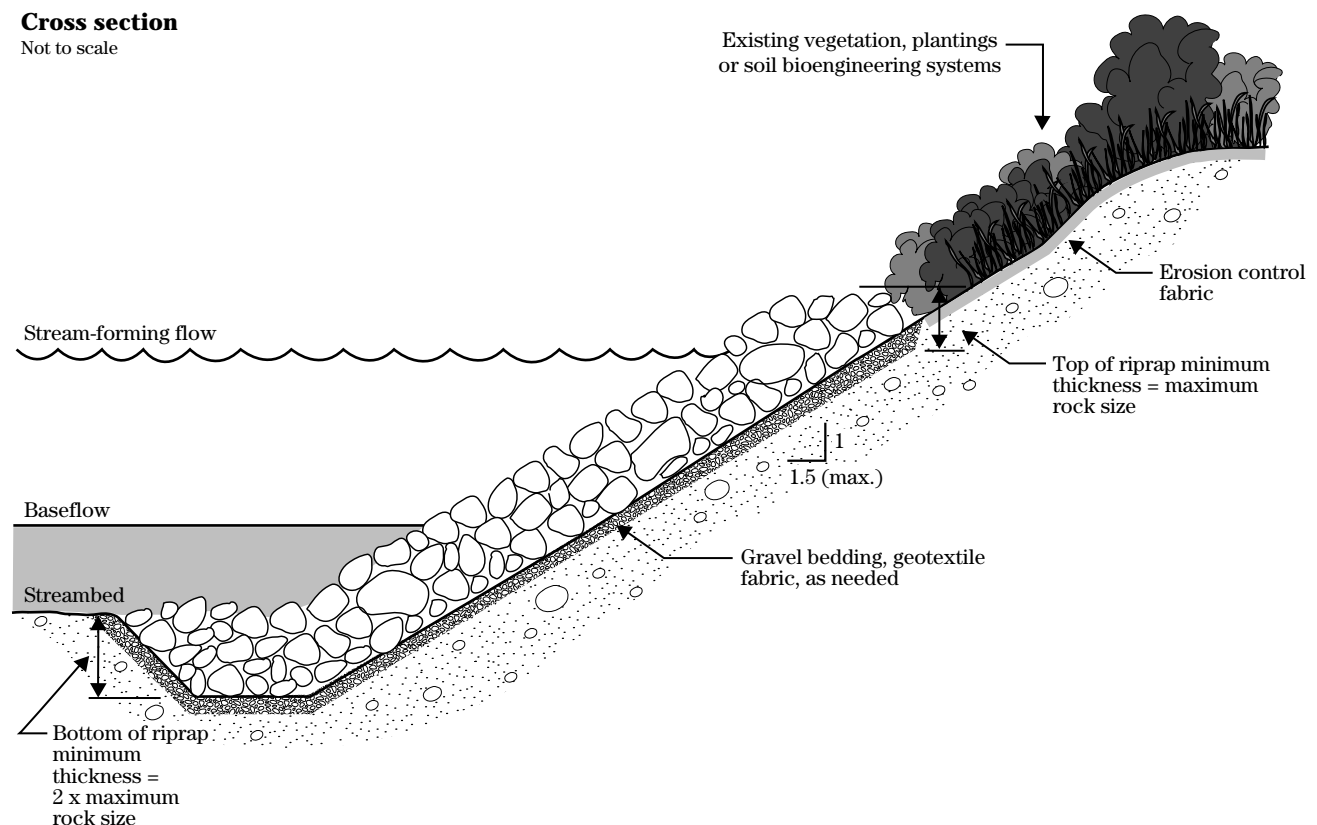
Inert materials—Cobbles and gravel obtained from the stream bed should not be used to armor streambanks unless the material is so abundant that its removal will not reduce habitat for benthic organisms and fish. Material forming an armor layer that protects the bed from erosion should not be removed. Use of stream cobble and gravel may require permission from state and local agencies.

Removing streambed materials tends to destroy the diversity of physical habitat necessary for optimum fish production, not only in the project area, but upstream and downstream as well. Construction activities often create channels of uniform depth and width in which water velocities increase. Following disruption of the existing streamflow by alteration of the stream channel, further damage results as the stream seeks to reestablish its original meander pattern.

Figure 16–32 Rock riprap details

Cross section

Not to scale



Upstream, the stream may seek to adjust to the new gradient by actively eroding or grading its banks and bed. The eroded material may be deposited in the channel downstream from the alteration causing additional changes in flow pattern. The downstream channel will then also adjust to the new gradient and increased streamflow velocity by scour and bank erosion or further deposition.

Rock riprap on streambanks is affected by the hydrodynamic drag and lift forces created by the velocity of flow past the rock. Resisting the hydrodynamic effects are the force components resulting from the submerged weight of the rock and its geometry. These forces must be considered in any analytical procedure for determining a stable rock size. Channel alignment, surface roughness, debris and ice impact, rock gradation, angularity, and placement are other factors that must be considered when designing for given site conditions.

Numerous methods have been developed for designing rock riprap. Nearly all use either an allowable velocity or tractive stress methodology as the basis for determining a stable rock size. Table 16–2 lists several accepted procedures currently used in the NRCS. The table provides summary information and references where appropriate. Two of the more direct methods of obtaining a rock size are included in appendix 16A. All four methods listed in the table provide the user with a design rock size for a given set of input parameters. The first time user is advised to use more than one method in determining rock size. Availability of rock and experience of the designer continue to play important roles in determining the appropriate size rock for any given job.

Figure 16–33 Rock riprap revetment system



A well graded rock provides the greatest assurance of stability and long-term protection. Poorly graded rock results in weak areas where individual stones are subject to movement and subsequent revetment failure. Satisfactory gradation limits and thickness of the rock riprap can be determined from the basic stone size. Figure 16A–3 in appendix 16A can help determine rock gradation limits for any calculated basic rock size (D_{50} , D_{75} , and so forth).

The void space between rocks in riprap is generally many times greater than the void space in existing bank materials. A transition zone serves two purposes:

- Distributes the weight of rock to the underlying soil.
- Prevents movement and loss of fine grained soil into the large void spaces of the riprap.

The transition zone can be designed as a filter, bedding, or geotextile. The bank soils, bank seepage, and rock gradation and thickness are factors to consider when determining the transition material.

Bedding material is generally a pit run sand-gravel mixture. Bedding is suitable for those sites where bank materials are plastic and forces can be considered external, that is, forces acting on the bedding result only from the action of flow past or over the rock riprap. Bedding is not recommended for conditions where flow occurs through the rock (as on steep slopes), where subject to wave action, or where flow velocity exceeds 10 feet per second.

Table 16–2 Methods for rock riprap protection

Method (reference)	Basis for rock size	Procedure	Comments
Isbash Curve Appendix 16A (reprint from SCS Engineering Field Manual, chapter 16, 1969).	Allowable velocity— Curve developed from Isbash work.	Use design velocity and curve to determine basic rock size (D_{100}).	Use judgment to factor in site conditions. The basic stone weight is often doubled to account for debris.
FWS-Lane Appendix 16A (reprint from SCS Engineering Design Standards—Far West States, 1970).	Tractive stress— Monograph developed from Lane's work.	Enter monograph with channel hydraulic and physical data to solve for basic rock size (D_{75}).	Easy to use procedure. Generally results in a conservative rock size.
COE Method Corps of Engineers, EM 1110-2-1601, 7/91, Hydraulic Design of Flood Control Channels.	Allowable velocity— Basic equation developed by COE from study of models and comparison to field data.	Use equation or graphs and site physical and hydraulic data to determine basic rock size (D_{30}).	Detailed procedure can be used on natural or prismatic channels.
Federal Highway Administration Hydraulic Engineering Circular No. 11, Design of Riprap Revetment (1989).	Tractive Force Theory— Uses velocity as a primary design parameter.	Use equation with known site data and user determined stability factor to solve for basic rock size (D_{50}).	Stability factor requires user judgment of site conditions.

A filter is a graded granular material designed to prevent movement of the bank soil. A filter is recommended where bank materials are nonplastic, seepage forces exist, or where bedding is not adequate protection for the external forces as noted above. The site should be evaluated for potential seepage pressures from existing or seasonal water table, rapid fluctuations in streamflow (rapid drawdown), surface runoff, or other factors. In critical applications or where experience indicates problems with the loss of bank material under riprap, use chapter 26, part 633 of the NRCS National Engineering Handbook, January 1994, for guidance in designing granular filters.

Nonwoven geotextiles are widely used as a substitute for bedding and filter material. Availability, cost, and ease of placement are contributing factors. For guidance in selection of the proper geotextile, refer to NRCS Design Note 24, *Guide to Use of Geotextile*.

Installation

- Minimum thickness of the riprap should at least equal the maximum rock size at the top of the revetment. The thickness is often increased at the base of the revetment to two or more times the maximum rock size.
- The toe for rock riprap must be firmly established. This is important where the stream bottom is unstable or subject to scour during flood flows.
- Banks on which riprap is to be placed should be sloped so that the pressure of the stone is mainly against the bank rather than against the stone in the lower courses and toe. This slope should not be steeper than 1.5:1. The riprap should extend up the bank to an elevation at which vegetation will provide adequate protection.
- A filter or bedding must be placed between the riprap and the bank except in those cases where the material in the bank to be protected is determined to be a suitable bedding or filter material. The filter or bedding material should be at least 6 inches thick.

- A nonwoven geotextile may be used in lieu of a bedding or filter layer under the rock riprap. The geotextile material must maintain intimate contact with the subsurface. Geotextile that can move with changes in seepage pressure or external forces permits soil particle movement and can result in plugging of the geotextile. A 3-inch layer of bedding material over the geotextile prevents this movement.
- Hand-placing all rock in a revetment should seldom, if ever, be necessary. While the revetment may have a somewhat less finished look, it is adequate to dump the rock and rearrange it with a minimum of hand labor. However, the rock must be dumped in a manner that will not separate small and large stones or cause damage to the filter fabrics. The finished surface should not have pockets of finer materials that would flush out and weaken the revetment. Sufficient hand placing and chinking should be done to provide a well-keyed surface.

The Engineering Field Handbook, Chapter 17, Construction and Construction Materials, has additional information on riprap construction and materials.

Manufacturers have developed design recommendations for various flow and soil conditions. Their recommendations are good references in use of gabions, cellular blocks, and similar systems.

Figure 16-34 Concrete cellular block details

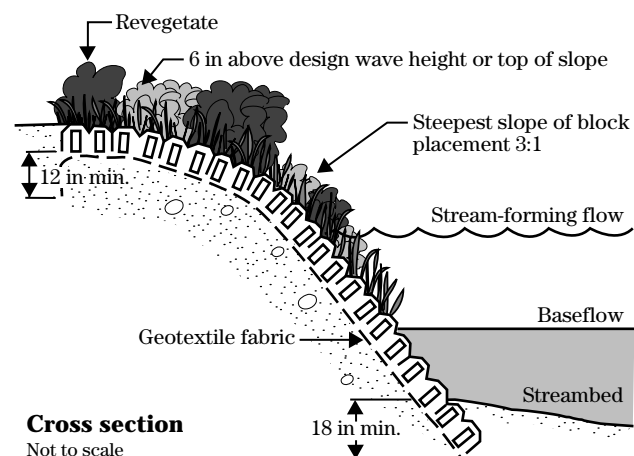


Figure 16-35a Concrete cellular block system before backfilling



Figure 16-35b Concrete cellular block system several years after installation



(viii) Coconut fiber rolls—Coconut fiber rolls are cylindrical structures composed of coconut husk fibers bound together with twine woven from coconut (figs. 16–36, 16–37a, and 16–37b). This material is most commonly manufactured in 12-inch diameters and lengths of 20 feet. It is staked in place at the toe of the slope, generally at the stream-forming flow stage.

Applications and effectiveness

- Protect slopes from shallow slides or undermining while trapping sediment that encourages plant growth within the fiber roll.
- Flexible, product can mold to existing curvature of streambank.
- Produce a well-reinforced streambank without much site disturbance.

- Prefabricated materials can be expensive.
- Manufacturers estimate the product has an effective life of 6 to 10 years.

Construction guidelines

- Excavate a shallow trench at the toe of the slope to a depth slightly below channel grade.
- Place the coconut fiber roll in the trench.
- Drive 2 inch x 2 inch x 36 inch stakes between the binding twine and coconut fiber. Stakes should be placed on both sides of the roll on 2 to 4 feet centers depending upon anticipated velocities. Tops of stakes should not extend above the top of the fiber roll.
- In areas that experience ice or wave action, notch outside of stakes on either side of fiber roll and secure with 16-gauge wire.

Figure 16–36 Coconut fiber roll details

Cross section

Not to scale

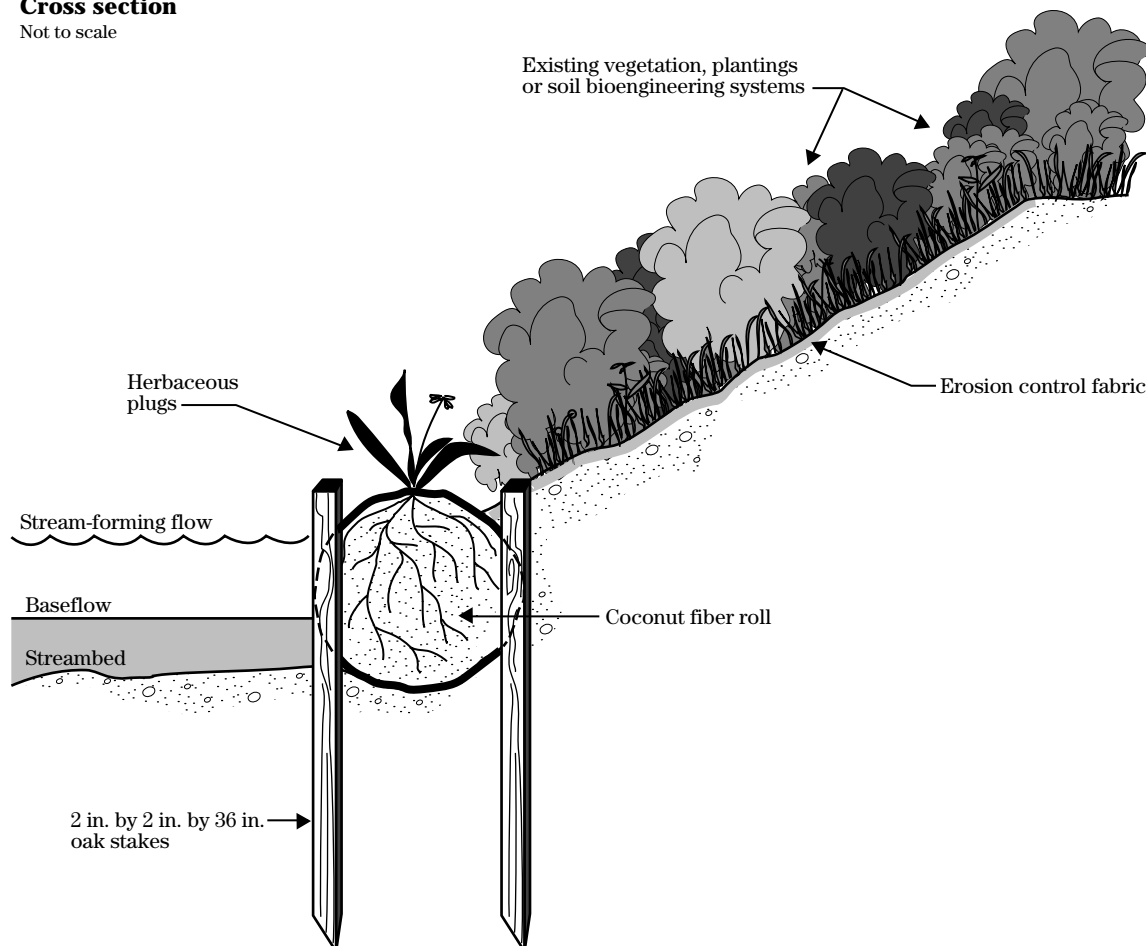
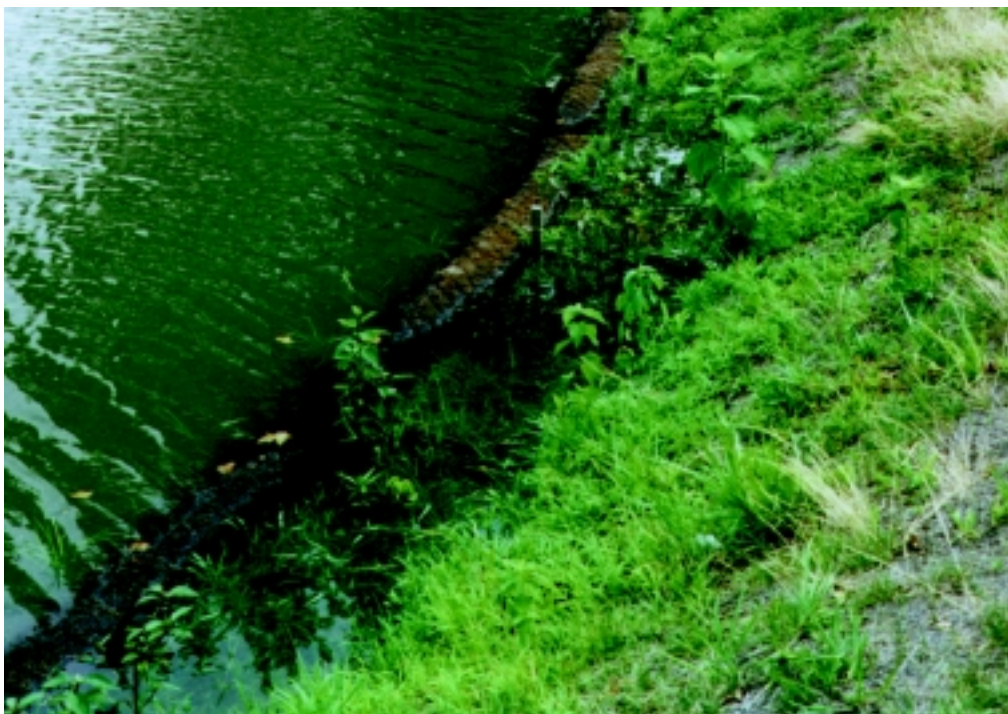


Figure 16-37a Coconut fiber roll



Figure 16-37b Coconut fiber roll system



- Backfill soil behind the fiber roll.
- If conditions permit, rooted herbaceous plants may be installed in the coconut fiber.
- Install appropriate vegetation or soil bioengineering systems upslope from fiber roll.

(ix) Stream jetties—Jetties are short dike-like structures that project from a streambank into a stream channel. They may consist of one or more structures placed at intervals along the bank to be protected. Most are constructed to the top of the bank and can be oriented either upstream, downstream, or perpendicular to the bank (figs. 16–38 and 16–39).

Jetties deflect or maintain the direction of flow through and beyond the reach of stream being protected. In function and design, jetties change the direction of flow by obstructing and redirecting the streamflow. Their design and construction require specialized skills. A fluvial geomorphologist, engineer, or other qualified discipline with knowledge of open channel hydraulics should be consulted for specific considerations and guidelines.

Applications and effectiveness

- Used successfully in a wide variety of applications in all types of rivers and streams.
- Effective in controlling erosion on bends in river and stream systems.
- Can be augmented with vegetation or soil bioengineering systems in some situations; i.e., deposited material upstream of jetties.
- May develop scour holes just downstream and off the end of the jetties.
- Can be complex and expensive.

