CHAPTER 3: EROSION AND SEDIMENTATION CONTROL PRACTICES
TABLE OF CONTENTS

CHAPTER 3: EROSION AND SEDIMENTATION CONTROL PRACTICES

3.1 INTRODUCTION

Erosion from construction sites, dirt roads and other disturbed lands are a source of sediment, toxic chemicals, and excess nutrients that can pollute coastal waters. Runoff from construction sites is by far the largest source of sediment in urbanizing areas (U.S. EPA, 1993; U.S. EPA, 1992). Sediment eroded from dirt roads, construction sites and other cleared areas is the primary pollutant impairing V.I. water quality (DPNR-DEP and USDA-NRCS, 1998). A 1986 study of erosion rates on St. Thomas and St. Croix estimated erosion from a disturbed dirt road site to be 591 tons/acre/year (Wernicke, Seymour and Mangold, 1986). Studies of erosion rates in the Fish Bay watershed on St. John have soil loss from dirt roads of between 100 to 600 tons per year (MacDonald, et. al., 1997; Sampson, 1997).

Erosion control practices reduce the amount of soil that erodes from construction sites. ***Sediment control practices*** remove eroded soil from stormwater before it leaves the construction site and is deposited onto roadways and down-slope properties and into guts, ponds and coastal waters. Using erosion and sediment control practices is an important part of stormwater pollution prevention. These practices have been developed by the USDA Soil Conservation Service/Natural Resources Conservation Service, various local and state government agencies, and erosion control professionals and product manufacturers.

The selection of the best soil erosion and sediment control practices for construction sites should be based upon the nature of the construction activity and the conditions that exist at the construction site. A properly designed erosion and sediment control plan should:

EROSION CONTROL KEYS

The keys to controlling erosion and soil loss on construction sites are to:

- **Protect the soil surface from rain drop impact,**
- **Maintain soil's water holding capacity,**
- **Slow storm water runoff speed,**
- **Minimize slope lengths,**
- **Plan to control storm water runoff,**
- **Match practices to individual site conditions, and**
- **Maintain erosion, sediment and stormwater control practices.**

- **Minimize the amount of disturbed soil** on the construction site. This will decrease the potential amount of soil that erodes from the site, reducing the number and complexity of practices needed to remove sediment from site runoff.

- **Prevent runoff from off-site areas from flowing across disturbed areas.** This will reduce the amount of stormwater that comes into contact with bare soils. Reducing runoff flow over bare soils decreases soil erosion and reduces the volume of stormwater needing treatment to remove sediment.

- **Slow the runoff flowing across the site.** High runoff velocities reduce water seepage into the soil, increase runoff volume, and cause soil particles to detach from the soil surface. High runoff velocities can cause severe gully erosion, especially on steep slopes. Make grades as gradual as possible without excessively modifying existing site conditions.

- **Remove sediment from on-site runoff before it leaves the site.** Because vegetation used for soil stabilization may not establish itself before a severe storm occurs, on most construction sites it will be necessary to install practices that can remove sediment from runoff before it leaves the site.

- **Plan soil disturbance activities for the dry season.** This will help to minimize erosion by scheduling site disturbance activities to occur during times of little or no rainfall.

How these objectives are met depend upon site characteristics and the type of construction activity. The following sections describe stabilization and structural practices for erosion and sediment control. Construction specifications and design procedures for each practice are provided in Appendix B.

3.2 STABILIZATION PRACTICES

Preserving existing vegetation and re-planting cleared/bare soils as soon as possible after earth change is the most effective way to control erosion. Plant cover reduces erosion potential by:

- Protecting the soil surface from the impact of falling rain drops (reducing erosion);
- Slowing runoff velocity (or speed) and allowing sediment to settle out (reducing off-site sediment loss);
- Physically holding the soil in place with plant roots (erosion control); and
- Increasing infiltration (or seepage) rates by improving the soil's structure and porosity.

Vegetative cover can be grass, trees, shrubs, ground covers, other types of plants, or any combination of these. Grasses are used most commonly because they grow quickly and have fibrous root systems that can rapidly stabilize soils. Other soil stabilization practices such as mulching or matting may be used during the dry season when seeds have difficulty establishing themselves. Newly planted shrubs and trees establish root systems more slowly, so keeping existing ones is a more effective practice. Existing vegetation is adapted to the area, whereas many exotic plant species that are planted after construction may prove to be less successful.

Vegetative and other stabilization practices can be either temporary or permanent. Temporary practices provide cover for exposed or disturbed areas for short time periods or until permanent erosion controls are in place. Permanent vegetative practices are used when soil-disturbing activities are completed or when erosion is occurring on a site that is otherwise stabilized. It is generally preferable to permanently stabilize disturbed soils as soon as possible. The stabilization practices presented in this chapter include:

- Preservation and Protection of Natural Vegetation
- Filter Strips
- Land Grading
- Surface Roughening
- Temporary Seeding
- Permanent Seeding and Planting
- Mulch, Mats and Geotextiles
- Soil Binders/Tackifiers
- Soil Retaining Walls
- Soil Bioengineering

<u>Stabilization practices should be initiated as soon as practicable in sections of the site where construction activities have temporarily or permanently ceased, but in no case more than 14 days after the construction activity in that part of the site has temporarily or permanently stopped.</u>

Preservation and Protection of Natural Vegetation

The preservation of natural vegetation (existing trees, vines, bushes, and grasses) provides natural buffer zones to slow runoff and filter sediment. Often areas of a construction site are unnecessarily cleared. Only those areas essential for construction activities should be cleared (building footprints, road/drive ways, cistern and septic system areas). Other areas should remain undisturbed, particularly critical areas such as those with steep slopes and/or highly erodible soils, or areas around guts, ponds or coastal waters.