Construction guidelines

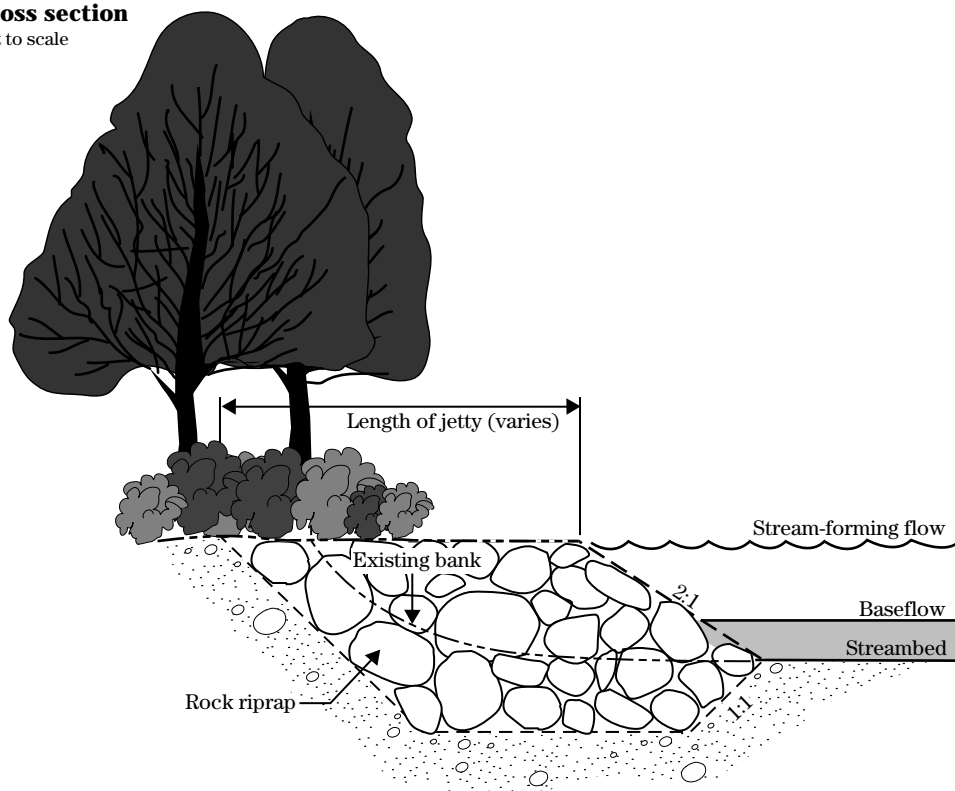
Inert materials—Rock filled jetties are the most common, however, other materials are used including timber, concrete, gabions, and rock protected earth.

Installation

- Use a D_{50} size rock equal to 1.5 to 2 times the d_{50} size determined from rock riprap design methods for bank full flow condition.
- Size and space jetties so that flow passing around and downstream from the outer end will intersect the next jetty before intersecting the eroding bank. The length varies but should not unduly constrict the channel. Rock jetties typically have 2:1 side slopes with an 8 to 12-foot top width and 2:1 end slope.
- Space jetties to account for such characteristics as stream width, stream velocity, and radius of curvature. Typical spacing is 2 to 5 times the jetty length.
- Construct jetties with a level top or a downward slope to the outer end (riverward). The top of the jetty at the bank should be equal to the bank height.
- Orient jetties either perpendicular to the streambank or angled upstream or downstream. Perpendicular and downstream orientation are the most common.
- Tie jetties securely back into the bank and bed to prevent washout along the bank and undercutting. Place rock a short distance on either side of the jetty along the bank to prevent erosion at this critical location. The base of the jetty should be keyed into the bed a minimum depth equal to the D_{100} rock size.

Figure 16-38 Stream jetty details**Cross section**

Not to scale

**Front elevation**

Not to scale

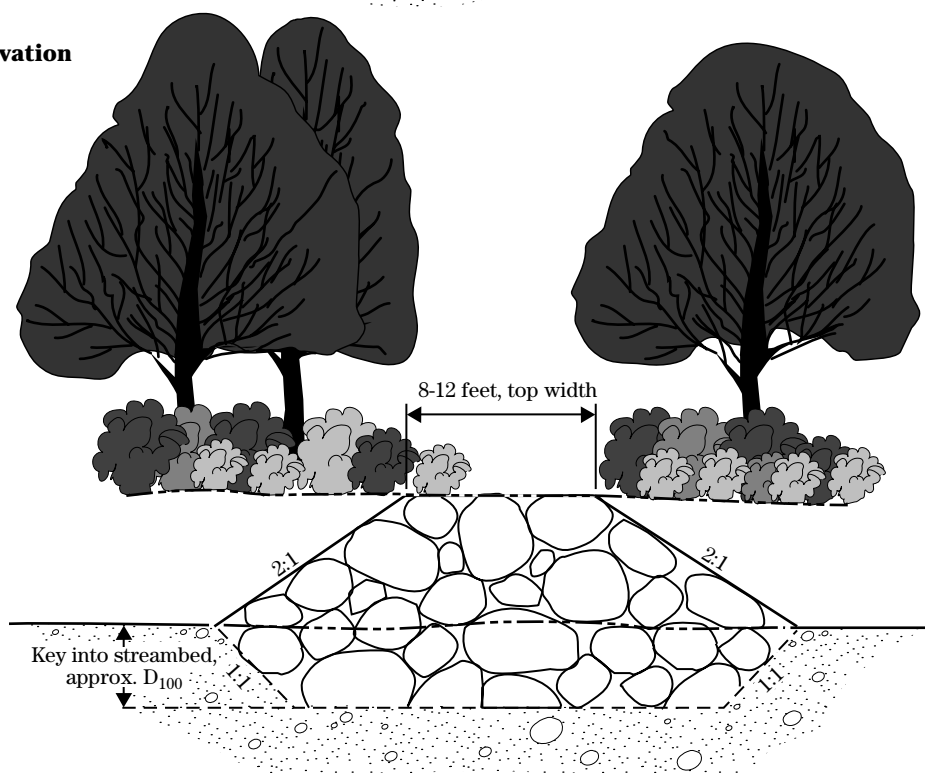


Figure 16-39a Stream jetty placed to protect railroad bridge



Figure 16-39b Long-established vegetated stream jetty, with deposition in foreground



(x) Stream barbs—Stream barbs are low rock sills projecting out from a streambank and across the stream's thalweg to redirect streamflow away from an eroding bank (figs. 16–40 and 16–41). Flow passing over the barb is redirected so that the flow leaving the barb is perpendicular to the barb centerline. Stream barbs are always oriented upstream.

Application and effectiveness

- Used in limited applications and range of applicability is unclear.
- Effective in control of bank erosion on small streams.
- Require less rock and stream disturbance than jetties.
- Improve fish habitat (especially when vegetated).
- Can be combined with soil bioengineering practices.
- Can be complex and expensive.

Construction guidelines

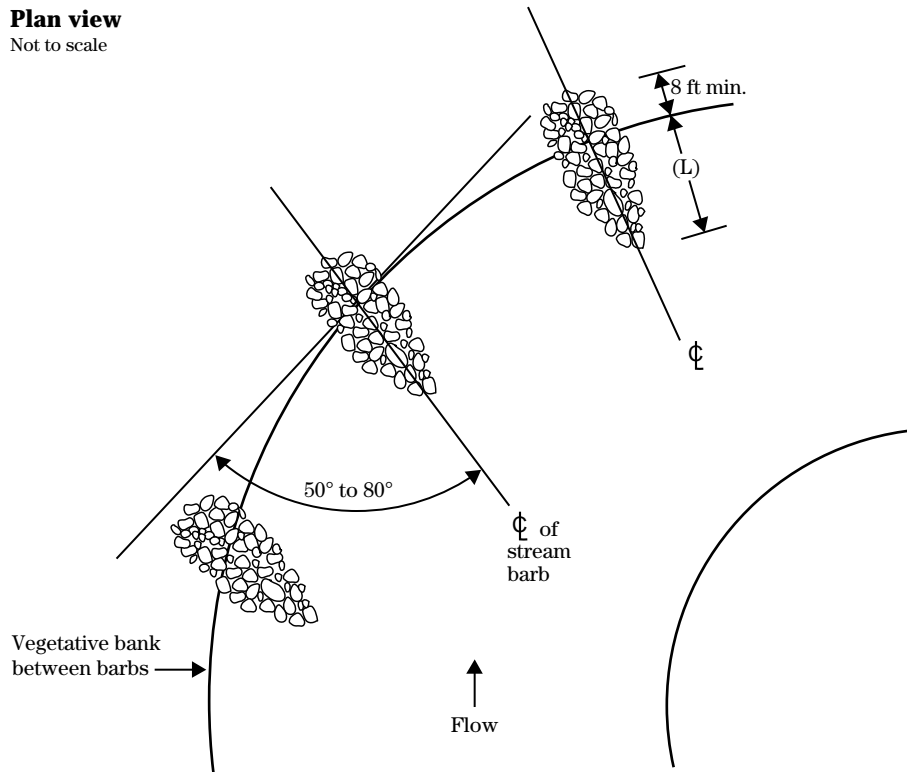
Inert materials—Stream barbs require the use of large rock.

Installation

- Use a D_{50} size rock equal to two times the d_{50} size determined from rock riprap design methods for bank full flow condition. The maximum rock size (D_{100}) should be about 1.5 to 2 times the D_{50} size. The minimum rock size should not be less than $.75D_{50}$.
- Key the barb into the stream bed to a depth approximately D_{100} below the bed.
- Construct the barb above the streambed to a height approximately equal to the D_{100} rock, but generally not over 2 feet. The width should be at least equal to 3 times D_{100} , but not less than a typical construction equipment width of 8 to 10 feet. Construction of barbs can begin at the streambank and proceed streamward using the barb to support construction equipment.
- Align the barb so that the flow off the barb is directed toward the center of the stream or away from the bank. The acute angle between the barb and the upstream bank typically ranges from 50 to 80 degrees.
- Ensure that, at a minimum, the barb is long enough to cross the stream flow low thalweg.
- Space the barbs apart from 4 to 5 times the barb's length. The specific spacing is dependent on finding the point at which the streamflow leaving the barb intersects with the bank.

Figure 16-40 Stream barb details**Plan view**

Not to scale

**Cross section**

Not to scale

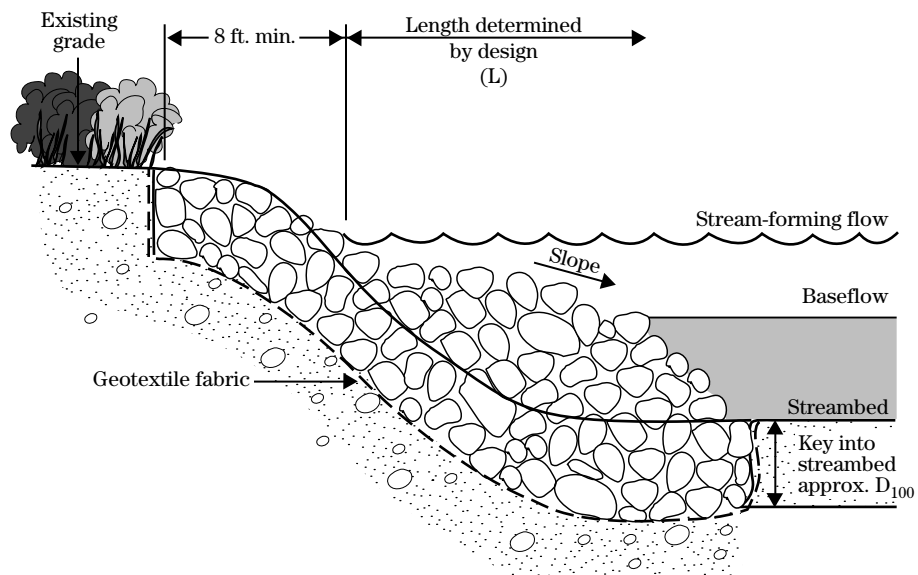


Figure 16-41 Stream barb system



(xi) Rock gabions—Rock gabions begin as rectangular containers fabricated from a triple twisted, hexagonal mesh of heavily galvanized steel wire. Empty gabions are placed in position, wired to adjoining gabions, filled with stones, and then folded shut and wired at the ends and sides. NRCS Construction Specification 64, Wire Gabions, provides detailed information on their installation.

Vegetation can be incorporated into rock gabions, if desired, by placing live branches on each consecutive layer between the rock-filled baskets (fig. 16–42 and 16–43). These gabions take root inside the gabion baskets and in the soil behind the structures. In time the roots consolidate the structure and bind it to the slope.

Applications and effectiveness

- Useful when rock riprap design requires a rock size greater than what is locally available.
- Effective where the bank slope is steep (typically greater than 1.5:1) and requires structural support.
- 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.
- Can be fabricated on top of the bank and then placed as a unit, below water if necessary.
- Lower initial cost than a concrete structure.
- Tolerate limited foundation movement.
- Have a short service life where installed in streams that have a high bed load. Avoid use where streambed material might abrade and cause rapid failure of gabion wire mesh.
- Not designed for or intended to resist large, lateral earth stresses. Should be constructed to a maximum of 5 feet in overall height, including the excavation required for a stable foundation.
- Useful where space is limited and a more vertical structure is required.
- Where gabions are designed as a structural unit, the effects of uplift, overturning, and sliding must be analyzed in a manner similar to that for gravity type structures.
- Can be placed as a continuous mattress for slope protection. Slopes steeper than 2:1 should be analyzed for slope stability.
- Gabions used as mattresses should be a minimum of 9 inches thick for stream velocities of up to 9 feet per second. Increase the thickness to a minimum of 1.5 feet for velocities of 10 to 14 feet per second.

Construction guidelines

Live material sizes—When constructing vegetated rock gabions, branches should range from 0.5 to 2.5 inches in diameter and must be long enough to reach beyond the back of the rock basket structure into the backfill or undisturbed bank.

Inert materials—Galvanized woven wire mesh or galvanized welded wire mesh baskets or mattresses may be used. The baskets or mattresses are filled with sound durable rock that has a minimum size of 4 inches and a maximum of 9 inches. Gabions can be coated with polyvinyl chloride to improve their service life where subject to aggressive water or soil conditions.

Installation

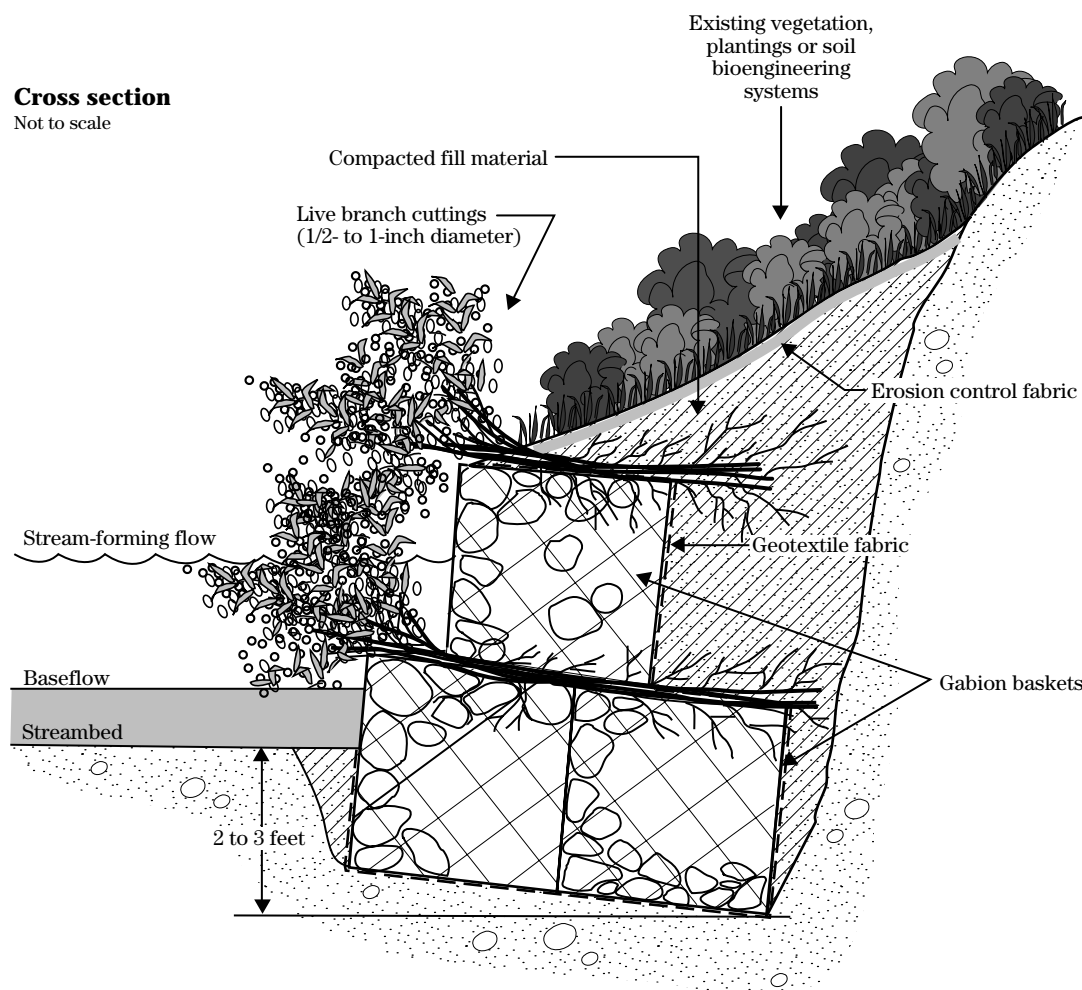
- Remove loose material from the foundation area and cut or fill with compacted material to provide a uniform foundation.
- Excavate the back of the stable foundation (closest to the slope) slightly deeper than the front to add stability to the structure. This provides additional stability to the structure and ensures that the living branches root well for vegetated rock gabions.
- Place bedding or filter material in a uniformly graded surface. Compaction of materials is not usually required. Install geotextiles so that they lie smoothly on the prepared foundation.
- Assemble, place, and fill the gabions with rock. Be certain that all stiffeners and fasteners are properly secured.
- Place the gabions so that the vertical joints are staggered between the gabions of adjacent rows and layers by at least one-half of a cell length.
- Place backfill between and behind the wire baskets.
- For vegetated rock gabions, 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.

- Where abrasive bedloads or debris can snag or tear the gabion wire, a concrete cap should be used to protect those surfaces subject to attack. A concrete cap 6 inches thick with 3 inches penetration into the basket is usually sufficient. The concrete for the cap should be placed after initial settlement has occurred.
- A filter is nearly always needed between the gabions and the foundation or backfill to prevent soil movement through the baskets. Geosynthetic materials can be used in lieu of granular filters for

many applications, however, when drainage is critical, the fabric must maintain intimate contact with the foundation soils. A 3-inch layer of sand-gravel between the gabions and the filter material assures that contact is maintained.

- At the toe and up and downstream ends of gabion revetments, a tieback into the bank and bed should be provided to protect the revetment from undermining or scour.

Figure 16-42 Vegetated rock gabion details



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

Figure 16-43 Vegetated rock gabion system (H.M. Schiechl photo)



650.1602 Shoreline protection

(a) General

Shoreline erosion results primarily from erosive forces in the form of waves generally perpendicular to the shoreline. As a wave moves toward shore, it begins to drag on the bottom, dissipating energy. This eventually causes it to break or collapse. This major turbulence stirs up material from the shore bottom or erodes it from banks and bluffs. Fluctuating tides, freezing and thawing, floating ice, and surface runoff from adjacent uplands may also cause shorelines to erode.

(1) Types of shoreline protection

Systems for shoreline protection can be living or nonliving. They consist of vegetation, soil bioengineering, structures, or a combination of these.