Preserving natural vegetation on the site by clearing only the area where structures will be built minimizes erosion potential, protects water quality, provides aesthetic benefits, and is cost-effective in the long term. This practice is a permanent control practice.

When and Where to Use Natural Vegetation Preservation

This practice applies to all construction sites. Natural vegetation preservation is particularly beneficial in or near floodplains, wetlands, guts, steep slopes, and other areas where erosion controls would be difficult to establish, install, and/or maintain. Virgin Islands Law (V.I. Code Annot. Title 12, sections 121 to 125) prohibits ***"...the cutting or injury of any tree or vegetation within 30 feet of the center of any natural watercourse, or within 25 feet of the edge of such watercourse, whichever is greater."*** This chapter goes further to define a natural watercourse as ***"...any stream with a reasonably well-defined channel, and includes streams which have a permanent flow, as well as those which result from the accumulation of water after rainfalls and which regularly flow through channels formed by the force of the waters,"*** i.e., guts. In many instances, guts may flow for only a few days or weeks during the year. However, the vegetation within or bordering these guts is very important for maintaining water quality and may contain rare, endangered or threatened plant and animal species.

What to Consider

On-site vegetation preservation should be planned before any site disturbance begins (Figure 3.1). Preservation requires good site management to minimize the impact of construction activities on existing vegetation. Heavy equipment can ruin the topsoil through compaction and kill desirable plants. **The proposed limits of land disturbance should be physically marked off to ensure that only the required land area is cleared.** Clearing promotes unwanted weed growth because of increased exposure to sunlight. Hard-to-control plants like guinea grass, vines, tan-tan and casha can rapidly take over cleared areas. Hand-clearing preserves existing vegetation while removing unwanted plants.

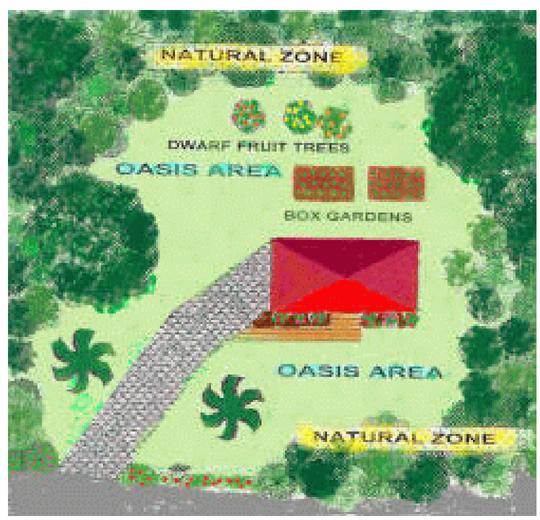

Figure 3.1. Diagram showing site where natural vegetation is preserved around the perimeter (*Toni Thomas, UVI-CES*).

Trees to be preserved should be clearly marked and protected from ground disturbances around the base of the tree. Trees should be protected with tree armoring, fencing, or a tree well (Figure 3.2). Limit soil placement over existing tree and shrub roots to a maximum of 3 inches. Retaining walls or terraces should be used to protect roots of trees and shrubs when grades are lowered. Lowered grades should start no closer than the tree's dripline. Care should be taken to minimize damage to tree limbs and root systems. Contact the

Department of Planning and Natural Resources (DPNR), the DPNR Division of Fish & Wildlife, the UVI Cooperative Extension Service (CES), or the V.I. National Park for information on rare or endangered species before removing trees or other vegetation.

Since soils are so shallow in the Virgin Islands, topsoil is a rare commodity and should be conserved. As little existing topsoil should be removed as possible. Where topsoil has been removed, soil should be stockpiled on the site so that it can be re-applied. **Soil stockpiles must be temporarily seeded or covered with a tarp, mat or geotextile to prevent erosion.** Compatibility of existing and imported topsoils should be checked to ensure maximum growth potential for the desired vegetation.

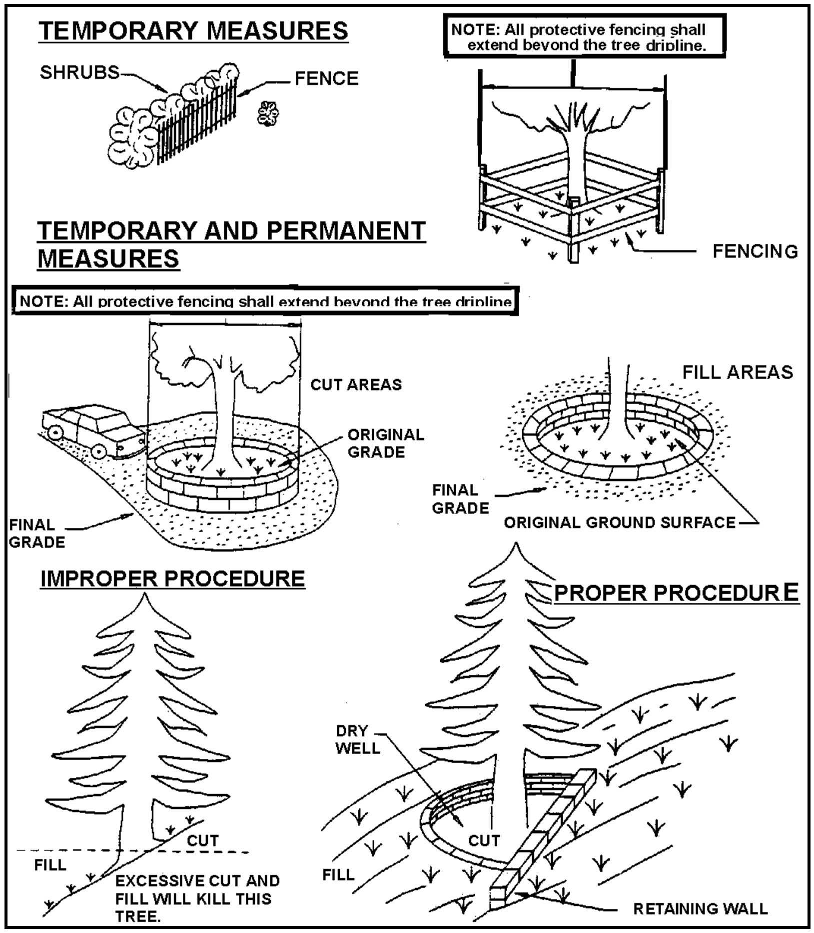

Figure 3.2. Tree protection practices (*Maryland Department of the Environment, 1994*).