(2) Planning for shoreline protection measures

The following items need to be considered for shoreline protection in addition to the items listed earlier in this chapter for planning streambank protection measures:

- Mean high and low water levels or tides.
- Potential wave parameters.
- Slope configuration above and below waterline.
- Nature of the soil material above and below water level.
- Evidence of littoral drift and transport.
- Causes of erosion.
- Adjacent land use.
- Maintenance requirements.

(b) Design considerations for shoreline protection

(1) Beach slope

Slopes should be determined above and below the waterline. The slope below waterline should be representative of the slope for a distance of at least 50 feet.

(2) Offshore depth and wave height

Offshore depth is a critical factor in designing shoreline protection measures. Structures that must be constructed in deep water, or in water that may become deep, are beyond the scope of this chapter. Other important considerations are the dynamic wave height acting in deep water (roughly, the total height of the wave is three times that visible) and the decreased wave action caused by shallow water. Effective fetch length also needs to be considered in determining wave height. Methods for computing wave height using fetch length are in NRCS Technical Releases 56 and 69.

(3) Water surface

The design water surface is the mean high tide or, in nontidal areas, the mean high water. This information may be obtained from tidal tables, records of lake levels, or from topographic maps of the reservoir site in conjunction with observed high and normal water lines along the shore.

(4) Littoral transport

The material being moved parallel to the shoreline in the littoral zone, under the influence of waves and currents should be addressed in groin design. It is important to determine that the supply of transport material is not coming from the bank being protected and the predominant direction of littoral transport. This information is used to locate structures properly with respect to adjacent properties and so that groins can fill most quickly and effectively. Another factor to be considered is that littoral transport often reverses directions with a change in season.

The rate of littoral transport and the supply are as important as the direction of movement. No simple ways to measure the supply are available. For the scope of this chapter, supply may be determined by observation of existing structures, sand beaches, auger samples of the sand above the parent material on the beach, and the presence of sandbars offshore. Other

considerations are existing barriers, shoreline configuration, and inlets that tend to push the supply offshore and away from the area in question. The net direction of transport is an important and complex consideration.

(5) Bank soil type

Determining the nature of bank soil material aids in estimating the rate of erosion. A very dense, heavy clay can offer more resistance to wave action than noncohesive materials, such as sand. A thin sand lens can result in erosion problems since it may be washed out when subjected to high tides or wave action for extended periods of time. The resulting void will no longer support the bank above it, causing it to break away.

(6) Foundation material

The type of existing foundation may govern the type of protection selected. For example, a rock bottom will not permit the use of sheet piling. If the use of riprap is being considered on a highly erodible foundation, a filter will be needed to prevent fine material from washing through the voids. A soft foundation, such as dredge spoil, may result in excessive flotation or movement of the structure in any direction.

(7) Adjacent shoreline and structures

Structures that might have an effect on adjacent shoreline or other structures must be examined carefully. End sections need to be adequately anchored to existing measures or terminated in stable areas.

(8) Existing vegetation

The installation of erosion control structures can have a detrimental effect upon existing vegetation unless steps are taken to prevent what is often avoidable site disturbance. Existing vegetation should be saved as an integral part of the erosion control system being installed.

(c) Protective measures for shorelines

The analysis and design of shoreline protection measures are often complex and require special expertise. For this reason the following discussion is limited to revetments, bulkheads, and groins no higher than 3 feet above mean high water, as well as soil bioengineering and other vegetative systems used alone or in combination with structural measures. Consideration must be given to the possible effects that erosion control measures can have on adjacent areas, especially estuarine wetlands.

(1) Groins

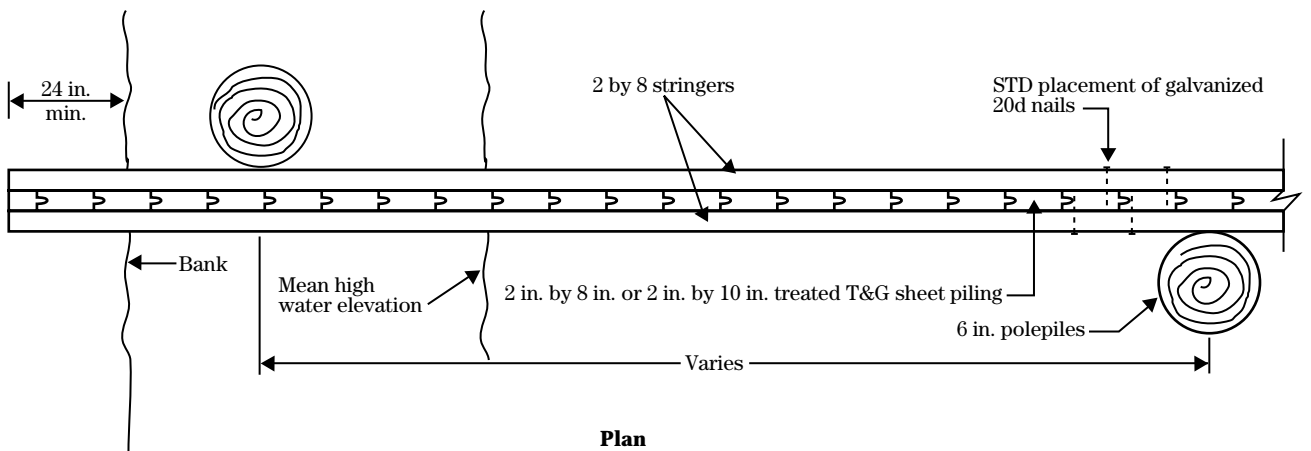
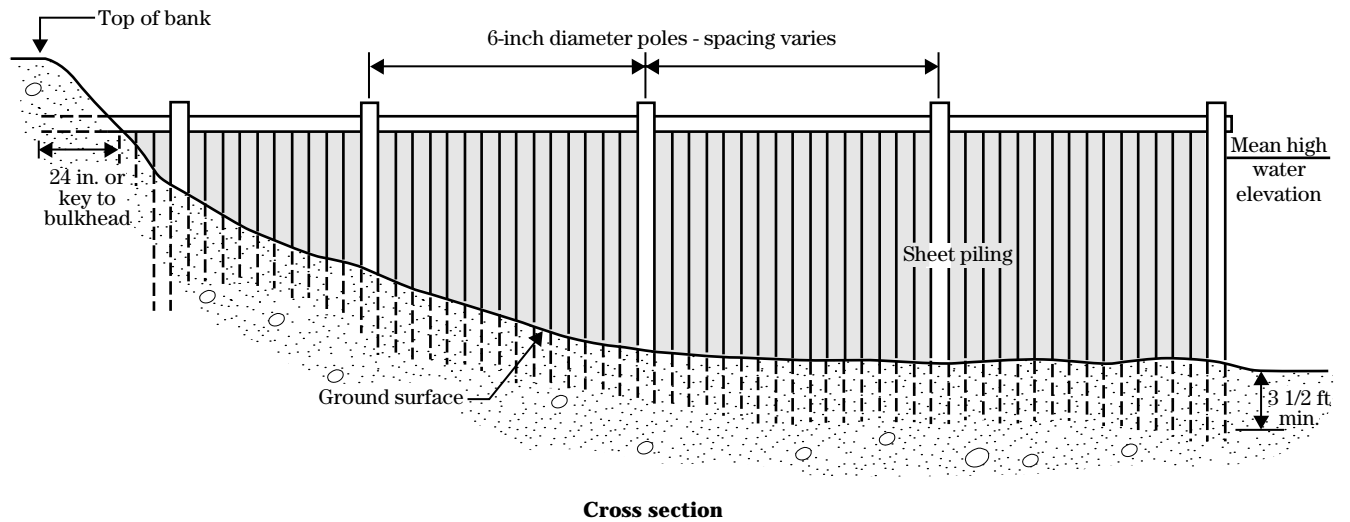
Groins are somewhat permeable to impermeable finger-like structures that are installed perpendicular to the shore. They generally are constructed in groups called groin fields, and their primary purpose is to trap littoral drift. The entrapped sand between the groins acts as a buffer between the incoming waves and shoreline by causing the waves to break on the newly deposited sand and expend most of their energy there (figs. 16–44 and 16–45).

Applications and effectiveness

- Particularly dependent on site conditions. Groins are most effective in trapping sand when littoral drift is transported in a single direction.
- Filling the groin field with borrowed sand may be necessary, if the littoral transport is clay or silt rather than sand.
- Will not fill until all preceding updrift groins have been filled.

Construction guidelines

Inert materials—The most common type of structural groin is built of preservative-treated tongue and groove sheet piling.

Figure 16-44 Timber groin details

Installation

- Groins must extend far enough into the water to retain desired amounts of sand. The distance between groins generally ranges from one to three times the length of the groin. When used in conjunction with bulkheads, the groins are usually shorter.
- Groins are particularly vulnerable to storm damage before they fill, so initially only the first three or four at the downdrift end of the system should be constructed.
- Install the second group of groins after the first has filled and the material passing around or over the groins has again stabilized the downdrift shoreline. This provides the means to verify or adjust the design spacing.
- Key the shoreward end of the groins into the shoreline bank for at least 2 feet or extend them to a bulkhead.
- Measure the groin height on the shoreline so that it will generally be at high tide or mean high water elevation plus 2 or 3 feet for wave surge height. Decrease the height seaward at a gradual rate to mean high water elevation.

Figure 16-45 Timber groin system



(3) Bulkheads

Bulkheads are vertical structures of timber, concrete, steel, or aluminum sheet piling installed parallel to the shoreline.

Applications and effectiveness

- Generally constructed where wave action will not cause excessive overtopping of the structure, which causes bank erosion to continue as though the bulkhead were not there.
- Scour at the base of the bulkhead also causes failure. The vertical face of the bulkhead re-directs wave action to cause excessive scour at the toe of the structure unless it is protected.

Construction guidelines

Inert materials—The most common materials used for bulkhead construction are timber (figs. 16-46 and 16-47), concrete (figs. 16-48 and 16-49), and masonry.

Installation

- Use environmentally compatible treated timber.
- Thickness and spacing of pilings, supports, cross member, and face boards must be engineered on a site-by-site basis.
- Pilings can be drilled, driven, or jetted depending on the foundation materials. Depth of piling must be at least equal to the exposed height below the point of maximum anticipated scour.
- Place stones or other appropriate materials at the base of the bulkhead to absorb wave energy.
- In salt water environments, use noncorrosive materials to the greatest extent possible.

Figure 16-46 Timber bulkhead system



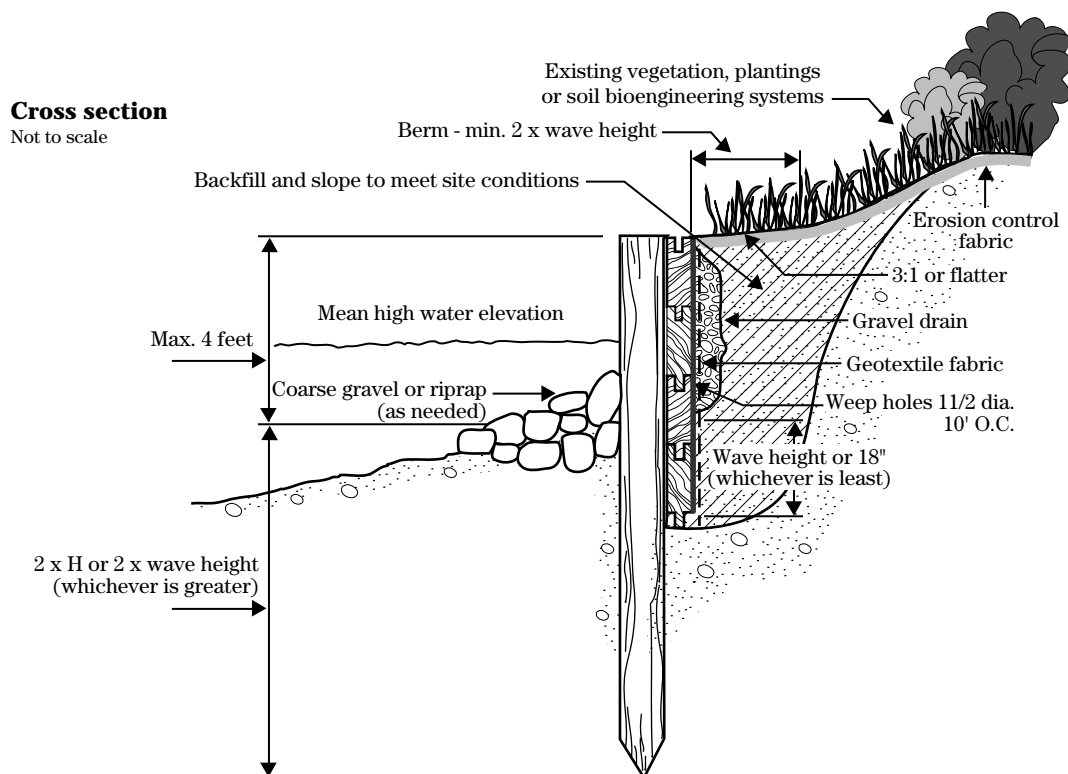
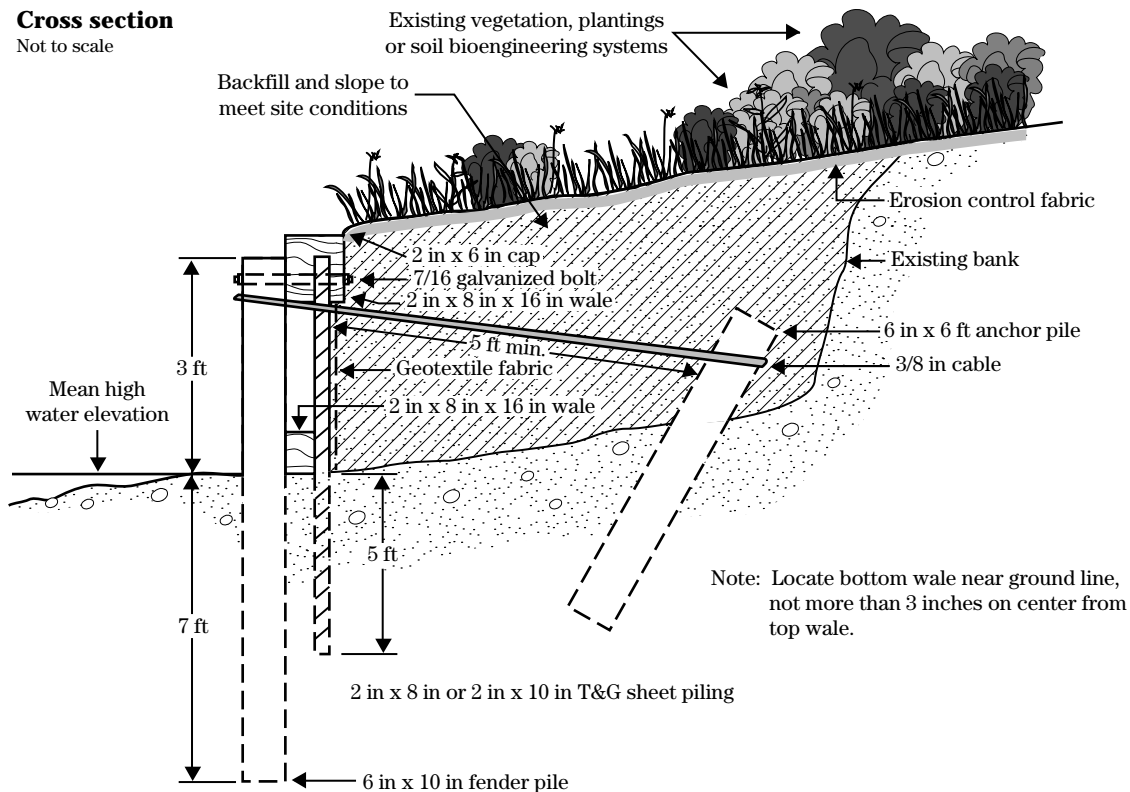
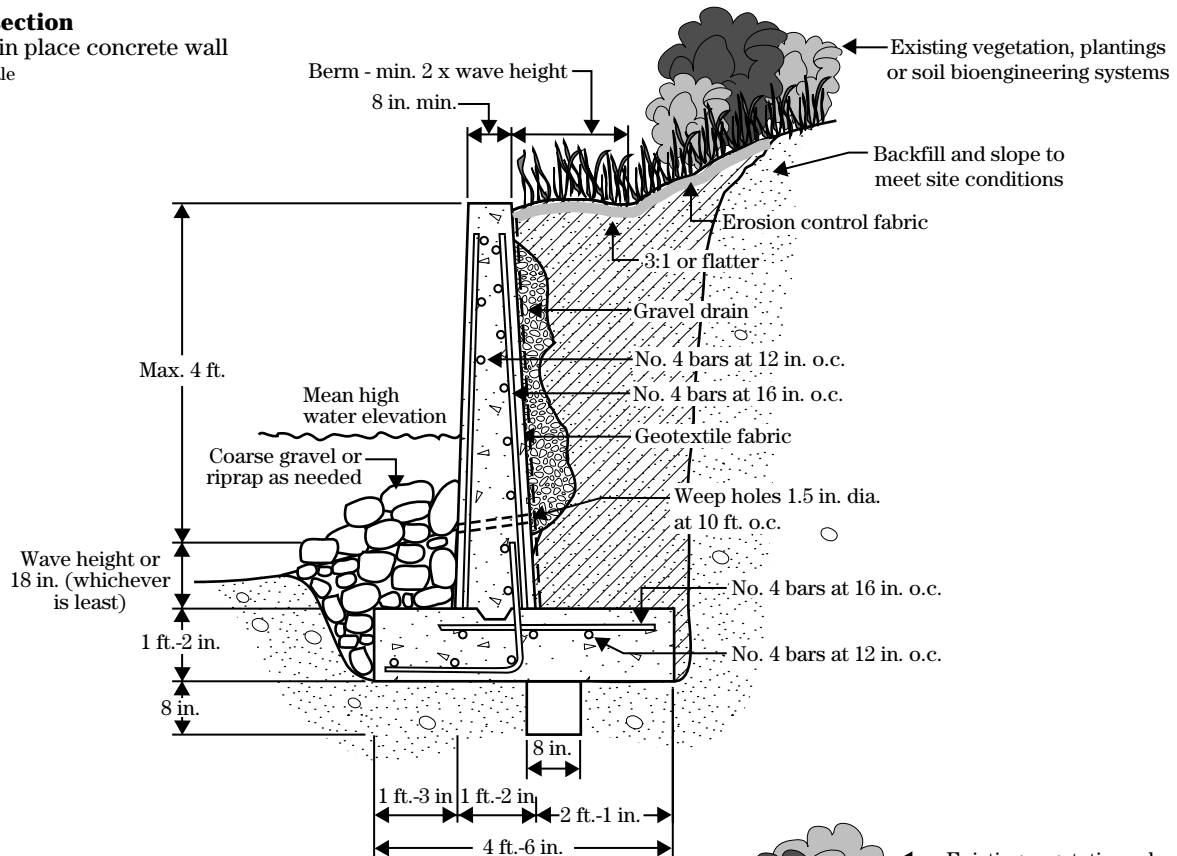
Figure 16-47 Timber bulkhead details

Figure 16-48 Concrete bulkhead details**Cross section**

Poured in place concrete wall

Not to scale

**Cross section**

Concrete block wall

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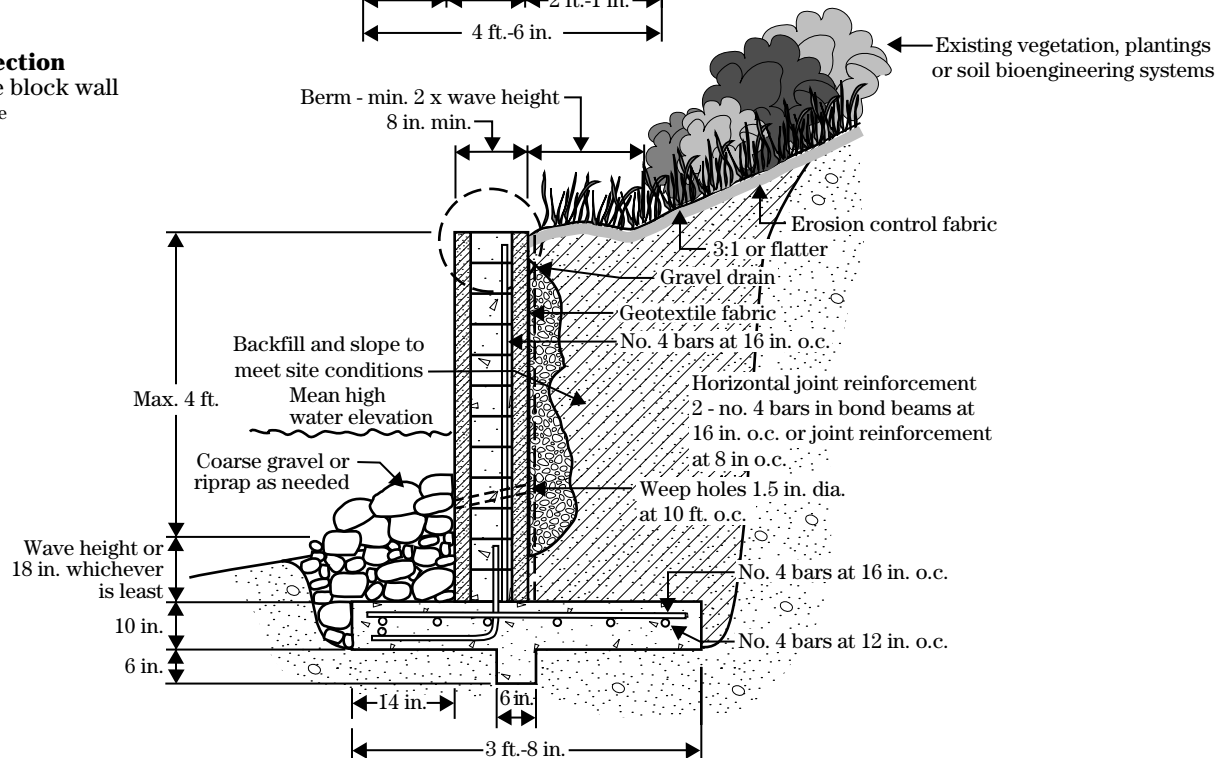


Figure 16-49 Concrete bulkhead system



(4) Revetments

Revetments are protective structures of rock, concrete, cellular blocks, or other material installed to fit the slope and shape of the shoreline (figs. 16–50 and 16–51).