How Effective is Natural Vegetation Preservation?

Preservation and enhancement of natural vegetation is the most effective erosion and sediment control practice. Any ground disturbance on a site results in increased erosion from that site. By minimizing land clearing to the areas where final structures will be located (building footprints, driveways, septic systems, etc.), overall site erosion is minimized. The vegetation remaining on the site also works as a filter to trap sediments and other pollutants (see ***Filter Strips***). A natural vegetation zone around the building area will also provide a windbreak, shade, privacy barrier, noise buffer, dust filter, and wildlife habitat. However, other practices may also be needed to control erosion and sediment loss, especially from roadways or driveways.

ADVANTAGES OF NATURAL VEGETATION PRESERVATION/PROTECTION
• Is inexpensive and already established.
• Can handle higher quantities of stormwater runoff than newly seeded areas.
• Is already established, therefore is immediately effective.
• Has good pollutant filtering capacity since preserved natural vegetation and root structure are usually denser than in newly seeded areas.
• Provides areas for infiltration, reducing stormwater runoff volume and velocity.
• Requires less maintenance than planting new vegetation and is more likely to successfully control erosion and sedimentation.
• Holds existing topsoil on ground so that new soil does not have to be brought in.
• Provides noise buffers and screens for onsite operations.
• Provides a windbreak, shade, privacy barrier, dust filter, and wildlife habitat.
• Enhances aesthetics and property values.

Filter Strips

Filter strips are vegetated strips of land used to remove sediment and other pollutants from stormwater runoff by slowing runoff speeds, filtering out sediment and other pollutants, and providing some infiltration. Filter strips are different from buffer strips (as described in Chapter 4) because their effectiveness is not measured by their ability to improve stormwater infiltration. A filter strip can be an area of vegetation that is left undisturbed during construction, or it can be newly planted. Filter strips can be either temporary or permanent practices.

When and Where to Use Filter Strips

Filter strips can be used at any site that can support vegetation. Filter strips are best suited for treating runoff from roads and highways, small parking lots, construction sites and pervious surfaces (CWP, 2000a). Filter strips are used at the lower edge of cleared or disturbed areas, small parking lots or home sites, or above structural practices such as swales or diversions. They are particularly effective on flood plains, next to wetlands, ponds and guts, and on steep unstable slopes. **Filter strips should always be used around guts and other drainage ways, ponds, and coastal waters, and are most effective if they are buffers (see Chapter 4) consisting of native vegetation left undisturbed during construction.** If native vegetation does not provide enough ground cover, it can be supplemented with native grass seed, such as bahia or hurricane grass.

What to Consider

The type and quantity of pollution that filter strips will be treating must be determined. Slopes, soils, plant species, construction timing, watering needs, and operation and maintenance methods should be considered in designing a filter strip. If the filter has outlet flow, it must be non-erosive.

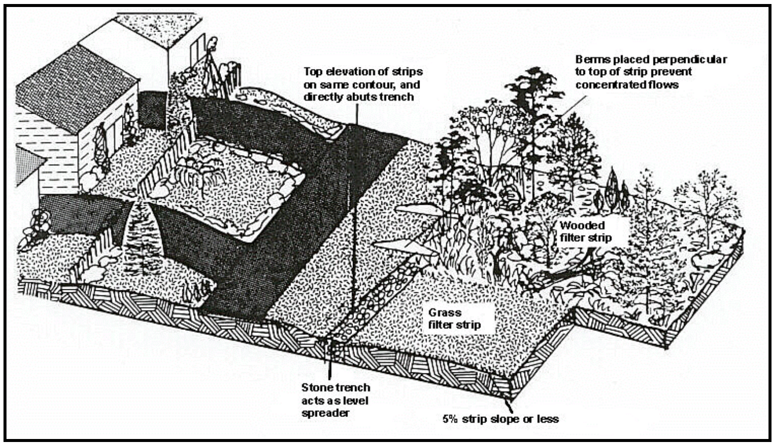

Figure 3.3. Vegetated buffer strip design (*Schueler, 1987*).

Filter strips are typically used to treat very small drainage areas. The limiting design factor is the length of flow contributing to the filter strip. The slope length contributing runoff to a filter strip should not exceed 75 feet for impervious areas (including compacted soil) or 150 feet for pervious areas (CWP, 2000a). Filter strips are most effective on slopes of 5% or less, and grassed filter strips should be at least 15 feet wide, forested filter strips should be at least 50 feet wide. Steeper slopes require wider widths (for example, a 20 - 30% slope requires a grassed strip at least 25 feet wide, (USDA-SCS, 1993a).

If filter strips are composed of preserved existing vegetation, good planning and site management are needed to protect them against disturbances such as grade changes, excavation, equipment damage, and other activities. Establishing new filter strips requires the establishment of good grass cover, trees and shrubs (see ***Preservation and Protection of Natural Vegetation*** (page 3-3) or ***Permanent Seeding and Planting*** (page 3-10)). Careful maintenance is important to ensure healthy vegetation. The need for routine maintenance like mowing, pruning, irrigation, and weed and pest control will depend on the species of plants and trees used. Native plant species will require minimum maintenance while exotic species may require significant inputs (irrigation, pesticides, nutrients). Maintaining planted areas may require debris removal and protection against unintended uses or traffic.