Applications and effectiveness

- Flexible and not impaired by slight movement caused by settlement or other adjustments.
- Preferred to bulkheads where the possibility of extreme wave action exists.
- Local damage or loss of rock easily repaired.
- No special equipment required for construction.
- Subject to scour at the toe and flanking, thus filters are important and should always be considered.
- Complex and expensive.

Construction guidelines

- The size and thickness of rock revetments must be determined to resist wave action. NRCS Technical Release 69, *Rock Riprap for Slope Protection Against Wave Action*, provides guidance for size, thickness, and gradation.
- The base of the revetment must be founded below the scour depth or placed on nonerosive material.
- Angular stone is preferred for revetments. If rounded stone is used, increase the layer thickness by a factor of 1.5.
- Use a minimum thickness of 6-inch filter material under rock.
- If geotextile is used in place of granular filter, cover the geotextile with a minimum of 3 inches of sand-gravel before placement of rock.

Figure 16–50 Concrete revetment (poured in place)



Figure 16-51 Rock riprap revetment



(5) Vegetative measures

If some vegetation exists on the shoreline, the shoreline problem may be solved with more vegetation. Determine if the vegetation disappeared because of a single, infrequent storm, or if plants are being shaded out by developing overstory trees and shrubs. In either case revegetation is a viable alternative. Consult local technical guides and plant material specialists for appropriate plant species and planting specifications. NRCS Technical Release 56, *Vegetative Control of Wave Action on Earth Dams*, provides additional guidance.

(6) Patching

A shoreline problem is often isolated and requires only a simple patch repair. Site characteristics that would indicate a patch solution may be appropriate include good overall protection from wave action, slight undercutting in spots with an occasional slide on the bank, and fairly good vegetative growth on the shoreline. The problems are often caused by boat wake or excessive upland runoff. Fill undercut areas with stone sandbags or grout-filled bags and repair with a grass transplant, reed clumps, branchpacking, vegetated geogrid, or vegetated riprap.

Slides that occur because of a saturated soil condition are best alleviated by providing subsurface drainage or a diversion. Leaning or slipping trees in the immediate slide area may need to be removed initially because of their weight and the forces they exert on the soil; however, once the saturated condition is remedied, disturbed areas should be revegetated with native trees, shrubs, grasses, and forbs to establish cover.

(7) Soil bioengineering systems

Soil bioengineering systems that are best suited to reducing erosion along shorelines are live stakes, live fascines, brushmattresses, live siltation, and reed clump constructions.

(i) Live stake—Live stakes offer no stability until they root into the shoreline area, but over time they provide excellent soil reinforcement. To reduce failure until root establishment occurs, installations may be enhanced with a layer of long straw mulch covered with jute mesh or, in more critical areas, a natural geotextile fabric.

Refer to streambank protection section of this chapter for appropriate applications and construction guidelines.

(ii) Live fascine—The live fascines previously described in this chapter work best in shoreline applications where the ground between them is also protected. Natural geotextiles, such as those manufactured from coconut husks, are strong, durable, and work well to protect the ground.

Construction guidelines

Live materials—Live cuttings as previously described for fabrication of live fascine bundles. Fabricate live fascine bundles approximately 8 inches in diameter. Live stakes should be about 3 feet long.

Inert materials—Dead stout stakes approximately 3 feet long to anchor well in loose sand. Jute mesh with long straw for low energy shorelines. Natural geotextile with long straw for higher energy shorelines.

Installation

The installation methods are similar to those discussed for live fascines, with the following variations:

- Excavate a trench approximately 10 inches wide and deep, beginning at one end of and parallel to the shoreline section to be repaired and extending to the other end.
- Spread jute mesh or geotextile fabric across the excavated trench and temporarily leave the remainder on the slope immediately above the trench.
- Place a live fascine bundle in the trench on top of the fabric and anchor with live and dead stout stakes.
- Spread long straw on the slope above the trench to the approximate location of the next trench to be constructed upslope.
- Pull the fabric upslope over the long straw and spread in the next excavated trench. Trenches should be spaced 3 to 5 feet apart and parallel to each other.
- Repeat the process until the system is in place over the treatment area.

(iii) Brushmattress—Brushmattresses for shorelines perform a similar function as those for streambanks. Therefore, effectiveness and construction guidelines are similar to those given earlier in this chapter, with the following additions.

Applications and effectiveness

- May be effective in lake areas that have fluctuating water levels since they are able to protect the shoreline and continue to grow.
- Able to filter incoming water because they also establish a dense, healthy shoreline vegetation.

Installation

- After the trench at the bottom has been dug and the mattress branches placed, the trench should be lined with geotextile fabric.
- Secure the live fascine, press down the mattress brush, and place the fabric on top of the brush.
- At this point, install the live and dead stout stakes to hold the brush in place. A few dead stout stakes may be used in the mattress branch and partly wired down before covering the fabric. This helps in the final steps of covering and securing the brush and the fabric.

(iv) Live siltation construction—Live siltation construction is similar to brushlayering except that the orientation of the branches are more vertical. Ideally live siltation systems are approximately perpendicular to the prevailing winds. The branch tips should slope upwards at 45 to 60 degrees. Installation is similar to brushlayering (see Engineering Field Handbook, chapter 18 for a more complete discussion of a brushlayer).

Live siltation branches that have been installed in the trenches serve as tensile inclusions or reinforcing units. The part of the brush that protrudes from the ground assists in retarding runoff and surface erosion from wave action and wind (figs. 16–52 and 16–53).

Applications and effectiveness

Live siltation systems provide immediate erosion control and earth reinforcement functions, including:

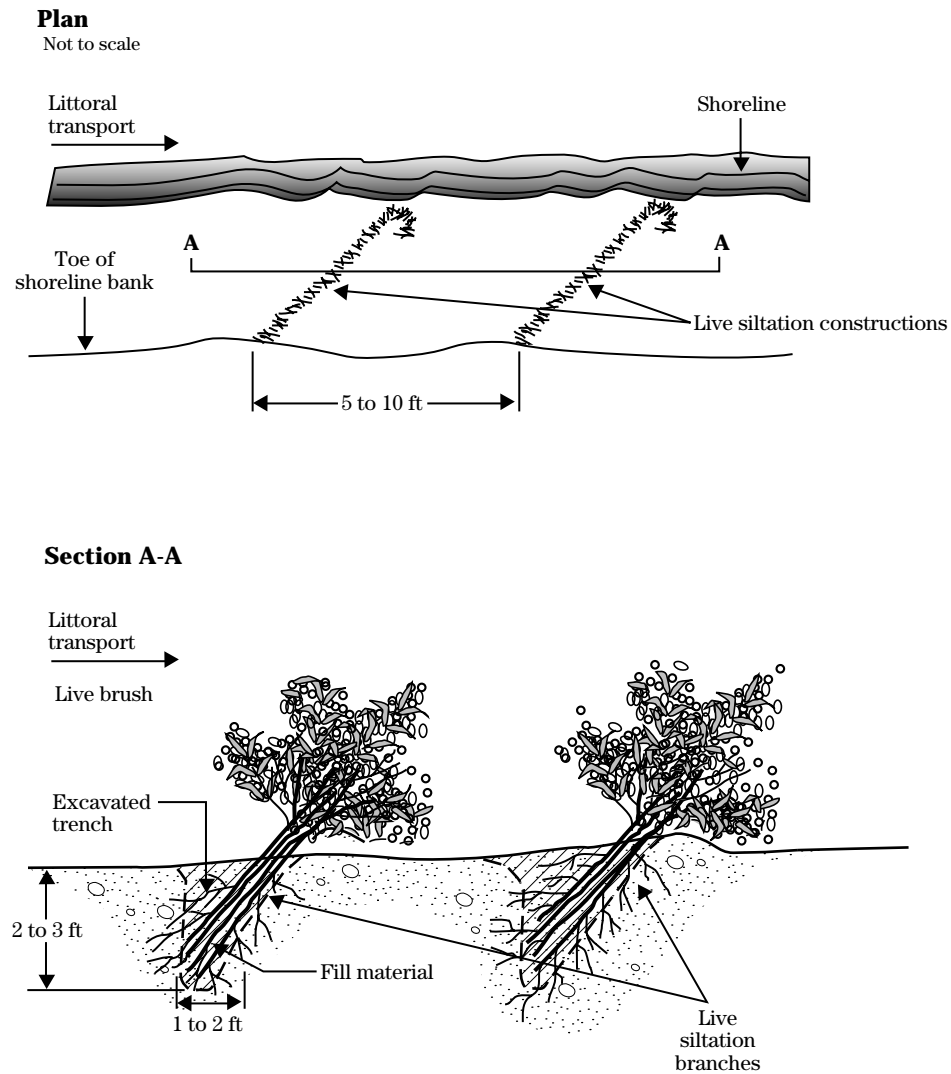
- Providing surface stability for the planting or establishment of vegetation.
- Trapping debris, seed, and vegetation at the shoreline.
- Reducing wind erosion and surface particle movement.
- Drying excessively wet sites through transpiration.
- Promoting seed germination for natural colonization.
- Reinforcing the soil with unrooted branch cuttings.
- Reinforcing the soil as deep, strong roots develop and adding resistance to sliding and shear displacement.

Construction guidelines

Live material—Live branch cuttings 0.5 to 1 inch in diameter and 4 to 5 feet long with side branches intact.

Installation

- Beginning at the toe of the shoreline bank to be treated, excavate a trench 2 to 3 feet deep and 1 to 2 feet wide, with one vertical side and the other angled toward the shoreline.
- Parallel live siltation rows should vary from 5 to 10 feet apart, depending upon shoreline conditions and stability required. Steep, unstable and high energy sites require closer spacing.

Figure 16-52 Live siltation construction details

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

Figure 16-53 Live siltation construction system (Robbin B. Sotir & Associates photo)



(v) Reed clump—Reed clump installations consist of root divisions wrapped in natural geotextile fabric, placed in trenches, and staked down. The resulting root mat reinforces soil particles and extracts excess moisture through transpiration. Reed clump systems are typically installed at the water's edge or on shelves in the littoral zone (fig. 16-54 and 16-55).

Applications and effectiveness

- Reduces toe erosion and creates a dense energy-dissipating reed bank area.
- Offers relatively inexpensive and immediate protection from erosion.
- Useful on shore sites where rapid repair of spot damage is required.
- Retains soil and transported sediment at the shoreline.
- Reduces a long beach wash into a series of shorter sections capable of retaining surface soils.
- Enhances conditions for natural colonization and establishment of vegetation from the surrounding plant community.
- Grows in water and survives fluctuating water levels.

Construction guidelines

Live materials—The reed clumps should be 4 to 8 inches in diameter and taken from healthy water-dependent species, such as arrowhead, cattail, or water iris. They may be selectively harvested from existing natural sites or purchased from a nursery.

Wrap reed clumps in natural geotextile fabric and bind together with twine. These clumps can be fabricated several days before installation if they are kept moist and shaded.

Inert materials—Natural geotextile fabric, twine, and 3- to 3.5-foot-long dead stout stakes are required.

Installation

- Reed root clumps are either placed directly into fabric-lined trenches or prefabricated into rolls 5 to 30 feet long. With the growing tips pointing up, space clumps every 12 inches on a 2- to 3-foot-wide strip of geotextile fabric to fabricate the rolls. The growing buds should all be oriented in the same upright direction for correct placement into the trench.
- Wrap the fabric from both sides to overlap the top, leaving the reed clumps exposed and bound with twine between each plant.
- Beginning at and parallel to the water's edge, excavate a trench 2 inches wider and deeper than the size of the prefabricated reed roll or reed clumps.
- To place reed clumps directly into trenches, first line the trench with a 2- to 3-foot-wide strip of geotextile fabric before spreading a 1-inch layer of highly organic topsoil over it at the bottom of the trench. Next, center the reed clumps on 12-inch spacing in the bottom of the trench. Fill the remainder of the trench between and around reed clumps with highly organic topsoil, and compact. Wrap geotextile fabric from each side to overlap at the top and leave the reed clumps exposed before securing with dead stout stakes spaced between the clumps. Complete the installation by spreading previously excavated soil around the exposed reed clumps to cover this staked fabric.
- To use the prefabricated reed clump roll, place it in the excavated trench, secure it with dead stout stakes, and backfill as described above.
- Repeat the above procedure by excavating additional parallel trenches spaced 3 to 6 feet apart toward the shoreline. Place the reed clumps from one row to the next to produce a staggered spacing pattern.

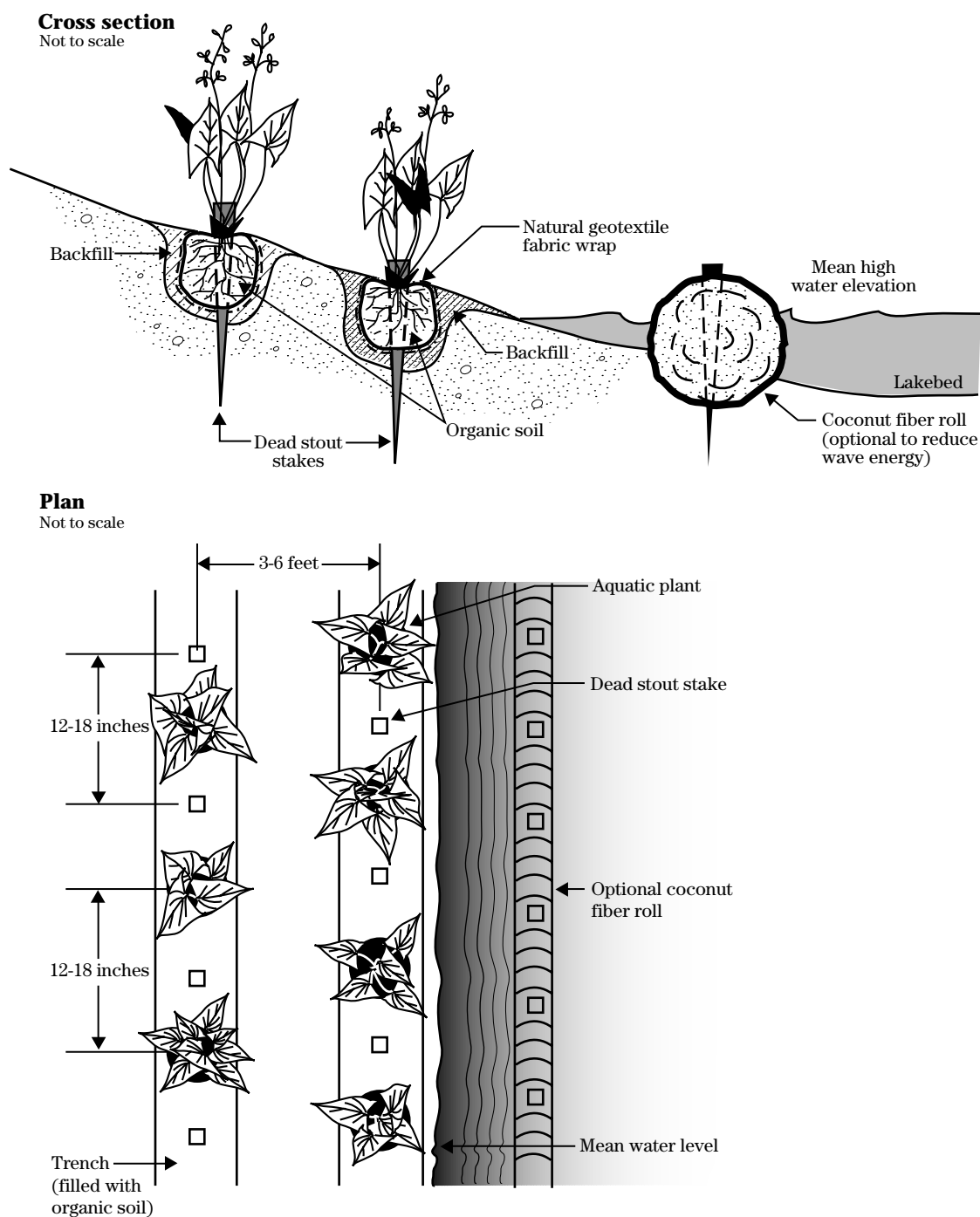
Figure 16-54 Reed clump details

Figure 16-55a Installing dead stout stakes in reed clump system (Robbin B. Sotir & Associates photo)



Figure 16-55b Completing installation of reed clump system (Robbin B. Sotir & Associates photo)



Figure 16-55c Established reed clump system (Robbin B. Sotir & Associates photo)



(8) Coconut fiber roll

Coconut fiber rolls are cylindrical structures composed of coconut fibers bound together with twine woven from coconut (figs. 16–56 and 16–57). This material is most commonly manufactured in 12-inch diameters and lengths of 20 feet. The fiber rolls function as breakwaters along the shores of lakes and embayments. In addition to reducing wave energy, this product can help contain substrate and encourage development of wetland communities.