How Effective Are Filter Strips?

Filter strips can be very effective in removing sediment from stormwater if dense plant growth is present (i.e., if existing vegetation is preserved or newly planted vegetation grows quickly and thickly). Filter strips can also slow and reduce stormwater flow through infiltration of excess water so that downstream erosion is greatly reduced.

ADVANTAGES OF FILTER STRIPS
• Filter sediment and other pollutants from stormwater runoff before it reaches drainage channels, guts, ponds, and/or coastal waters.
• Prevent erosion on the vegetated area of the site.
• Provide areas for infiltration, reducing the volume and speed of stormwater runoff.
• Native (or existing growth) filter strips have lower maintenance requirements.
• Are very low cost if using existing vegetation.
• Provide screens and buffers for noise and privacy, provide areas for wildlife habitat and improve site appearance.
DISADVANTAGES OF FILTER STRIPS
• Limit the amount of land area to be used for construction and other activities.
• Require plant growth before they are effective (for newly planted filter strips).
• May not be feasible for small lots.

Land Grading

Land grading is the reshaping or alteration of the existing land surface to provide for better utilization, improvement of drainage, and erosion control (Figure 3.4). Land grading requires a well-developed plan using an engineering survey and layout. The land grading specification is used to provide for erosion control and vegetation establishment on those areas of the construction site where the existing land surface will be disturbed by grading activities.

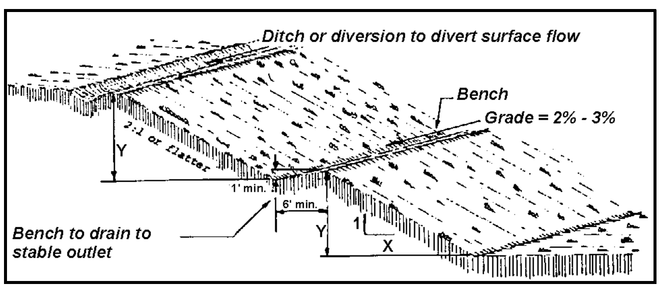

Figure 3.4. Land grading details (*Empire State Chapter, Soil and Water Conservation Society, 1991*).

When and Where to Use Land Grading

Proper land grading practices should be used in all land disturbing activities, and particularly on sites where surface irregularities, slopes, soil type, obstructions, or wetness interfere with planned uses; or where the desired land use requires designed land surfaces. **Serrated cut slopes (Figure 3.5) should be used for steep cuts behind buildings or adjacent to driveways or roads to prevent landslides.** These slopes can then be planted with temporary or permanent vegetation (see ***Seeding & Planting*** section). Special attention should be given to maintaining or improving habitat for rare, threatened or endangered species, where applicable (contact the DPNR Division of Fish and Wildlife for information on Virgin Islands habitat requirements).

What to Consider

The grading plan should incorporate building designs and street layouts that fit into and utilize the existing topography, vegetation and other desirable natural features to avoid extreme grade modifications. The effect of grading on runoff quantity and surface storage should be considered. Stormwater runoff will be increased by removal of vegetation and surface storage areas (depressions).

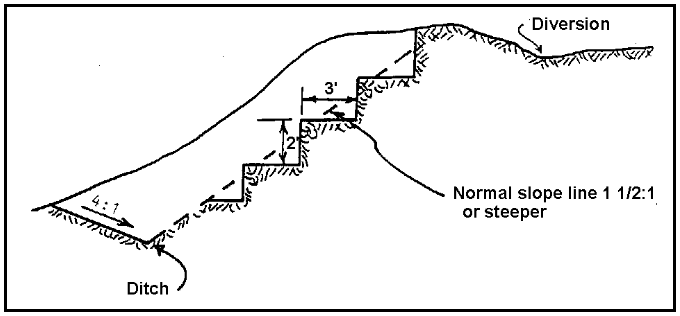

Figure 3.5. Typical section of serrated cut slope *(Empire State Chapter Soil and Water Conservation Society, 1991)*.

Water quality will be affected by an increased rate of erosion during construction. Sediment loss will vary with changes in runoff. Factors determining potential sediment loss (and appropriate control practices) include slope before and after grading, results of the construction process, and the amount of vegetation re-established on the graded or shaped site. **All disturbed areas MUST be stabilized structurally or vegetatively upon completion of construction activities**.

ADVANTAGES OF LAND GRADING
• Minimizes the amount of erosion from graded areas and cut and/or fill slopes.
• Prepares land for construction purposes.
DISADVANTAGES OF LAND GRADING
• May be difficult on small lots and/or lots with steep slopes.

Surface Roughening

Surface roughening roughens a bare soil surface with horizontal grooves running across the slope, stair-stepping, or tracking with construction equipment (Figure 3.6). This practice is used to ease establishment of vegetation by seed, to reduce stormwater runoff velocity, increase infiltration, reduce erosion, and trap sediment.

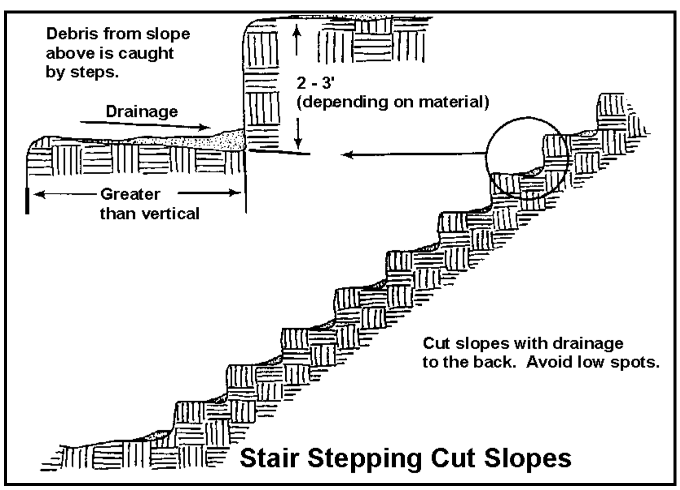

Figure 3.6. Surface roughening details - stair-stepping *(Empire State Chapter Soil & Water Conservation Society, 1991)*.

When and Where to Use Surface Roughening

All slopes, especially those steeper than 3:1 (33%), require surface roughening to facilitate vegetative stabilization.

What to Consider

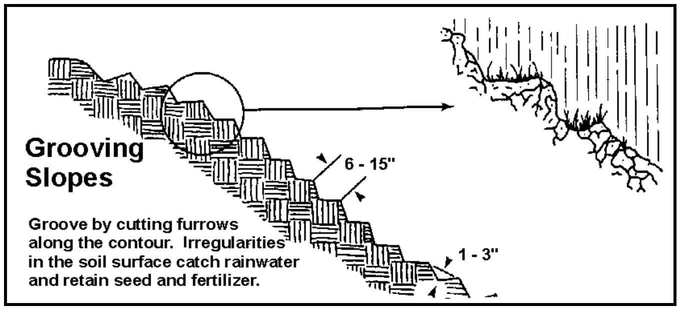

Figure 3.7. Surface roughening details - grooving *(Empire State Chapter Soil & Water Conservation Society, 1991)*.

There are many different ways to roughen soil surfaces. Selecting the best method depends on the type of slope. Steepness, mowing requirements (if any), and a cut or fill slope operation are all factors that need to be considered in selecting a roughening method. A common roughening method on moderate slopes is to run the bulldozer/backhoe up and down the slope so that the treads create horizontal indentations (grooving, Figure 3.7).

ADVANTAGES OF SURFACE ROUGHENING
• Reduce runoff speed and decrease the distance of overland runoff flow. • Hold moisture better than do smooth slopes and minimize sheet and rill erosion.
DISADVANTAGES OF SURFACE ROUGHENING
• May increase cut and fill costs and cause sloughing if excessive water infiltrates the soil.

Temporary Seeding

Temporary seeding is used to reduce erosion and sedimentation on areas that will not be stabilized for a long time or where permanent plant growth is not necessary or appropriate. A short-term cover of fast-growing grasses is seeded on a cleared or disturbed site to keep soils from being carried offsite by stormwater runoff or wind. Seeding can be performed by hydroseeding, hand broadcasting, or installing seeded erosion control mats. Seeded areas can also be covered with erosion control mats to conserve moisture, prevent wash out, and protect seeds from birds and insects (see ***Mulch, Mats & Geotextiles***, page 3-11).

When and Where to Use Temporary Seeding

Temporary seeding should be performed no later than 14 days after the halt of construction activities on all disturbed areas that are likely to be re-disturbed, but not for several weeks or more. This includes denuded areas, cuts, fills, soil stockpiles, sides of sediment basins, and temporary roadbanks. **Temporary seeding should take place as soon as possible after the last land disturbing activity in an area.** It is especially important on critical areas such as dams, dikes, levees, cuts, fills, and denuded or gullied areas.

What to Consider

Proper seed bed preparation and the use of high-quality seed are needed to grow grass for effective erosion control. Soil that has been compacted by heavy equipment may need to be loosened with a rake or tiller. Top-soiling is not necessary for temporary seeding, but it may improve chances for vegetation establishment. Seed bed preparation may also require fertilizer application to make conditions more favorable to plant growth. Proper fertilizer application, seeding mixtures and seeding rates vary depending on site location, soil type, slope, and weather.

It is very important to select appropriate grass species and to time seeding. Seeding native or naturalized grass species will increase the odds for success in establishing vegetation. Native species also tend to have lower maintenance needs because they are adapted to the environmental conditions in the area. The UVI Cooperative Extension Service or USDA Natural Resources Conservation Service (NRCS, formerly the Soil Conservation Service) can supply information on suitable native grasses. Local suppliers, the Cooperative Extension Service, or USDA-NRCS can supply information on best seed mixes and fertilizer and irrigation needs.

Seeded areas on slopes steeper than 4:1 or in sandy, clayey or caliche soils should be covered with mulch or erosion control mats (see ***Mulch, Mats & Geotextiles***, page 3-11) to provide protection from rainfall and to prevent birds from eating the seed. Seeded areas should also be mulched and matted if the weather is excessively dry or if heavy rain is expected before the seed sprouts. Frequent inspections are necessary to ensure that the grass is growing properly and to determine if irrigation is needed. If grass does not grow quickly or thick enough to prevent erosion, the area should be reseeded as soon as possible.

Figure 3.8. Hydroseeding side slopes and outside rim of a sediment basin (*Estate New Hernhut, St. Thomas, 1998*).

Hydroseeding is an erosion control practice used to rapidly stabilize disturbed soils with grasses (Figure 3.8). Hydroseeding equipment is used to uniformly apply a combination of grass seed, water, fertilizer, mulch and tackifier to an area to be seeded. Grass seed, paper fiber mulch, water, and even fertilizer are mixed together in the hydroseeder tank and then sprayed out over the disturbed soil area. This equipment allows rapid stabilization of a site with a minimum amount of labor. DPNR-CZM owns two hydroseeders maintained by the UVI Cooperative Extension Service (CES) that are leased to government agencies and the general public upon completion of an equipment certification workshop. For more information on the DPNR/UVI-CES hydroseeding program, contact CES at (340) 693-1080.