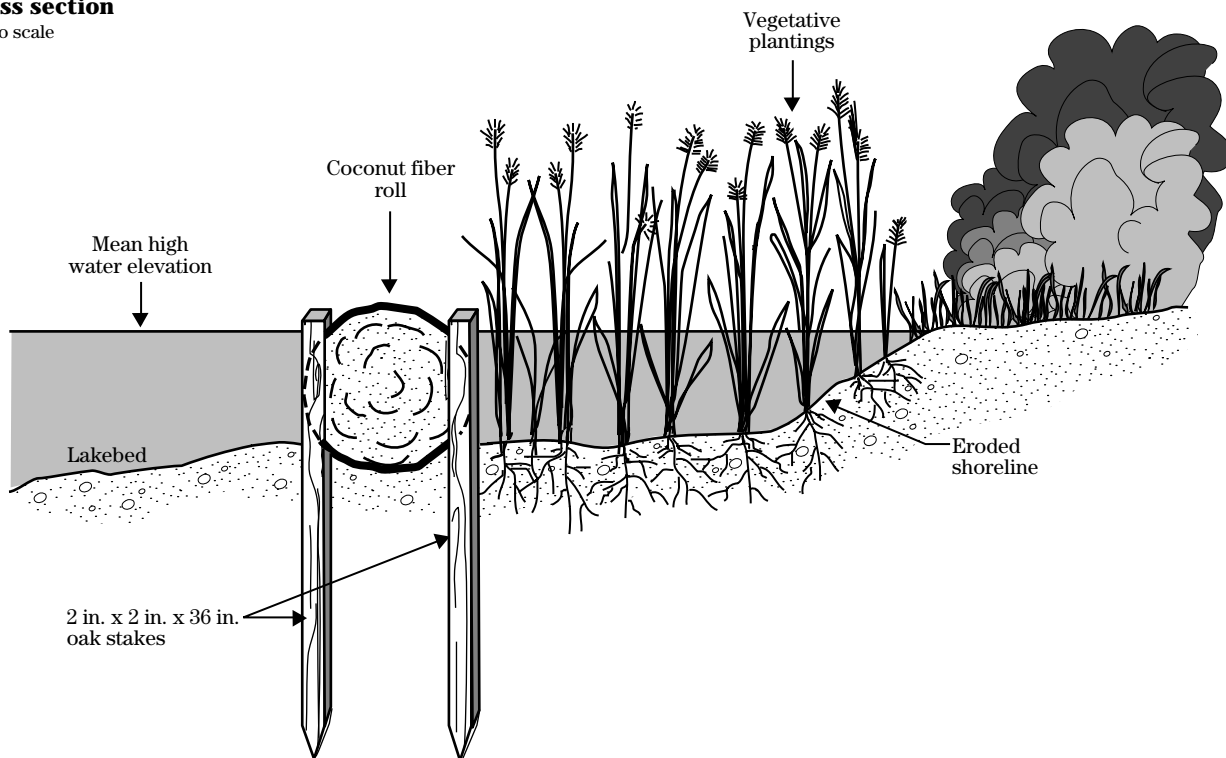
Applications and effectiveness

- Effective in lake areas where the water level fluctuates because it is able to protect the shoreline and encourage new vegetation.
- Flexible, can be molded to the curvature of the shoreline.
- Prefabricated materials can be expensive.
- Manufacturers estimate the product has an effective life of 6 to 10 years.

Figure 16–56 Coconut fiber roll details

Cross section

Not to scale



Installation

- Fiber roll should be located off shore at a distance where the top of the fiber roll is exposed at low tide. In nontidal areas, the fiber roll should be placed where it will not be overtopped by wave action.
- Drive 2 inch x 2 inch stakes between the binding twine and the coconut fiber. Stakes should be placed on 4-foot centers and should not extend above the fiber roll.
- If desired, rooted cuttings can be installed between the coconut fiber roll and the shoreline.

Figure 16-57 Coconut fiber roll system



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Glossary

Bankfull discharge	Natural streams—The discharge that fills the channel without overflowing onto the flood plain. Modified or entrenched streams—The streamflow volume and depth that is the 1- to 3-year frequency flow event. The discharge that determines the stream's geomorphic planform dimensions.
Bar	A streambed deposit of sand or gravel, often exposed during low-water periods.
Baseflow	The ground water contribution of streamflow.
Bole	Trunk of a tree.
Branchpacking	Live, woody, branch cuttings and compacted soil used to repair slumped areas of streambanks.
Brushmattress	A combination of live stakes, fascines, and branch cuttings installed to cover and protect streambanks and shorelines.
Bulkhead	Generally vertical structures of timber, concrete, steel, or aluminum sheet piling used to protect shorelines from wave action.
Channel	A natural or manmade waterway that continuously or intermittently carries water.
Cohesive soil	A soil that, when unconfined, has considerable strength when air dried and significant strength when wet.
Current	The flow of water through a stream channel.
Dead blow hammer	A hammer filled with lead shot or sand.
Deadman	A log or concrete block buried in a streambank to anchor revetments.
Deposition	The accumulation of soil particles on the channel bed, banks, and flood plain.
Discharge	The volume of water passing through a channel during a given time, usually measured in cubic feet per second.
Dormant season	The time of year when plants are not growing and deciduous plants shed their leaves.
Duration of flow	Length of time a stream floods.
Erosion control fabric	Woven or spun material made from natural or synthetic fibers and placed to prevent surface erosion.

Erosion	The wearing away of the land by the natural forces of wind, water, or gravity.
Erosive (erodible)	A soil whose particles are easily detached and entrained in a fluid, either air or water, passing over or through the soil. The most erodible soils tend to be silts and/or fine sands with little or no cohesion.
Failure	Collapse or slippage of a large mass of streambank material.
Filter	A layer of fabric, sand, gravel, or graded rock placed between the bank revetment or channel lining and soil to prevent the movement of fine grained sizes or to prevent revetment work from sinking into the soil.
Fines	Silt and clay particles.
Flanking	Streamflow between a structure and the bank that creates an area of scour.
Flow rate	Volume of flow per unit of time; usually expressed as cubic feet per second.
Footer log	A log placed below the expected scour depth of a stream. Foundation for a rootwad and boulders.
Gabion	A wire mesh basket filled with rock that can be used in multiples as a structural unit.
Geotextile	Any permeable textile used with foundation soil, rock, or earth as an integral part of a product, structure, or system usually to provide separation, reinforcement, filtration, or drainage.
Groin	A structure built perpendicular to the shoreline to trap littoral drift and retard erosion.
Ground water	Water contained in the voids of the saturated zone of geologic strata.
Headcutting	The development and upstream movement of a vertical or near vertical change in bed slope, generally evident as falls or rapids. Headcuts are often an indication of major disturbances in a stream system or watershed.
Joint planting	The insertion of live branch cuttings in openings or interstices of rocks, blocks, or other inert revetment units and into the underlying soil.
Littoral drift	The movement of littoral drift either transport parallel (long shore transport) or perpendicular (on-shore transport) to the shoreline.
Littoral	The sedimentary material of shorelines moved by waves and currents.
Littoral zone	An indefinite zone extending seaward from the shoreline to just beyond the breaker zone.

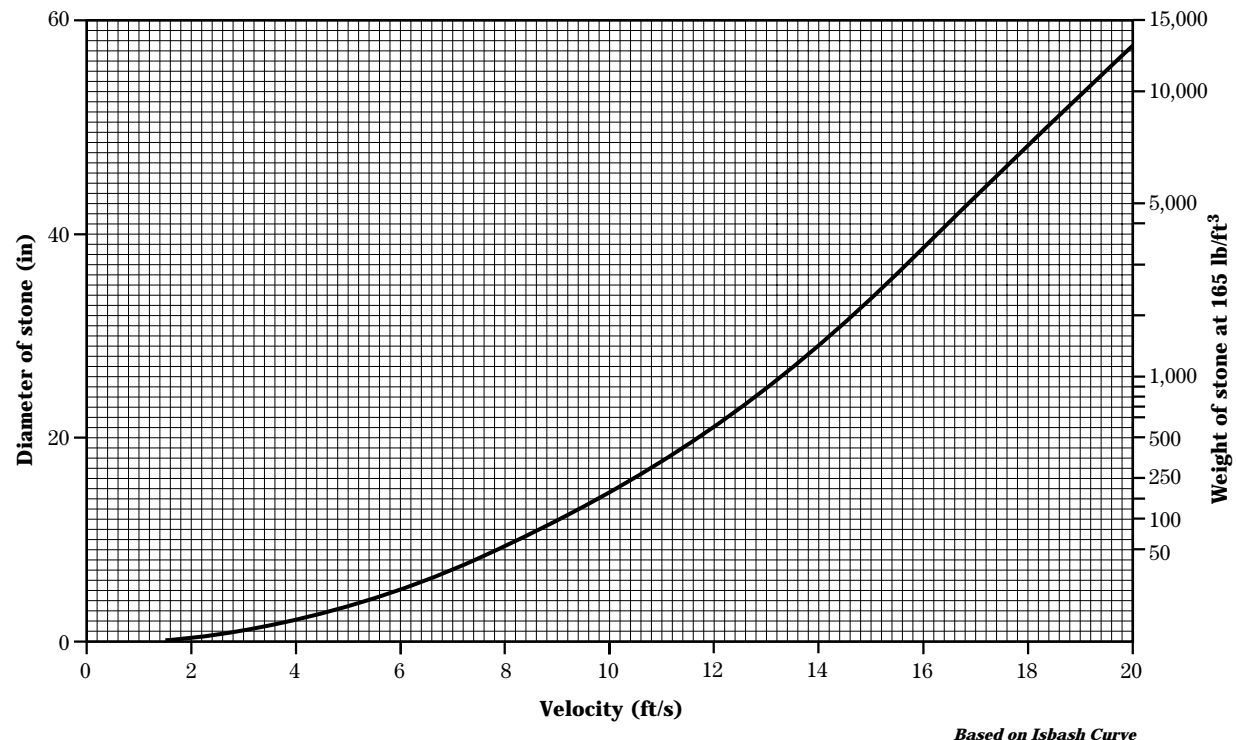
Live branch cuttings	Living, freshly cut branches from woody shrub and tree species that readily propagate when embedded in soil.
Live cribwall	A rectangular framework of logs or timbers filled with soil and containing live woody cuttings that are capable of rooting.
Live fascine	Bound, elongated, cylindrical bundles of live branch cuttings that are placed in shallow trenches, partly covered with soil, and staked in place.
Live siltation construction	Live branch cuttings that are placed in trenches at an angle from shoreline to trap sediment and protect them against wave action.
Live stake	Live branch cuttings that are tamped or inserted into the earth to take root and produce vegetative growth.
Noncohesive soil	Soil, such as sand, that lacks significant internal strength and has little resistance to erosion.
Piling (sheet)	Strips or sheets of metal or other material connected with meshed or interlocking members to form an impermeable diaphragm or wall.
Piling	A long, heavy timber, concrete, or metal support driven or jetted into the earth.
Piping	The progressive removal of soil particles from a soil mass by percolating water, leading to the development of flow channels or tunnels.
Reach	A section of a stream's length.
Reed clump	A combination of root divisions from aquatic plants and natural geotextile fabric to protect shorelines from wave action.
Revetment (armoring)	A facing of stone, interlocking pavers, or other armoring material shaped to conform to and protect streambanks or shorelines.
Riprap	A layer, facing, or protective mound of rubble or stones randomly placed to prevent erosion, scour, or sloughing of a structure of embankment; also, the stone used for this purpose.
Rootwad	A short length of tree trunk and root mass.
Scour	Removal of underwater material by waves or currents, especially at the base or toe of a streambank or shoreline.
Sediment deposition	The accumulation of sediment.
Sediment load	The amount of sediment in transport.
Sediment	Soil particles transported from their natural location by wind or water.

Seepage	The movement of water through the ground, or water emerging on the face of a bank.
Slumping (sloughing)	Shallow mass movement of soil as a result of gravity and seepage.
Stream-forming flow	The discharge that determines a stream's geomorphic planform dimensions. Equivalent to the 1- to 3-year frequency flow event (see Bankfull discharge).
Streambank	The side slopes within which streamflow is confined.
Streambed (bed)	The bottom of a channel.
Streamflow	The movement of water within a channel.
Submerged vanes	Precast concrete or wooden elements placed in streambeds to deflect secondary currents away from the streambank.
Thalweg	The deepest part of a stream channel where the fastest current is usually found.
Toe	The break in slope at the foot of a bank where it meets the streambed.
Vegetated geogrid	Live branch cuttings placed in layers with natural or synthetic geotextile fabric wrapped around each soil lift.
Vegetated structural revetments	Porous revetments, such as riprap or interlocking pavers, into which live plants or cuttings can be placed.
Vegetated structures	A retaining structure in which live plants or cuttings have been integrated.

Isbash Curve

The Isbash Curve, because of its widespread acceptance and ease of use, is a direct reprint from the previous chapter 16, Engineering Field Manual. The curve was developed from empirical data to determine a rock size for a given velocity. See figure 16A-1. The user can read the D_{100} rock size (100 percent of riprap \leq this size) directly from the graph in terms of weight (pounds) or dimension (inches). Less experienced users should use this method for quick estimates or comparison with other methods before determining a final design.

Figure 16A-1 Rock size based on Isbash Curve



Procedure

1. Determine the design velocity.
2. Use velocity and fig. 16A-1 (Isbash Curve) to determine basic rock size.
3. Basic rock size is the D_{100} size.

Figure 16A-2 Rock size based on Far West States (FWS)-Lane method

$$D_s = \frac{3.5}{CK} w D S \quad D_s = D_{75} \text{ size rock in inches}$$

Notes:

1. Ratio of channel bottom width to depth (D) greater than 4.
2. Specific gravity of rock not less than 2.56.
3. Additional requirements for stable riprap include fairly well graded rock, stable foundation, and minimum section thickness (normal to slope) not less than D_s at maximum water surface elevation and $3 D_s$ at the base.
4. Where a filter blanket is used, design filter material grading in accordance with criteria in NRCS Soil Mechanics Note 1.

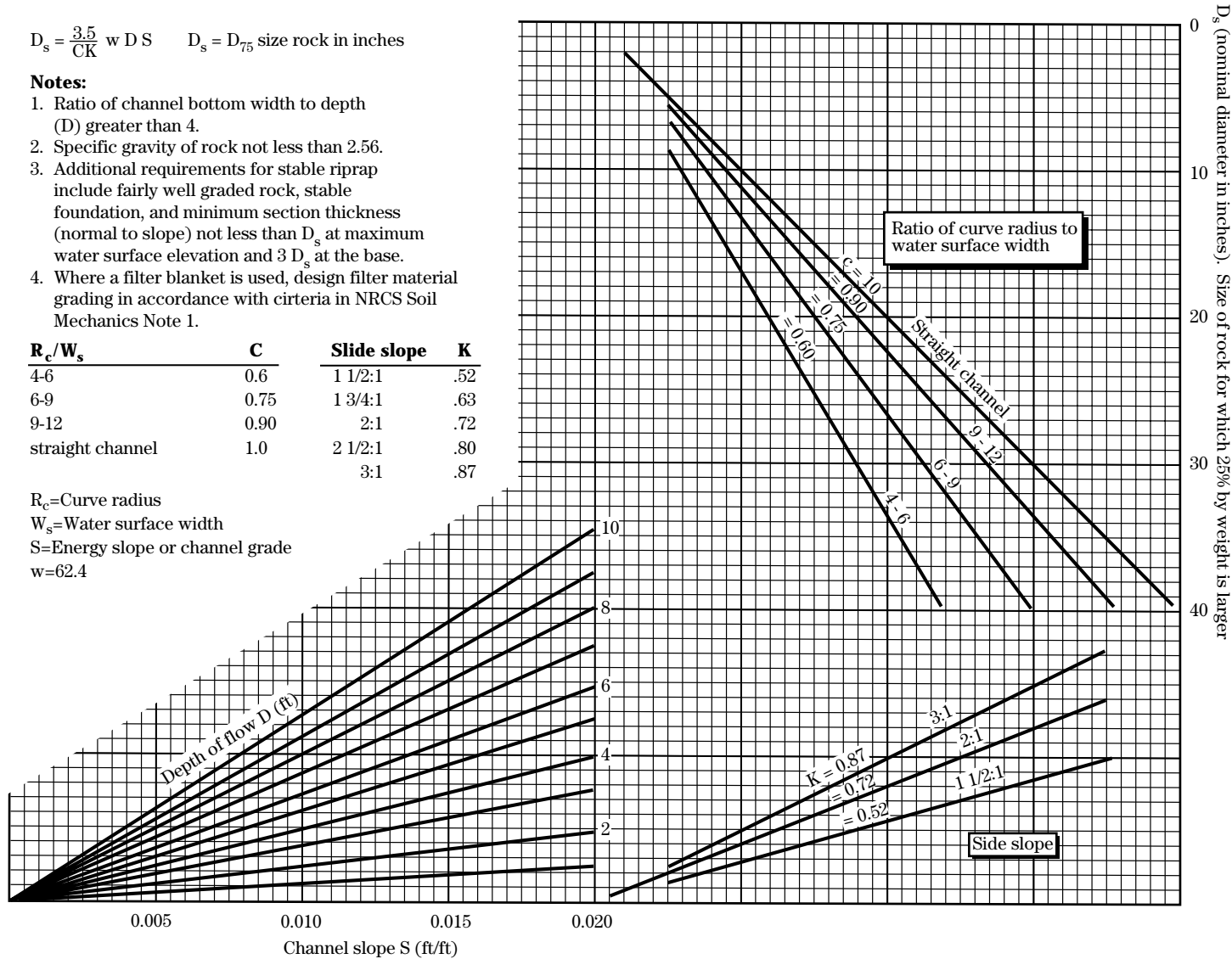
R_c/W_s	C	Slide slope	K
4-6	0.6	1 1/2:1	.52
6-9	0.75	1 3/4:1	.63
9-12	0.90	2:1	.72
straight channel	1.0	2 1/2:1	.80
		3:1	.87

R_c =Curve radius

W_s =Water surface width

S=Energy slope or channel grade

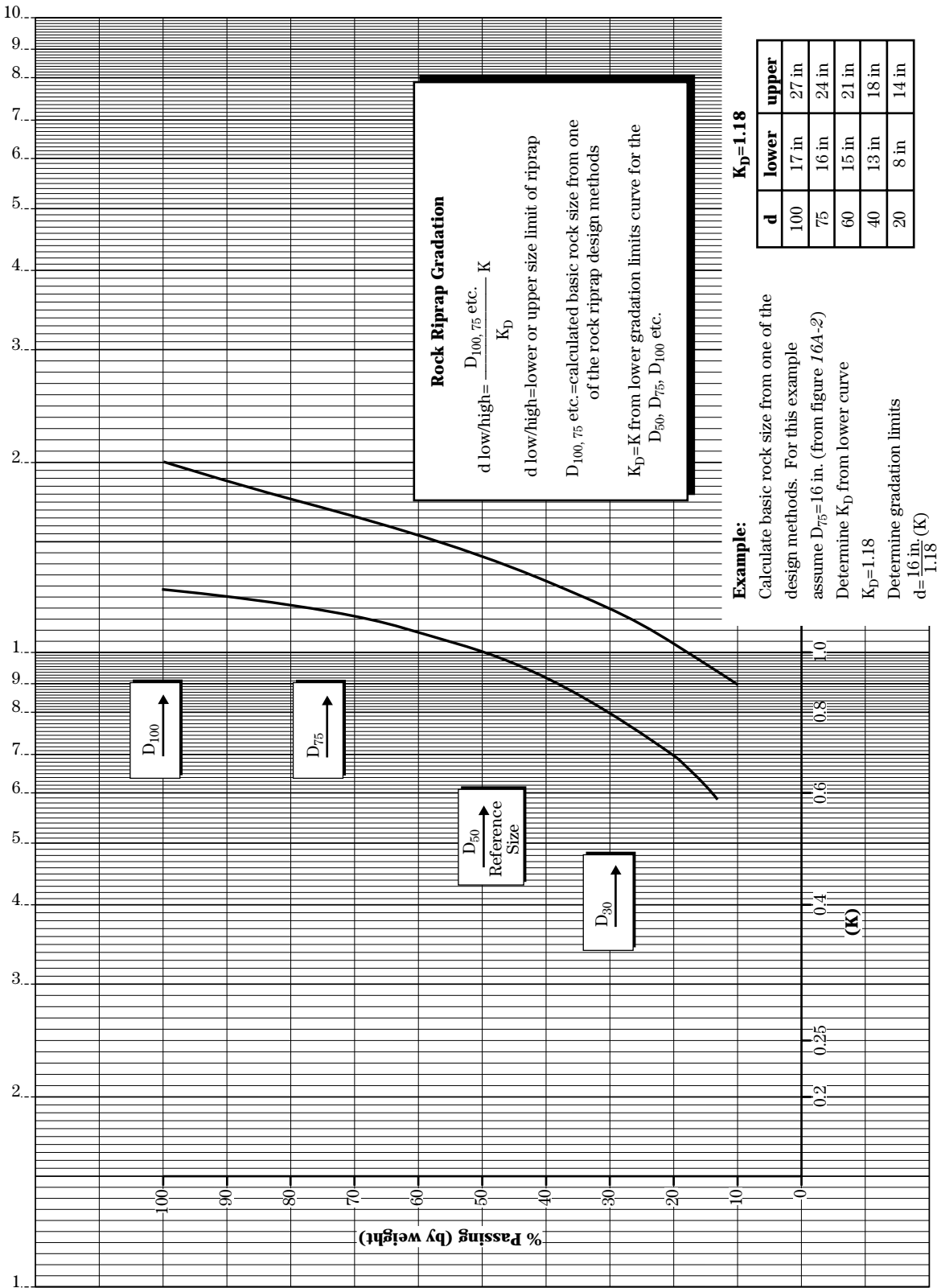
w=62.4



Procedure

1. Determine the average channel grade or energy slope.
2. Enter fig. 16A-2 with energy slope, flow depth, and site physical characteristics to determine basic rock size.
3. Basic rock size is the D_{75} size.