How Effective is Temporary Seeding?

This practice, along with ***Preservation and Protection of Natural Vegetation*** (page 3-3) and ***Permanent Seeding and Planting*** (page 3-10), is most effective in reducing erosion and sedimentation from a construction site, especially in areas where soils are unstable because of their slope, texture, structure, a high water table, or high winds. However, seeding with non-native grasses not adapted to the Virgin Islands climate and soil conditions may not be as effective due to low survival rate and higher maintenance requirements.

Once vegetation is established, its roots hold the soil in place and the vegetation also slows down runoff, increases infiltration, and filters sediments from runoff. However, temporary seeding may not be effective in arid and semi-arid regions (eastern portions of the islands) or during dry seasons (where/when climate prevents fast plant growth). In those areas, mulch, erosion control mats or geotextiles may be more appropriate for the short term.

ADVANTAGES OF TEMPORARY SEEDING
• Is generally inexpensive and easy to do.
• Quickly establishes grass cover when conditions are adequate.
• Provides excellent soil stabilization, provides sediment filtering capability, and is visually pleasing.
• May help reduce costs of maintenance of other erosion controls (i.e., silt fences, sediment traps/basins may need to be cleaned out less often).
• Reduces stormwater runoff rates and volume.
• Hydroseeding has lower labor costs than hand application methods – one person can operate a hydroseeder to apply seed, mulch and fertilizer simultaneously.
• Hydroseeding also applies grass seed more evenly, results in faster germination, produces better grass stands, and provides for easier transportation and storage.
• Improves the appearance of the site.
DISADVANTAGES OF TEMPORARY SEEDING
• Depends on adequate rainfall or irrigation for success, especially prior to establishment.
• May require fertilizing of plants grown on some soils (particularly caliche), which can be more expensive and cause downstream water quality problems.
• Temporary vegetation requires protection from equipment and heavy use once seeded.

Permanent Seeding and Planting

Permanent seeding and planting is the planting of permanent plant cover such as trees, shrubs, vines, grasses or legumes on highly erodible or critically eroding areas, or on disturbed soils at the completion of earth change activities. This practice provides soil stabilization and reduces stormwater runoff and sediment loads to guts and coastal waters by slowing runoff velocity and increasing runoff infiltration. Vegetation also filters sediment and other pollutants, improves wildlife habitat, and enhances the appearance of a site and its property value.

When and Where to Use Permanent Seeding & Planting

Permanent seeding and planting should be used to stabilize all disturbed areas once construction has been completed in that area. Permanent vegetation establishment is especially important on steep slopes and grades, in filter strips, buffer areas, and vegetated swales, and along guts, ponds and coastal areas.

Figure 3.9. A low-maintenance, natural landscape in a dry area (*Estate Nazareth, St. Thomas, 1995*).

What to Consider

It is very important to select appropriate plant species and to carefully time planting. Planting native or naturalized species will increase the odds for success in establishing vegetation. Native species also tend to have lower maintenance needs because they are adapted to local environmental conditions. Many low-maintenance, native plants can be added to the site's landscaping (Figure 3.9). Some good native plants available in local nurseries include wild frangipani, orange man jack, pink cedar, sea grape, lignum vitae, turpentine tree, teyer palm, sabal palm, wild ferns, wild anthurium, and spider lily.

Figure 3.10. Newly planted vetiver hedge *(UVI St. Thomas, 1999)*.

Some exotic plants can also be incorporated into the landscape. Be careful to choose species that won't escape into natural areas and crowd out native plants. Vetiver grass (*Vetiveria zizanioides*) hedges can be planted across slopes (along the contour) to form a living terrace (Figure 3.10). Vetiver is a non-native, non-invasive, clumping grass species. It is used in Africa, India and Southeast Asia to stabilize slopes and channels by trapping sediment behind the grass. Some exotic ornamental plant species that can be used around the home include hibiscus, bougainvillea, oleander, croton, heliconia, ginger, isora, aralia, agave, and non-native palms. Fruit trees and vegetable gardens can also be planted once construction is completed. The UVI Cooperative Extension Service (CES) or USDA Natural Resources Conservation Service (NRCS, formerly the Soil Conservation Service, SCS) can supply information on suitable native and exotic plant species. Local suppliers, CES or USDA-NRCS can supply information on best seed mixes and fertilizer and irrigation needs.

ADVANTAGES OF PERMANENT SEEDING & PLANTING
• Quickly establishes vegetative cover when conditions are adequate.
• Provides excellent soil stabilization and sediment filtering capability.
• Improves stormwater infiltration, reducing stormwater runoff speed and volume.
• Provides a windbreak, shade, privacy barrier, dust filter, and wildlife habitat.
• Improves site appearance and property values.
DISADVANTAGES OF PERMANENT SEEDING & PLANTING
• Depends on adequate rainfall or irrigation for success.
• May require fertilizing of plants grown on some soils (particularly caliche), which can be more expensive and cause downstream water quality problems.
• Permanent vegetation requires protection from equipment and heavy use once seeded.

Mulch, Mats and Geotextiles

Mulching is a temporary soil stabilization or erosion control practice. Mulching uses materials such as cut grass, woodchips, wood fibers, straw, or gravel to cover the soil surface to temporarily stabilize disturbed areas until vegetation is established or construction is completed. Mulching also reduces the speed of stormwater runoff over bare soils. When used together with seeding and planting, mulching can aid in plant establishment by holding seed, fertilizer, and topsoil in place; by helping to retain moisture; by insulating against high temperature, and by protecting seed from birds.