Figure 16A-3 Gradation limits curve for determining suitable rock gradation



Appendix 16B

Plants for Soil Bioengineering and Associated Systems

The information in appendix 16B is from the Natural Resources Conservation Service's data base for Soil Bioengineering Plant Materials (biotype). The plants are listed in alphabetical order by scientific name. Further subdivision of the listing should be considered to account for local conditions and identify species suitable only for soil bioengineering systems.

Table header definitions (in the order they occur on the tables):

Scientific name—Genus and species name of the plant.

Common name—Common name of the plant.

Region of occurrence—Region(s) of occurrence using the regions of distribution in PLANTS (Plant List of Attributes, Nomenclature, Taxonomy, and Symbols, 1994). Region code number or letter:

- 1 Northeast—ME, NH, VT, MA, CT, RI, WV, KY, NY, PA, NJ, MD, DE, VA, OH
- 2 Southeast—NC, SC, GA, FL, TN, AL, MS, LA, AR
- 3 North Central—MO, IA, MN, MI, WI, IL, IN
- 4 North Plains—ND, SD, MT (eastern)
WY (eastern)
- 5 Central Plains—NE, KS, CO (eastern)
- 6 South Plains—TX, OK
- 7 Southwest—AZ, NM
- 8 Intermountain—NV, UT, CO (western)
- 9 Northwest—WA, OR, ID, MT (western)
WY (western)
- 0 California—Ca
- A Alaska—AK
- C Caribbean—PR, VI, CZ, SQ
- H Hawaii—HI, AQ, GU, IQ, MQ, TQ, WQ, YQ

Commercial availability—Answers whether the plant is available from commercial plant vendors.

Plant type—Short description of the type of plant: tree, shrub, grass, forb, legume, etc.

Root type—Description of the root of the plant: tap, fibrous, suckering, etc.

Rooting ability from cutting—Subjective rating of cut stems of the plant to root without special hormone and/or environmental surroundings provided.

Growth rate—Subjective rating of the speed of growth of the plant: slow, medium, fast, etc.

Establishment speed—Subjective rating of the speed of establishment of the plant.

Spread potential—Subjective rating of the potential for the plant to spread: low, good, etc.

Plant materials—The type of vegetation plant parts that can be used to establish a new colony of the species.

Notes—Other important or interesting characteristics about the plant.

Soil preference—Indication of the type of soil the plant prefers: sand, loam, clay, etc.

pH preference—Lists the pH preference(s) of the plant.

Drought tolerance—Subjective rating of the ability of the plant to survive dry soil conditions.

Shade tolerance—Subjective rating of the ability of the plant to tolerate shaded sites.

Deposition tolerance—Subjective rating of the ability of the plant to tolerate deposition of soil or organic debris around or over the roots and stems.

Flood tolerance—Selective rating of the ability of the plant to tolerate flooding events.

Flood season—Time of the year that the plant can tolerate flooding events.

Minimum water depth—The minimum water depth required by the plant for optimal growth.

Maximum water depth—The maximum water depth the plant can tolerate and not succumb to drowning.

Wetland indicator—A national indicator from National List of Plant Species that Occur in Wetlands: 1988 National Summary.

Table 16B-1 Woody plants for soil bioengineering and associated systems

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Acer circinatum</i>	vine maple	9,0	yes, but in limited quantities	shrub to small tree	fibrous, rooting at nodes	fair to good	slow	slow	good	plants	Branches often touch & root at ground level. Often occurs with conifer overstory. Occurs British Columbia to CA.
<i>Acer glabrum</i>	dwarf maple	4,5,7, 8,9,0, A	yes	small tree		poor				plants	usually dioecious, grows in poor soils.
<i>Acer negundo</i>	boxelder	1,2,3, 4,5,6, 7,8,9, 0	yes	small to medium tree	fibrous, moderately deep, spreading, suckering	poor	fast	fast	fair	plants, rooted cuttings	Use in sun & part shade. Survived deep flooding for one season in Pacific NW.
<i>Acer rubrum</i>	red maple	1,2,3, 6	yes	medium tree	shallow	poor	fast when young	medium	good	plants	Not tolerant of high pH sites. Occurs on and prefers sites with a high water table and/or an annual flooding event.
<i>Acer saccharinum</i>	silver maple	1,2,3, 4,5,6, 8	yes	medium tree	shallow, fibrous	poor	fast when young	medium	fair	plants	Plants occur mostly east of the 95th parallel. Survived 2 years of flooding in MS.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Alnus pacifica</i>	pacific alder			tree		poor	most alders are fast			plants	A species for forested wetland sites in the Pacific northwest. Plant on 10- to 12-foot spacing.
<i>Alnus rubra</i>	red alder	9,0,A	yes	medium tree	shallow, spreading, suckering	poor to fair	fast	fast	good	plants	Usually grows west of the Cascade Mtns, within 125 miles of the ocean & below 2,400 feet elevation. A nitrogen source. Short lived species. May be seedable. Susceptible to caterpillars.
<i>Alnus serrulata</i>	smooth alder	1,2,3,5,6	yes	large shrub	shallow, spreading	poor	slow	medium	fair	plants	Thicket forming. Survived 2 years of flooding in MS. Roots have relation with nitrogen-fixing actinomycetes, susceptible to ice damage, needs full sun.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Alnus viridis ssp. sinuata</i>	sitka alder	9,0,A	yes, but very limited quantities	shrub to small tree	shallow	poor	rapid first year, moderate thereafter	medium	fair to good	plants	A nitrogen source. Occurs AK to CA.
<i>Amelanchier alnifolia</i> var. <i>cusickii</i>	cusick's serviceberry	9	yes	shrub		poor	medium	medium	medium	plants	Usually seed propagated. Occurs in eastern WA, northern ID, & eastern OR. A different variety is Pacific serviceberry <i>A. alnifolia</i> var. <i>semitintegrifolia</i> . Host to several insect & disease pests.
<i>Amelanchier utahensis</i>	utah serviceberry	9		small to large shrub						plants	Occurs in southeast OR, south ID, NV, & UT.
<i>Amorpha fruticosa</i>	false indigo	1,2,3, 4,5,6, 7,8,0	yes	shrub		poor	medium	fast	poor	plants, seed	Supposedly root suckers. Has been seeded directly on roadside cut and fill sites in MD.
<i>Aronia arbutifolia</i>	red chokeberry	1,2,3, 6	yes	shrub		poor	fast	fast		plants, seed	Rhizomatous. May produce fruit in second year.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Asimina triloba</i>	pawpaw	1,2,3, 5,6	yes	small tree	tap and root suckers	poor to fair	fast		poor	root cuttings, plants	Does produce thickets where native & can be propagated by layering & root cuttings. Occurs NY to FL & TX.
<i>Baccharis glutinosa</i>	seepwillow	6,7,8, 0	yes	medium shrub	deep & wide-spreading, fibrous	good				plants	Thicket forming.
<i>Baccharis halimifolia</i>	eastern baccharis	1,2,6	yes	medium shrub	fibrous	good	fair	fast	fair	fascines, cuttings, plants,	Resistant to salt spray; unisexual plants. Occurs MA to FL & TX.
<i>Baccharis pilularis</i>	coyotebush	9,0		medium evergreen shrub	fibrous	good			fair	fascines, stakes, brush mats, layering, cuttings	Pioneer in gullies, many forms prostrate & spreading. May be seedable. Colony-forming to 1 foot high in CA coastal bluffs.
<i>Baccharis salicifolia</i>	water wally	6,7,8, 0		medium evergreen shrub	fibrous, deep, wide-spreading	good			fair	fascines, brush mats, stakes, layering, cuttings	Was B. glutinosa. Thicket forming, unisexual plants.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Baccharis viminea</i>	mulefat baccharis	6,7,8,0		medium evergreen shrub	fibrous	good				fascines, stakes, brush mats, layering, cuttings	May be <i>B. salicifolia</i> .
<i>Betula nigra</i>	river birch	1,2,3,5,6	yes	medium to large tree		poor	fast when young	fast	poor	plants	Plants coppice when cut. Survived 1 year of flooding in MS. Hybridizes with <i>B. papyrifera</i> .
<i>Betula occidentalis</i>	water birch	4,5,7,8,9,0,A	yes	medium tree	fibrous, spreading					plants	Occurs on the Pacific Coast to CO.
<i>Betula papyrifera</i>	paper birch	1,3,4,5,9,A	yes	medium tree	shallow, fibrous	poor	fast when young	fast	poor	plants	Not tolerant of more than a few days inundation in a New England trial. Short lived but the most resistant to borers of all birches.
<i>Betula pumila</i>	low birch	1,3,4,8,9		small to large shrub	fibrous	poor				plants	Occurs Newfoundland to NJ & MN.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Carpinus caroliniana</i>	american hornbeam	1,2,3, 6	yes, limited sources	small tree		poor	slow	slow	poor	plants	Not tolerant of flooding in TN Valley trial. Occurs MD to FL & west to southern IL & east TX. A northern form occurs from New England to NC & west to MN & AR.
<i>Carya aquatica</i>	water hickory	1,2,3, 6	yes	tall tree	tap to shallow lateral	poor	slow	fast	poor	plants	A species for forested wetland sites.
<i>Carya cordiformis</i>	bitternut hickory	1,2,3, 5,6	yes	tree	tap & dense laterals	poor	slow		poor	plants	Roots & stumps coppice. Not tolerate flooding in a MO trial. Occurs Quebec to FL & LA. Transplants with difficulty.
<i>Carya ovata</i>	shagbark hickory	1,2,3, 4,5,6	yes	medium tree	tap	poor	slow	slow	poor	plants	Hard to transplant. Occurs Quebec to FL & TX.
<i>Catalpa bignonioides</i>	southern catalpa	1,2,3, 5,6,7	yes	tree		poor	fair	fair	poor	plants	Occurs in SW GA to LA; naturalized in New England, OH, MI, & TX.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Celtis laevigata</i>	sugarberry	1,2,3, 5,6,7, 9,0	yes	medium tree	relatively shallow	poor	medium	slow	low	plants	Very resistant to witches-broom. Occurs FL, west to TX & southern IN. Also in Mexico. Leaf fall allelopathic.
<i>Celtis occidentalis</i>	hackberry	1,2,3, 4,5,6, 8	yes	medium tree	medium to deep fibrous	poor	medium to fast	slow	low	plants	Survived 2 years of flooding in MS. Not tolerate more than a few days inundation in a MO trial. Susceptible to witches-broom. Occurs Quebec to NC & AL.
<i>Cephalanthus occidentalis</i>	buttonbush	1,2,3, 5,6,7, 8,0	yes	large shrub		fair to good	slow	medium	poor	brush mats, layering, plants	Survived 3 years of flooding in MS. Will grow in sun or shade.
<i>Cercis canadensis</i>	redbud	1,2,3, 5,6,7, 8	yes	small tree	tap	poor	slow	slow	poor	plants	Juvenile wood & roots will root.
<i>Chilopsis linearis</i>	desert willow	6,7,8, 0	yes	shrub	fibrous		medium	medium	low	plants	Occurs TX to southern CA & into Mexico. 'Barranco,' 'Hope,' & 'Regal' cultivars were released in New Mexico.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Chionanthus virginicus</i>	fringetree	1,2,3, 6	yes	small tree		poor	slow		poor	plants	Susceptible to severe browsing & scale. Occurs PA to FL & west to TX.
<i>Clematis ligusticifolia</i>	western clematis	1,2,4, 5,6,7, 8,9,0	yes	vine	shallow & fibrous	poor	fast	fast	good	plants	Produces new plants from layering in sandy soils at 7- to 8-inch precip & 1,000-foot elevation.
<i>Clethra alnifolia</i>	sweet pepperbush	1,2,6	yes	shrub		poor	slow			plants	Has rhizomes; salt tolerant on coastal sites. Occurs ME to FL.
<i>Cornus amomum</i>	silky dogwood	1,2,3, 4,5,6	yes	small shrub	shallow, fibrous	fair	fast	medium	poor	fascines, stakes, brush mats, layering, cuttings, plants	Pith brown, tolerates partial shade. 'Indigo' cultivar was released by MI cuttings, PMC.
<i>Cornus drummondii</i>	roughleaf dogwood	1,2,3, 4,5,6	yes	large shrub	root suckering, spreading	fair			fair	fascines, stakes, layering, brush mats, cuttings, plants	Root suckers too. Pith usually brown. Occurs Saskatchewan to KS & NE, south to MS, LA, & TX.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Cornus florida</i>	flowering dogwood	1,2,3, 5,6	yes	small tree	shallow, fibrous	poor	fair	fair	poor	plants	Hard to transplant as bare root; coppices freely. Not tolerant of flooding in TN Valley trial.
<i>Cornus foemina</i>	stiff dogwood	1,2,3, 4,5,6		medium shrub		fair	fast			fascines, plants	Formerly <i>C. racemosa</i> Occurs VA to FL & west to TX. Pith white.
<i>Cornus racemosa</i>	gray dogwood	1,2,3, 4,5,6	yes	medium to small shrub	shallow, fibrous	fair	medium		fair	fascines, stakes, brush mats, layering, cuttings, plants	Forms dense thickets. Pith usually brown, tolerates city smoke. Occurs ME & MN to NC & OK.
<i>Cornus rugosa</i>	roundleaf dogwood	1,3		medium to small shrub	shallow, fibrous	fair to good				fascines, cuttings, plants	Pith white. Use in combination with species with root_abil = good to excellent. Occurs Nova Scotia to VA & ND.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Cornus sericea</i> ssp <i>sericea</i>	red-osier dogwood	1,3,4, 5,7,8, 9,0,A	yes	medium shrub	shallow	good	fast	medium	fair	fascines, stakes, brush mats, layering, cuttings, plants	Forms thickets by rootstocks & rooting of branches. Survived 6 years of flooding in MS. Pith white, tolerates partial shade. Formerly <i>C. stolonifera</i> . 'Ruby' cultivar was released by NY PMC.
<i>Cornus stricta</i>	swamp dogwood			shrub		poor				plants	May be same as <i>C. foemina</i> .
<i>Crataegus douglasii</i>	douglas hawthorn	3,8,9, 0,A	yes	small tree	tap to fibrous	poor to fair	slow		poor	cuttings, plants	Forms dense thickets on moist sites. Grown from seed or grafted. Occurs British Columbia to CA & MN.
<i>Crataegus mollis</i>	downy hawthorn	1,2,3, 4,5,6	yes	tree	tap	poor to fair				plants	Occurs Ontario & MN to AL, AR & MS. 'Homestead' cultivar was released by ND PMC.
<i>Cyrilla racemiflora</i>	titi	1,2,6, C		small tree		poor				plants	Semievergreen, a good honey plant. Occurs VA to FL & on to South America. Prefers organic sites.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Diospyros virginiana</i>	persimmon	1,2,3,5,6	yes	medium tree	tap	poor	slow	fair	poor	plants	Forms dense thickets on dry sites. Stoloniferous & tap rooted. Occurs CT to FL & TX.
<i>Elaeagnus commutata</i>	silverberry	1,3,4,8,9,A	yes	small tree	shallow, fibrous	poor to fair	fast	fast	fair	plants	Grows well in limestone & alkaline soils.
<i>Forestiera acuminata</i>	swamp privet	1,2,3,6	yes	large shrub to small tree		fair	slow		poor	plants	Thicket forming. Survived 3 years of flooding in MS.
<i>Fracinus caroliniana</i>	carolina ash	1,2,6		large tree	fibrous	poor	fast	fast		plants	Easily transplanted. Occurs in swamps VA to TX.
<i>Fracinus latifolia</i>	oregon ash	9,0	yes	medium tree	moderately shallow, fibrous	poor	fast when young	medium	fair	plants	May be grown from seed but usually grafted. Usually occurs west of the Cascade Mtns.
<i>Fracinus pennsylvanica</i>	green ash	1,2,3,4,5,6,8,9	yes	medium tree	shallow, fibrous	poor	fast	fast	good	plants	Survived 3 years of flooding in MS. 'Cardan' cultivar was released by ND PMC.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Gleditsia triacanthos</i>	honeylocust	1,2,3, 4,5,6, 7,8,9	yes	medium tree	deep & wide-spread	poor to fair	fast	fast	medium	plants	Survived deep flooding for 100 days 3 consecutive years. Has been used in reg_occ 7,8,9. Native ecotypes have thorns!
<i>Hibiscus aculeatus</i>	hibiscus	2,6	yes	shrub		poor				plants	
<i>Hibiscus laevis</i>	halberd-leaf marshmallow		yes	shrub		poor				plants	Was H. militaris.
<i>Hibiscus moscheutos</i>	common rose mallow	1,2,3, 5,6,7, 0	yes	shrub		poor				plants	
<i>Hibiscus moscheutos</i> ssp. <i>lasiocarpus</i>	hibiscus		yes	shrub		poor				plants	
<i>Holodiscus discolor</i>	oceanspray	9,0	yes, from contract growers.	shrub		poor to fair	medium to rapid	fast	poor	plants	Often pioneers on burned areas. Occurs from British Columbia to CA to ID. Usually grown from seed or cuttings.
<i>Ilex coriacea</i>	sweet gallberry	1,2,6, C	yes	small to large shrub		poor				plants	Evergreen.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Ilex decidua</i>	possumhaw	1,2,3,5,6	yes	large shrub to small tree		poor	slow			plants	Survived 3 years of flooding in MS.
<i>Ilex glabra</i>	bitter gallberry	1,2,6	yes	small shrub		poor	slow			plants	Evergreen, sprouts after fire. Stoloniferous! Occurs eastern US & Canada.
<i>Ilex opaca</i>	american holly	1,2,3,6	yes	small tree	tap root & prolific laterals	poor	slow	medium	poor	plants	Easy to transplant when young.
<i>Ilex verticillata</i>	winterberry	1,2,3,6	yes	small to large shrub		poor	slow			plants	Prefers seasonally flooded sites. Plants dioecious.
<i>Ilex vomitoria</i>	yaupon	1,2,6	yes	large shrub		poor				plants	Root suckers.
<i>Juglans nigra</i>	black walnut	1,2,3,4,5,6	yes	medium tree	tap & deep & wide-spread laterals	poor	fair	fair	poor	plants	Though drought tolerant, will not grow on poor or dry soil sites. Not tolerate flooding in TN Valley trial.
<i>Juniperus virginiana</i>	eastern redcedar	1,2,3,4,5,6	yes	large tree	tap & dense fibrous laterals	poor	slow	medium	good	plants	Not tolerate flooding in TN Valley trial.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Leucothoe axillaris</i>	leucothoe	1,2	yes	small to large shrub		poor	slow			plants	Evergreen.
<i>Lindera benzoin</i>	spicebush	1,2,3, 5,6	yes	shrub		poor	slow			plants	Prefers acid soils. Dioecious.
<i>Liquidambar styraciflua</i>	sweetgum	1,2,3, 6	yes	large tree	tap to fibrous	poor	slow		fair	plants	A species for forested wetland sites.
<i>Liriodendron tulipifera</i>	tulip poplar	1,2,3, 5,6	yes	large tree	deep & wide-spreading	poor	fast	fast		plants	Hard to transplant.
<i>Lonicera involucrata</i>	black twinberry	3,7,8, 9,0,A	yes	small to large shrub	fibrous & shallow	good	fast	fast	poor to fair	fascines, stakes, cuttings, plants	
<i>Lyonia lucida</i>	fetterbush	1,2		small to large shrub		poor				plants	Evergreen.
<i>Magnolia virginiana</i>	sweetbay	1,2,6	yes	small tree		poor	slow			plants	Occurs in swamps from MA to FL and west to east TX.
<i>Myrica cerifera</i>	southern waxmyrtle	1,2,6, c	yes	small shrub	fibrous	poor	medium	slow	slow	plants	Evergreen. Occurs east TX & OK, east to FL & north to NJ.
<i>Nyssa aquatica</i>	swamp tupelo	1,2,3, 6	yes	large tree	shallow, fibrous	poor		slow		plants	Trees from the wild do not transplant well.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Nyssa ogeeche</i>	ogeeche lime	2		large shrub to small tree	sparse, fibrous	poor	slow	medium	poor	plants	Largest fruit of all Nyssa. Vegetative reproduction not noted. Only grows close to perennial wetland sites.
<i>Nyssa sylvatica</i>	blackgum	1,2,3,6	yes	tall tree	sparse, fibrous, very long, decending	poor	medium	slow	fair	plants	A species for forested wetland sites. Difficult to transplant but plant in sun or shade on 10- to 12-foot spacing.
<i>Ostrya virginiana</i>	hophornbeam	1,2,3,4,5,6	yes	small tree		poor	slow	slow		plants	Difficult to transplant. Tolerated flooding for up to 30 days during 1 growing season.
<i>Persea borbonia</i>	redbay	1,2,6	yes	small to large evergreen tree		poor	slow	slow		plants	
<i>Philadelphus lewisii</i>	lewis mockorange	9,0	yes	large shrub	fibrous	poor	fast	medium to fast	medium	plants	Usually grown from seed.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Physocarpus capitatus</i>	pacific ninebark	8,9,0, A	yes	large shrub	fibrous	good				fascines, brush mats, layering, cuttings, plants	Usually occurs west of the Cascade Mtns.
<i>Physocarpus malvaceus</i>	mallow ninebark	8,9	yes	small shrub	shallow but with rhizomes	fair				cuttings, plants	Propagated by seed or cuttings. Usually occurs east of the Cascade Mtns.
<i>Physocarpus opulifolius</i>	common ninebark	1,2,3, 4,5,6, 8,9	yes	medium shrub	shallow, lateral	fair	slow	slow	poor	fascines, brush mats, layering, cuttings, plants	Use in combination with other species with rooting ability good to excellent.
<i>Pinus taeda</i>	loblolly pine	1,2,3, 6	yes	medium tree	short tap changes to shallow spreading laterals	poor	fast	fast	poor	plants	
<i>Planera aquatica</i>	water elm	1,2,3, 5,6		small tree		poor	fairly fast			plants	Occurs KY to FL, west to IL & TX.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Platanus occidentalis</i>	sycamore	1,2,3,5,6	yes	large tree	fibrous, wide-spreading	poor	fast	fast	medium	plants	A species for forested wetland sites. Tolerates city smoke & alkali sites. Plant on 10- to 12-foot spacing. Transplants well.
<i>Platanus racemosa</i>	California sycamore	0		tall tree						plants	A species for forested wetlands sites in CA.
<i>Populus angustifolia</i>	narrowleaf cottonwood	4,5,6,7,8,9,0		large tree	shallow	v good				fascines, stakes, poles, brush mats, layering, cuttings, plants	Under development in ID for riparian sites.
<i>Populus balsamifera</i>	balsam poplar	1,2,3,4,5,8,9,O,A	yes	tall tree	deep, fibrous	v good	fast	fast		fascines, stakes, poles, brush mats, layering, cuttings, plants	