Erosion control mats are materials (straw, coconut, wood, or synthetic fiber) that have been woven into a mat or blanket and are backed with plastic or jute netting. Erosion control mats offer the same benefits as mulch but are more stable and can withstand much higher stormwater velocities than loose mulch. They are used to temporarily stabilize bare soils or slopes during construction when it is difficult to establish temporary vegetation (due to dry, stony, or steep soil conditions). Mats are also used with permanent seeding and planting to help hold soils in place until grass or other plants can become established. Figure 3.10 shows how erosion control mats are used for erosion control in a drainage swale.

Netting is typically made from jute, coconut or other wood fiber, plastic, paper or cotton and can be used to hold mulch onto the ground. Netting can also be used alone to stabilize soils while plants, such as ground covers, become established. However, it does not retain moisture or temperature well.

Other materials, called filter fabrics or ***geotextiles***, are also used for erosion control. These materials are made by weaving or bonding fibers made from synthetic materials such as polyester, nylon, polyvinyl chloride (PVC), or other material. Mats, netting and other filter fabrics are used in areas with steep slopes where loose mulch and seed are vulnerable to being washed away, or where vegetation is difficult to establish.

When and Where to Use Mulch, Mats and Geotextiles

Loose mulch should only be used on fairly level slopes, or in areas that only need short-term stabilization. Erosion control mats or geotextiles are often used alone in areas where temporary seeding cannot be used because of season or soil/slope conditions. Mats can provide immediate, effective erosion control. In critical areas such as drainage swales , channels, or along shorelines, mats or geotextiles can be used to provide channel stabilization. There are many different types of erosion control mats. Erosion control mats can be used for a wide range of slopes and stormwater flow rates. For example, 100% straw mats can be used on slopes up to 3:1 in steepness and 75 feet in length or in low-flow swales (Figure 3.11). Straw/coconut mats can be used on steeper slopes (2:1 - 1:1, depending on length) and medium flow discharge channels. Coconut fiber or synthetic mats provide long term protection on steeper slopes or in high discharge channels. Check the manufacturer's specifications to determine which material is appropriate for a given application.

Figure 3.11. Straw mat used to stabilize seeded slope (*UVI St. Thomas, 1999*).

Geotextiles can be used alone as matting to stabilize flow in channels and swales, to protect seedlings on recently planted slopes, or to protect tidal or drainage banks where moving water may wash out new plantings. When properly anchored, geotextiles can provide stabilization on slopes up to 30-40% (depending upon material type). Geotextiles are also used as separators. For example, filter fabric can be placed between gravel or rip-rap and soil. This "sandwiching" prevents the gravel from being compacted into the underlying soil and prevents the soil underneath the rip-rap from being eroded.

What to Consider

Mulch should be applied to moderate slopes ($<$ 10%) and soils that are not highly erodible. On steep slopes, highly erodible soils, or in swales (see sections on ***Drainage Swales*** and ***Grassed Swales***) erosion control mats or geotextiles should be used and anchored into place with staples (anchoring patterns depend on slope steepness and length and flow rate, see Figure 3.12). On extremely arid sites where grasses cannot survive, native ground covers or shrubs can be planted in jute or coir (coconut fiber) netting. Filter fabric or erosion control mats can also be used for this purpose. Before stabilizing an area, it is important to have all sediment controls installed and for runoff to be diverted away from the area to be planted.

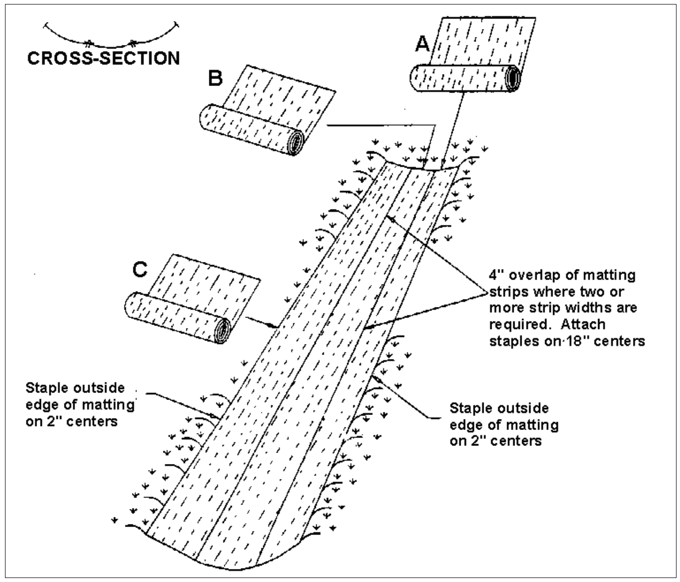

Figure 3.12. An example of erosion control matting of a drainage swale (*Maryland Department of the Environment, 1994*).

Final grading is not necessary before mulching. Mulched areas should be inspected often to find where mulch has been loosened or removed. These areas should be reseeded, if necessary, and the mulch cover replaced immediately.

When selecting erosion control mats or geotextiles, choose an appropriate type for the intended use. Follow manufacturer recommendations or seek advice from the USDA Natural Resources Conservation Service or the UVI Cooperative Extension Service. Areas covered with mats or geotextiles should be inspected regularly to determine if cracks, tears, or breaches have occurred. If so, repairs should be made immediately.

Effective netting and matting requires firm and continuous contact between the fabric and the soil. If there is no contact, the material will not hold the soil in place and erosion will occur underneath it. Matting should be able to withstand stormwater runoff speeds of up to 5 feet per second.

How Effective are Mulch, Mats, and Geotextiles?

Mulch, mats and geotextiles are very effective in reducing erosion and are very cost-effective, as compared to retaining walls or purchasing new top soil. Mulch alone should only be used for temporary protection of the soil surface on fairly level slopes. The useful life of mulch, mats and geotextiles varies according to the material and amount of rainfall, from a minimum of 1 month for mulch to 3 years for geotextiles.