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Populus deltoides</i>	eastern cottonwood	1,2,3, 4,5,6, 7,8,9	yes	tall tree	shallow, fibrous, suckering	v good	fast	fast	poor	fascines, stakes, poles, brush mats, layering, cuttings, root suckers, plants	Short lived. Endures heat & sunny sites. Survived over 1 year of flooding in MS. Hybridizes with several other poplars. Plant roots may be invasive. May be sensitive to aluminum in the soil.
<i>Populus fremontii</i>	fremont cottonwood	6,7,8, 0		tree	shallow, fibrous	v good	fast			fascines, stakes, poles, brush mats, layering, cuttings, plants	Tolerates saline soils. Dirty tree.
<i>Populus tremuloides</i>	quaking aspen	1,2,3, 4,5,7, 8,9,0, A	yes	medium tree	shallow, profuse suckers, vigorous under-ground runners	poor to fair	fast	fast	fair	layering, root cuttings, plants	Short lived. A pioneer species on sunny sites. Normal propagation is by root cuttings. Not tolerant of more than a few days inundation in a New England trial. Use rooted plant materials.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Populus trichocarpa</i>	black cottonwood	4,7,8,9,0,A	yes	large tree	deep & wide-spread, fibrous	v good	fast	fast	good	fascines, stakes, poles, brush mats, layering, cuttings, plants	A species for forested wetland sites. Was <i>P. trichophora</i> . Usually grown from cuttings. Under development in ID for riparian sites. Plant on 10- to 12-foot spacing. May be <i>P. balsamifera</i>
<i>Prunus angustifolia</i>	wild plum	1,2,3,5,6	yes	small shrub	fibrous, spreading, suckering	poor	medium	fast	good	plants, root cuttings	Thicket forming. 'Rainbow' cultivar released by Knox City, TX, PMC.
<i>Prunus virginiana</i>	common chokecherry	1,2,3,4,5,6,7,8,9,0,A	yes	large shrub	shallow, suckering	poor	medium	medium	fair	plants	A species for forested wetland sites. Has hydrocyanic acid in most parts, especially the seeds. Usually grown from seed. Thicket forming. Plant on 5- to 8-foot spacing. Reportedly poisonous to cattle.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Quercus alba</i>	white oak	1,2,3,5,6	yes	large tree	tap to deep, well-developed fibrous	poor	slow	slow	slow	plants	Did not survive more than a few days flooding in a trial in New England. Difficult to transplant larger specimens.
<i>Quercus bicolor</i>	swamp white oak	1,2,3,5,6	yes	medium tree	somewhat shallow	poor	fast	medium	fair	plants	Survived 2 years of flooding in MS.
<i>Quercus garryana</i>	oregon white oak	9,0	yes	shrub to large tree	deep tap & well-developed laterals	poor	slow	slow	fair	plants	Usually grows west of the Cascade Mtns, in the Columbia River Gorge to the Dalles & to Yakima, WA. Propagated from seed sown in fall.
<i>Quercus laurifolia</i>	swamp laurel oak	1,2,6		tree	tap	poor	fast	fast		plants	Often used as a street tree in the southeast US.
<i>Quercus lyrata</i>	overcup oak	1,2,3,6	yes	medium tree	tap deteriorates to dense shallow laterals	poor	slow	slow	slow	plants	Often worthless as a lumber species.
<i>Quercus macrocarpa</i>	bur oak	1,2,3,4,5,6,9	yes	large tree	deep tap & well-developed laterals	poor	medium	fast	poor	plants	Survived 2 years of flooding in MS. 'Boomer' cultivar released by TX PMC.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Quercus michauxii</i>	swamp chestnut oak	1,2,3, 6		medium tree	tap & deep laterals	poor	fair	fair	poor	plants	
<i>Quercus nigra</i>	water oak	1,2,3, 6		medium tree	shallow & spreading	poor	fast on good sites	slow	poor	plants	Easily transplanted.
<i>Quercus pagoda</i>	cherrybark oak			tree		poor				plants	
<i>Quercus palustris</i>	pin oak	1,2,3, 5,6	yes	large tree	well-developed fibrous laterals after taproot disintegrates	poor	fast	fast	fair	plants	A species for forested wetland sites. Survived 2 years of flooding in MS. Plant on 10- to 12-foot spacing.
<i>Quercus phellos</i>	willow oak	1,2,3, 6	yes	medium to large tree	shallow, fibrous	poor	fast	medium	fair	plants	Easily transplanted.
<i>Quercus shumardii</i>	shumard oak	1,2,3, 5,6	yes	large tree	shallow	poor	medium	slow	low	plants	
<i>Rhododendron atlanticum</i>	coast azalea	1,2		small shrub		poor	fast		good by stolons	plants	Mat forming from suckers & stolons. Occurs from DE to SC.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Rhododendron viscosum</i>	swamp azalea	1,2		shrub		poor	slow			plants	Has stoloniferous forms. Occurs from ME to SC. Highly susceptible to insects & diseases.
<i>Rhus copallina</i>	flameleaf sumac	1,2,3, 4,5,6	yes	medium shrub	fibrous, suckering	poor to fair	fast	fast	fair	root cuttings, root suckers, plants	Thicket forming.
<i>Rhus glabra</i>	smooth sumac	1,2,3, 4,5,6, 7,8,9	yes	large shrub	fibrous, suckering	poor to fair	fast	fast	fair to good	root cuttings, root suckers, plants	Thicket forming.
<i>Robinia pseudoacacia</i>	black locust	1,2,3, 4,5,6, 7,8,9, 0	yes	medium tree	shallow	poor	medium to fast	fast	good	root cuttings, plants	Normal propagation is by root cuttings or seed. Not tolerant of flooding in TN Valley trial. Escaped in regions 5,7,8,9,0. Reported toxic to livestock.
<i>Rosa gymnocarpa</i>	baldhip rose	9,0		shrub		fair to good				cuttings, plants	A browsed species.
<i>Rosa nutkana</i>	nootka rose	7,8,9, 0,A		shrub		fair to good				cuttings, plants	A browsed species.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Rosa palustris</i>	swamp rose	1,2,3,5		small shrub	shallow	good				fascines, plants	
<i>Rosa virginiana</i>	virginia rose	1,2,3	yes	small shrub	rhizomatous & fibrous	good	fair	fast	fair	plants	
<i>Rosa woodsii</i>	woods rose	3,4,5,6,7,8,9,0,A		shrub		fair to good				cuttings, plants	A browsed species.
<i>Rubus allegheniensis</i>	allegheny blackberry	1,2,3,5,6,0		small shrub	fibrous	good				plants	Normal propagation is by root cuttings.
<i>Rubus idaeus</i> ssp. <i>strigosus</i>	red raspberry	1,2,3,4,5,6,7,8,9,A		small shrub	fibrous	good				plants	Was <i>R. strigosus</i> . Normal propagation is by root cuttings.
<i>Rubus spectabilis</i>	salmonberry	9,0,A		small shrub	fibrous	good				plants	Normal propagation is by root cuttings. Use in combination with other species. Rooting ability is good to excellent.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Salix X cottetii</i>	dwarf willow	not native	yes	small shrub	shallow	v good	medium	fast	poor	fascines, stakes, brush mats, layering, cuttings, plants	Not a native species. Plant on 2' to 6' spacing. 'Bankers' cultivar released by Kentucky PMC.
<i>Salix amygdaloides</i>	peachleaf willow	1,2,3, 4,5,6, 7,8,9	yes	large shrub to small tree	shallow to deep	v good	fast	fast		fascines, stakes, poles, brush mats, layering, cuttings, plants	Often roots only at callus cut. May be short-lived. Under development in ID for riparian sites. Not tolerant of shade. Hybridized with several other willow species.
<i>Salix bebbiana</i>	bebb's willow	1,3,4, 5,7,8, 9,A		small shrub to large tree	fibrous					cuttings, plants	Does not form suckers. Usually east of the Cascade Mtns & in ID & MT.
<i>Salix bonplandiana</i>	pussy willow	7	yes	medium shrub to large tree	fibrous	v good				fascines, stakes, poles, brush mats, layering, cuttings, plants	Eaten by livestock when young.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Salix boothii</i>	booth willow	8,9		shrub							Under development in Idaho for riparian sites.
<i>Salix discolor</i>	pussy willow	1,2,3, 4,9	yes	large shrub	shallow, fibrous, spreading	v good	rapid			fascines, stakes, poles, layering, cuttings, plants	Use on sunny to partial shade sites.
<i>Salix drummondiana</i>	drummond's willow	7,8,9, 0	yes	shrub		good				fascines, cuttings, plants	Usually east of the Cascade Mtns. Under development in ID for riparian sites. 'Curlew' cultivar released by WA PMC.
<i>Salix eriocephala</i>	erect willow	7,8,9, 0	yes	large shrub	fibrous	v good		fast		fascines, stakes, poles, layering, cuttings, plants	A botanic discrepancy in the name, it may be <i>S. ligulifolia</i> . 'Placer' cultivar released by OR PMC.
<i>Salix exigua</i>	coyote willow	1,2,3, 4,5,6, 7,8,9, 0,A	yes	medium shrub	shallow, suckering, rhizomatous	good	fast			fascines, stakes, poles, brush mats, layering, cuttings, plants	Relished by livestock. Under development in ID for riparian sites. 'Silver' cultivar released by WA PMC.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Salix geyeriana</i>	geyer's willow	7,8,9,0		small to large shrub						cuttings, plants	Occurs east of the Cascade Mtns at higher elevations. Relished by livestock. Under development in ID for riparian sites.
<i>Salix gooddingii</i>	goodding willow	6,7,8,0		small shrub to large tree	shallow to deep	good to excel	fast	fast		fascines, stakes, poles, brush mats, layering, cuttings, plants	Not tolerate alkaline sites. Some say this is western black willow.
<i>Salix hookeriana</i>	hooker willow	9,0	yes	large shrub to small tree	fibrous, dense	v good	rapid when young, medium thereafter	medium		fascines, stakes, poles, brush mats, layering, cuttings, plants	May have salt tolerance. Can compete well with grasses. 'Clatsop' cultivar was released by OR cuttings, PMC.
<i>Salix humilis</i>	prairie willow	1,2,3,4,5,6		medium shrub	fibrous, spreading	good		medium		fascines, stakes, poles, brush mats, layering, cuttings, plants	Thicket forming.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Salix interior</i>	sandbar willow	1,3,4, 5,7,8, 9,A	yes	large shrub	shallow to deep	excellent	medium	medium	fair	fascines, stakes, poles, brush mats, layering, cuttings, plants	Thicket forming. This species has been changed to <i>S. exigua</i> . Use in combination with species with rooting ability good to excellent.
<i>Salix lasiolepis</i>	arroyo willow	6,7,8, 9,0	yes	tall shrub to small tree	fibrous	very good	rapid when young, medium thereafter	medium		fascines, stakes, poles, brush mats, layering, cuttings, plants	Roots only on lower 1/3 of cutting or at callus. 'Rogue' cultivar released by OR PMC.
<i>Salix lemmonii</i>	lemmon's willow	8,9,0	yes	medium shrub	fibrous	very good		fast		fascines, stakes, poles, brush mats, layering, cuttings, plants	Occurs at high elevations, east of the Cascade Mtns. Under development in ID for riparian sites. 'Palouse' cultivar released by WA PMC.
<i>Salix lucida</i>	shining willow	1,3,4, 5,7,8, 9,0		medium to tall shrub	fibrous, spreading	very good	rapid			fascines, stakes, poles, brush mats, layering, cuttings, plants	

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Salix lucida</i> ssp. <i>lasianдра</i>	pacific willow	4,7,8,9,0,A	yes	large shrub to small tree	fibrous	v good	medium to slow	medium to slow		fascines, stakes, poles, brush mats, layering, cuttings, plants	A species for forested wetlands sites. There are several subspecies of <i>S. lucida</i> . Under development in ID for riparian sites. Susceptible to several diseases and insects. Plant on 10- to 12-foot spacing. 'Nehalem' cultivar released by OR PMC.
<i>Salix lutea</i>	yellow willow	1,4,5,7,8,9,0		medium to tall shrub	fibrous	v good				fascines, stakes, poles, brush mats, layering, cuttings, plants	Usually browsed by livestock. Under development in ID for riparian sites.
<i>Salix nigra</i>	black willow	1,2,3,5,6,7,8	yes	small to large tree	dense, shallow, sprouts readily	good to excel	fast	fast	good	fascines, stakes, poles, brush mats, layering, cuttings, root cuttings, plants	May be short lived. Survived 3 years of flooding in MS. Needs full sun. Susceptible to several diseases & insects.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Salix pentandra</i>	laural willow	not native	yes	large shrub to small tree	fibrous, spreading	good	fast	medium	poor	fascines, stakes, poles, brush mats, layering, cuttings, plants	From Europe, sparingly escaped in the East. Insects may defoliate it regularly.
<i>Salix purpurea</i>	purpleosier willow	1,2,3, 5	yes	medium tree	shallow	excel	fast	fast	poor	fascines, stakes, poles, brush mats, layering, cuttings, plants	Tolerates partial shade. 'Streamco' cultivar released by NY PMC.
<i>Salix scouleriana</i>	scouler's willow	4,7,8, 9,0,A		large shrub to small tree	shallow	v good	fast			fascines, stakes, poles, brush mats, layering, cuttings, plants	Pioneers on burned sites. Occurs on both sides of the Cascade Mtns in low to high elevations. Often roots only at callus.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Salix stitchensis</i>	sitka willow	9,0,A	yes	very large shrub		v good	rapid when young, medium thereafter	medium		fascines, stakes, poles, brush mats, layering, cuttings, plants	Occurs on both sides of the Cascade Mtns. Vigorous shoots branch freely; lends itself to bioengineering uses; excellent survival in trials. 'Plumas' cultivar released by OR PMC.
<i>Sambucus canadensis</i>	american elder	1,2,3, 4,5,6, 8,9	yes	medium shrub	fibrous & stoloniferous	good	fast	fast	poor	fascines, cuttings, plants	Softwood cuttings root easily in spring or summer. Pith white.
<i>Sambucus cerulea</i>	blue elderberry	6,7,8, 9,0	yes	large shrub	fibrous	poor	v fast	v fast	poor	plants	
<i>Sambucus cerulea</i> ssp. <i>mexicana</i>	mexican elder	6,7,8, 0,H		large shrub		good				fascines, plants	Was S. mexicana. Evergreen. Softwood cuttings root easily in spring or summer.
<i>Sambucus racemosa</i>	red elderberry	1,2,3, 4,7,8, 9,0,A	yes	medium shrub		good	medium	slow		fascines, brush mats, layering, cuttings, plants	Softwood cuttings root easily in spring or summer. Pith brown. This may be S. callicarpa.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Sambucus racemosa</i> <i>ssp. pubens</i>	red elder	1,2,3, 4,9,A		medium shrub	deep laterals	fair to good				fascines, plants	Occurs west of the Cascade Mtns, usually within 10 miles of the ocean & on the coastal bays & estuaries. Softwood cuttings root easily in spring or summer. Pith brown. Use in combination with species with rooting ability good to excellent.
<i>Spiraea alba</i>	meadow-sweet spirea	1,2,3, 4	yes	short dense tree	dense shallow, lateral	fair to good		medium		plants	Propagation by leafy softwood cuttings in midsummer under mist.
<i>Spiraea betulifolia</i>	shinyleaf spirea	1,2,4, 9		shrub						plants	Usually grown from seed. Occurs east of the Cascade Mtns at medium to high elevations.
<i>Spiraea douglasii</i>	douglas spirea	2,3,9, 0	yes	small dense shrub	fibrous, suckering	good	rapid	fast	excellent	fascines, brush mats, layering, cuttings, division of suckers, plants	Resists fire & prolific sprouter (forms thickets). Propagation by leafy softwood cuttings in midsummer under mist. 'Bashaw' cultivar released by WA PMC.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Spiraea tomentosa</i>	hardhack spirea	1,2,3, 5		small shrub	dense, shallow	poor to fair				plants	Propagation by leafy softwood cuttings in mid-summer under mist. A weed in New England pastures. Use rooted materials.
<i>Styrax japonica</i>	Japanese snowbell	1,2,3, 5,6	yes	large shrub		poor				plants	
<i>Symphoricarpos albus</i>	snowberry	1,3,4, 5,7,8, 9,0,A	yes	small shrub, dense colony forming	shallow, fibrous, freely suckering	good	rapid	slow	fair	fascines, brush mats, layering, cuttings, plants	Plant in sun to part shade, especially on wet sites.
<i>Taxodium distichum</i>	baldcypress	1,2,3, 5,6	yes	medium tree	tap with laterals for knees for aeration	poor	medium	fast	poor	plants	Plant on 10- to 12-foot spacing. Tolerates upland sites in region 6 with 32" rainfall.
<i>Tsuga canadensis</i>	eastern hemlock	1,2,3	yes	large tree	shallow fibrous	poor	slow	slow	low	plants	

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Ulmus americana</i>	american elm	1,2,3, 4,5,6, 8	yes	large tree	tap on dry sites to shallow fibrous on moist sites	poor	medium	medium	poor	plants	A species for forested wetland sites. Survived near 2 years of flooding in MS. Plant on 10- to 12-foot spacing; tolerates full shade.
<i>Viburnum dentatum</i>	arrowwood	1,2,3, 6	yes	medium to tall shrub	shallow, fibrous	good	fast	slow		layering, cuttings, plants	Thicket forming; tolerates city smoke. Use rooted plant materials.
<i>Viburnum lantanoides</i>	hubblebush viburnum	1,2,3		medium shrub	shallow, fibrous	good				fascines, stakes, brush mats, layering, cuttings, plants	Was <i>V. alnifolium</i> . Thicket forming. Branch tips root at soil.
<i>Viburnum lentago</i>	nannyberry	1,2,3, 4,5,9	yes	large shrub	shallow	fair to good	fast	fast		fascines, cuttings, stakes, plants	Thicket forming; tolerates city smoke. Tolerates full shade. Older branches often root when they touch soil. Use in combination with species with rooting ability good to excellent.

Table 16B-1 Woody plants for soil bioengineering and associated systems—Continued

scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
<i>Viburnum nudum</i>	swamp haw	1,2,6		large shrub		poor				plants	D. Wymann says it is more adapted to the South than <i>V. cassinoides</i> .
<i>Viburnum trilobum</i>	american cranberry-bush	1,3,4, 5,9	yes	medium shrub		poor	medium	slow		layering, plants	Use rooted plant materials. Fruits are edible.

Table 16B-2 Woody plants with fair to good or better rooting ability from unrooted cuttings

Scientific name	Common name	Scientific name	Common name
<i>Acer circinatum</i>	vine maple	<i>Salix bonplandiana</i>	pussy willow
<i>Baccharis glutinosa</i>	seepwillow	<i>Salix discolor</i>	pussy willow
<i>Baccharis halimifolia</i>	eastern baccharis	<i>Salix drummondiana</i>	drummond's willow
<i>Baccharis pilularis</i>	coyotebush	<i>Salix eriocephala</i>	erect willow
<i>Baccharis salicifolia</i>	water wally	<i>Salix exigua</i>	coyote willow
<i>Baccharis viminea</i>	mulefat baccharis	<i>Salix gooddingii</i>	goodding willow
<i>Cephalanthus occidentalis</i>	buttonbush	<i>Salix hookeriana</i>	hooker willow
<i>Cornus amomum</i>	silky dogwood	<i>Salix humilis</i>	prairie willow
<i>Cornus drummondii</i>	roughleaf dogwood	<i>Salix interior</i>	sandbar willow
<i>Cornus foemina</i>	stiff dogwood	<i>Salix lasiolepis</i>	arroyo willow
<i>Cornus racemosa</i>	gray dogwood	<i>Salix lemmonii</i>	lemmon's willow
<i>Cornus rugosa</i>	roundleaf dogwood	<i>Salix lucida</i>	shining willow
<i>Cornus sericea ssp sericea</i>	red-osier dogwood	<i>Salix lucida ssp. lasiandra</i>	pacific willow
<i>Lonicera involucrata</i>	black twinberry	<i>Salix lutea</i>	yellow willow
<i>Physocarpus capitatus</i>	pacific ninebark	<i>Salix nigra</i>	black willow
<i>Physocarpus opulifolius</i>	common ninebark	<i>Salix pentandra</i>	laural willow
<i>Populus angustifolia</i>	narrowleaf cottonwood	<i>Salix purpurea</i>	purpleosier willow
<i>Populus balsamifera</i>	balsam poplar	<i>Salix scouleriana</i>	scouler's willow
<i>Populus deltoides</i>	eastern cottonwood	<i>Salix sitchensis</i>	sitka willow
<i>Populus fremontii</i>	fremont cottonwood	<i>Sambucus canadensis</i>	american elder
<i>Populus trichocarpa</i>	black cottonwood	<i>Sambucus cerulea</i> <i>ssp. mexicana</i>	mexican elder
<i>Rosa gymnocarpa</i>	baldhip rose	<i>Sambucus racemosa</i>	red elderberry
<i>Rosa nutkana</i>	nootka rose	<i>Sambucus racemosa</i> <i>ssp. pubens</i>	red elder
<i>Rosa palustris</i>	swamp rose	<i>Spiraea alba</i>	meadowsweet spirea
<i>Rosa virginiana</i>	virginia rose	<i>Spiraea douglasii</i>	douglas spirea
<i>Rosa woodsii</i>	woods rose	<i>Symphoricarpos albus</i>	snowberry
<i>Rubus allegheniensis</i>	allegheny blackberry	<i>Viburnum dentatum</i>	arrowwood
<i>Rubus idaeus</i>	red raspberry	<i>Viburnum lantanoides</i>	hubblebush viburnum
<i>ssp. strigosus</i>		<i>Viburnum lentago</i>	nannyberry
<i>Rubus spectabilis</i>	salmonberry		
<i>Salix X cottetii</i>	dwarf willow		
<i>Salix amygdaloides</i>	peachleaf willow		

Table 16B-3 Woody plants with poor or fair rooting ability from unrooted cuttings

Scientific name	Common name	Scientific name	Common name
<i>Acer glabrum</i>	dwarf maple	<i>Fraxinus pennsylvanica</i>	green ash
<i>Acer negundo</i>	boxelder	<i>Gleditsia triacanthos</i>	honeylocust
<i>Acer rubrum</i>	red maple	<i>Hibiscus aculeatus</i>	hibiscus
<i>Acer saccharinum</i>	silver maple	<i>Hibiscus laevis</i>	halberd-leaf marshmallow
<i>Alnus pacifica</i>	pacific alder	<i>Hibiscus moscheutos</i>	common rose mallow
<i>Alnus rubra</i>	red alder	<i>Hibiscus moscheutos</i> <i>ssp. lasiocarpus</i>	hibiscus
<i>Alnus serrulata</i>	smooth alder	<i>Holodiscus discolor</i>	oceanspray
<i>Alnus viridis ssp.sinuata</i>	sitka alder	<i>Ilex coriacea</i>	sweet gallberry
<i>Amelanchier alnifolia</i> <i>var cusickii</i>	cusick's serviceberry	<i>Ilex decidua</i>	possumhaw
<i>Amorpha fruticosa</i>	false indigo	<i>Ilex glabra</i>	bitter gallberry
<i>Aronia arbutifolia</i>	red chokeberry	<i>Ilex opaca</i>	american holly
<i>Asimina triloba</i>	pawpaw	<i>Ilex verticillata</i>	winterberry
<i>Betula nigra</i>	river birch	<i>Ilex vomitoria</i>	yaupon
<i>Betula papyrifera</i>	paper birch	<i>Juglans nigra</i>	black walnut
<i>Betula pumila</i>	low birch	<i>Juniperus virginiana</i>	eastern redcedar
<i>Carpinus caroliniana</i>	american hornbeam	<i>Leucothoe axillaris</i>	leucothoe
<i>Carya aquatica</i>	water hickory	<i>Lindera benzoin</i>	spicebush
<i>Carya cordiformis</i>	bitternut hickory	<i>Liquidambar styraciflua</i>	sweetgum
<i>Carya ovata</i>	shagbark hickory	<i>Liriodendron tulipifera</i>	tulip poplar
<i>Catalpa bignonioides</i>	southern catalpa	<i>Lyonia lucida</i>	fetterbush
<i>Celtis laevigata</i>	sugarberry	<i>Magnolia virginiana</i>	sweetbay
<i>Celtis occidentalis</i>	hackberry	<i>Myrica cerifera</i>	southern waxmyrtle
<i>Cercis canadensis</i>	redbud	<i>Nyssa aquatica</i>	swamp tupelo
<i>Chionanthus virginicus</i>	fringetree	<i>Nyssa ogeeche</i>	ogeeche lime
<i>Clematis ligusticifolia</i>	western clematis	<i>Nyssa sylvatica</i>	blackgum
<i>Clethra alnifolia</i>	sweet pepperbush	<i>Ostrya virginiana</i>	hophornbeam
<i>Cornus florida</i>	flowering dogwood	<i>Persea borbonia</i>	redbay
<i>Cornus stricta</i>	swamp dogwood	<i>Philadelphus lewesii</i>	lewis mockorange
<i>Crataegus douglasii</i>	douglas' hawthorn	<i>Physocarpus malvaceus</i>	mallow ninebark
<i>Crataegus mollis</i>	downy hawthorn	<i>Physocarpus opulifolius</i>	common ninebark
<i>Cyrilla racemiflora</i>	titi	<i>Pinus taeda</i>	loblolly pine
<i>Diospyros virginiana</i>	persimmon	<i>Planera aquatica</i>	water elm
<i>Dlaeagnus commutata</i>	silverberry	<i>Platanus occidentalis</i>	sycamore
<i>Forestiera acuminata</i>	swamp privet	<i>Populus tremuloides</i>	quaking aspen
<i>Fraxinus caroliniana</i>	carolina ash	<i>Prunus angustifolia</i>	wild plum
<i>Fraxinus latifolia</i>	oregon ash		

Table 16B-3 Woody plants with poor or fair rooting ability from unrooted cuttings—Continued

Scientific name	Common name	Scientific name	Common name
<i>Prunus virginiana</i>	common chokecherry	<i>Rhododendron atlanticum</i>	coast azalea
<i>Quercus alba</i>	white oak	<i>Rhododendron viscosum</i>	swamp azalea
<i>Quercus bicolor</i>	swamp white oak	<i>Rhus copallina</i>	flameleaf sumac
<i>Quercus garryana</i>	oregon white oak	<i>Rhus glabra</i>	smooth sumac
<i>Quercus laurifolia</i>	swamp laurel oak	<i>Robinia pseudoacacia</i>	black locust
<i>Quercus lyrata</i>	overcup oak	<i>Sambucus cerulea</i>	blue elderberry
<i>Quercus macrocarpa</i>	bur oak	<i>Spiraea tomentosa</i>	hardhack spirea
<i>Quercus michauxii</i>	swamp chestnut oak	<i>Styrax americanus</i>	Japanese snowbell
<i>Quercus nigra</i>	water oak	<i>Taxodium distichum</i>	bald cypress
<i>Quercus pagoda</i>	cherrybark oak	<i>Tsuga canadensis</i>	eastern hemlock
<i>Quercus palustris</i>	pin oak	<i>Ulmus americana</i>	american elm
<i>Quercus phellos</i>	willow oak	<i>Viburnum nudum</i>	swamp haw
<i>Quercus shumardii</i>	shumard oak	<i>Viburnum trilobum</i>	american cranberrybush

Table 16B-4 Grasses and forbs useful in conjunction with soil bioengineering and associated systems

Scientific name	Common name	Warm season or non-competitive	Soil preference	pH preference	Drought tolerance	Shade tolerance	Deposition tolerance	Flood tolerance	Flood season	Min. h ₂ O	Max. h ₂ O	Wetland indicator ^{1/}
<i>Agrostis alba</i>	redtop											
<i>Ammophila breviligulata</i>	American beachgrass		sands	5.5	fair	poor	good			0		1,facu- 2,upl 3,upl*
<i>Andropogon gerardii</i>	big bluestem	yes	loams	6.0	good	poor	poor	fair		0		1,fac 2,fac 3,fac- 4,facu 5,fac- 6,facu 7,fac- 8,facu 9,facu
<i>Arundo donax</i>	giant reed		sandy	7.0	good	poor		poor		0	1"	1,facu- 2,facw 3,facw 6,fac+ 7,facw 8,facw 0,facw C,ni H,ni
<i>Elymus virginicus</i>	wildrye	yes noncompetitive	loams	6.0	fair	good	fair	good		0		1,facw-
<i>Eragrostis trichodes</i>	sand lovegrass	yes	sands	6.0	good	poor	poor	poor		0		
<i>Festuca rubra</i>	red fescue	noncompetitive	loams	6.5	good	good	poor	fair		0		1,facu

Table 16B-4 Grasses and forbs useful in conjunction with soil bioengineering and associated systems—Continued

Scientific name	Common name	Warm season or noncompetitive	Soil preference	pH preference	Drought tolerance	Shade tolerance	Deposition tolerance	Flood tolerance	Flood season	Min. h ₂ O	Max. h ₂ O	Wetland indicator ^{1/}
<i>Hemarthria altissima</i>	limpograss		sandy		poor	poor	poor	good		0	1'	1,facw 2,facw 6,facw
<i>Panicum amarulum</i>	coastal panicgrass	yes	sands to loams	5.5	good	poor	fair	good		0		1,facu- 2,fac 6,facu-
<i>Panicum clandestinum</i>	deertongue	yes										
<i>Panicum virgatum</i>	switchgrass	yes	loams to sands	6.0	good	poor	fair	good	all	0		1,fac 2,fac+ 3,fac+ 4,fac 5,fac 6,facw 7,fac+ 8,fac 9,fac+ H,ni
<i>Paspalum vaginatum</i>	seashore paspalum		sandy			poor		good		1/2'	1'	2,obl 6,facw* C,ni H,ni
<i>Pennisetum purpureum</i>	elephant-grass					poor				0	2'	2,facu+ C,ni H,ni

Table 16B-4 Grasses and forbs useful in conjunction with soil bioengineering and associated systems—Continued

Scientific name	Common name	Warm season or non-competitive	Soil preference	pH preference	Drought tolerance	Shade tolerance	Deposition tolerance	Flood tolerance	Flood season	Min. h ₂ O	Max. h ₂ O	Wetland indicator ^{1/}
<i>Poa pratensis</i>	Kentucky bluegrass		loam	6.5	poor	poor	poor	fair		0		1, facu
<i>Schizachyrium scoparium</i>	little bluestem	yes	sands to loams	6.5	good	poor	poor	poor		0		1, facu
<i>Sorghastrum nutans</i>	Indiangrass	yes	sands to loams	6.5	fair	poor	poor	poor		0		1, upl
<i>Spartina pectinata</i>	prairie cordgrass	yes	sands to loams	6.0	good	fair	fair	fair		0	1"	1, obl 2, obl 3, facw+ 4, facw 5, facw 6, facw+ 7, facw 8, obl 9, obl
<i>Zizaniopsis miliacea</i>	giant cutgrass		loam	4.3-6.0	poor	poor		good	all	1/2'	2'	1, obl 2, obl 3, obl 6, obl

Table 16B-4 Grasses and forbs useful in conjunction with soil bioengineering and associated systems—Continued

Scientific name	Common name	Warm season or non-competitive	Soil preference	pH preference	Drought tolerance	Shade tolerance	Deposition tolerance	Flood tolerance	Flood season	Min. h ₂ O	Max. h ₂ O	Wetland indicator ^{1/}
1/ Wetland indicator terms (from USDI Fish and Wildlife Service's National List of Plant Species That Occur in Wetlands, 1988):												
Region code number or letter:												
1 Northeast (ME, NH, VT, MA, CT, RI, WV, KY, NY, PA, NJ, MD, DE, VA, OH)												
2 Southeast (NC, SC, GA, FL, TN, AL, MS, LA, AR)												
3 North Central (MO, IA, MN, MI, WI, IL, IN)												
4 North Plains (ND, SD, MT (eastern), WY (eastern))												
5 Central Plains (NE, KS, CO (eastern))												
6 South Plains (TX, OK)												
7 Southwest (AZ, NM)												
8 Intermountain (NV, UT, CO (western))												
9 Northwest (WA, OR, ID, MT (western), WY (western))												
0 California (Ca)												
A Alaska (AK)												
C Caribbean (PR, VI, CZ, SQ)												
H Hawaii (HI, AQ, GU, IQ, MQ, TQ, WQ, YQ)												
Indicator categories (estimated probability):												
fac	Facultative—Equally likely to occur in wetlands or nonwetlands (34-66%).											
facu	Facultative upland—Usually occur in nonwetlands (67-99%), but occasionally found in wetlands (1-33%)											
facw	Facultative wetland—Usually occur in wetlands (67-99%), but occasionally found in nonwetlands.											
obl	Obligate wetland—Occur almost always (99%) under natural conditions in wetlands.											
upl	Obligate upland—Occur in wetlands in another region, but occur almost always (99%) under natural conditions in nonwetlands in QæB ₂ regioK ₂ QpC ₂ Üh ² DGed ₂ 'e ₂ ' Qpec%Cs BMæQnMt Mccur%an wetlands in any region, it is not on the National List.											
Frequency of occurrence:												
-	(negative sign) indicates less frequently found in wetlands.											
+	(positive sign) indicates more frequently found in wetlands.											
*	(asterisk) indicates wetlands indicators were derived from limited ecological information.											
ni	(no indicator) indicates insufficient information was available to determine an indicator status.											