ADVANTAGES OF MULCH, MATS AND GEOTEXTILES
C Provide immediate, effective protection of exposed and/or eroding soils.
C Mulch, mats and geotextiles retain moisture, minimizing the need for watering.
C Organic mulch, mats and netting do not need to be removed because they are biodegradable.
C Mats protect seeds from birds and other animals.
C Mats and geotextiles are less expensive than structural practices and a wide variety are available to match specific needs.
C Are convenient to install.
DISADVANTAGES OF MULCH, MATS AND GEOTEXTILES

- Mulch and/or mats may delay seed germination in some species.
- Mulch can be easily blown or washed away by runoff if not secured.
- Mats are difficult to anchor into stony or compacted clay soils.
- Mats may inadvertently contribute to weed growth, since they hold in moisture.
- Geotextile effectiveness may be reduced significantly if the fabric is not properly selected or installed.
- Many geotextiles are photodegradable and must be protected prior to installation.

Soil Binders/Tackifiers

Soil binders or tackifiers are chemical polymers or emulsions sprayed onto the soil surface to provide soil stabilization. There are many different types of chemical polymers on the market that provide varying degrees of stabilization. Soil polymers are used for temporary erosion control, and are typically applied using hydroseeding equipment, with or with out seed and/or mulch.

When and Where to Use Soil Binders/Tackifiers

Soil binders are often used on extreme slopes and droughty (very dry) soils where it is difficult to establish vegetation. Tackifiers are typically used in conjunction with hydroseeding (see ***Temporary Seeding*** page 3-8) to stabilize soils and hold grass seed and mulch in place until germination and root establishment occurs. Binders and/or tackifiers can also be used to hold loose mulch in place on soils. Some tackifiers and binders can also help to conserve moisture in soils. These chemicals are also effectively used on construction sites for dust suppression.

What to Consider

There are many different types of soil binders and tackifiers available. Some materials are more toxic than others, and some may or may not be biodegradable. The type of material chosen depends on the site's slope and soils, the season and geographic area of the site (for example, whether the site is on the dry east end or wetter north side of an island), the longevity of the material, whether or not seed and/or mulch will be applied with the material, and whether or not it is an acceptable material to be used in the hydroseeding equipment. Products should be carefully investigated. Practice application/installation varies by manufacturer; see manufacturer guidelines for specific installation specifications. The International Erosion Control Association (IECA) website provides a partial list of erosion control product vendors at: www.ieca.org.

ADVANTAGES OF SOIL BINDERS/TACKIFIERS

- Provide short-term stabilization of severe, dry and/or stony slopes that are difficult to vegetate.
- Can provide stabilization for 2 to 18 months, depending on the material and site conditions.
- Are useful for holding seed, mulch and fertilizer in place on steep slopes.
- Aid in conserving soil moisture.
- Provide excellent dust control.
- Some are non-toxic and/or biodegradable.

DISADVANTAGES OF SOIL BINDERS/TACKIFIERS

- Many are not suitable for long term stabilization (over 6 months).
- Some may be toxic or persist in the environment.
- Some forms may clog hydroseeding equipment used to apply material.
- Do not prevent mass-wasting (landslides).

Soil Retaining Walls

Soil retaining walls are structures used to hold loose or unstable soil firmly in place. For example, soil tie backs and retaining walls can be used during excavation to prevent cave-ins and accidents, but they also are excellent permanent erosion control practices that retain soils and slopes to prevent them from moving. There are many different types of soil retaining structures that can be used. Some basic ones include:

- **Skeleton Sheeting:** Skeleton sheeting is the least expensive soil retaining system. It requires the soil to be cohesive (like clay). Construction grade lumber is used to brace the excavated face of the slope. This is a temporary practice.

- **Continuous Sheeting:** Continuous sheeting uses a material such as steel, concrete or wood to cover the face of the slope in a continuous manner. Struts and boards are placed along the slope to provide continuous support to the slope face.

- **Permanent Retaining Walls:** Permanent retaining walls may be necessary to provide support to the slope after construction is completed. Concrete, stone, or wood (horizontal telephone poles, etc.) retaining walls can be built and left in place.

When and Where to Use Retaining Walls

Soil retaining walls should be used where other methods of soil retention are not practical. They are especially applicable in the Virgin Islands to retain cut slopes along road and drive ways, parking lots, building sites, and other cut and fill areas where slopes or soils are not suitable for vegetative stabilization (Figure 3.13).

Figure 3.13. Rock retaining walls installed to stabilize base of steep slope above a sediment basin (*Estate New Hernhut, St. Thomas, 2000*).

What to Consider

Soil retaining walls are used for both erosion control and safety purposes. Retaining wall design must address foundation bearing capacity, sliding, overturning, drainage, and loading systems. These are complex systems and all but the smallest retaining walls should be designed by a licensed engineer.

ADVANTAGES OF RETAINING WALLS
• Provide safety to workers. • Can be used as either temporary or permanent structures (depending upon design). • Are exceptionally effective in preventing erosion and landsliding from unstable slopes and soils that cannot be stabilized using conventional methods.
DISADVANTAGES OF RETAINING WALLS
• Require the expertise of a professional engineer for all but the smallest retaining walls. • May be expensive to design and install, depending upon site constraints, size and material used.

Soil Bioengineering

Soil bioengineering combines mechanical, biological and ecological concepts to stop and prevent shallow slope failures (or landslides) and erosion. The soil bioengineering practices discussed in this section can be divided into two general categories: living and non-living.

The *living approach* uses live plants to provide soil reinforcement and prevent surface erosion. Vegetated rock gabions and vegetated rock walls use porous structures with openings that plant cuttings are inserted into. The rock provides immediate resistance to sliding, erosion and washout. As the vegetation becomes established, roots bind the slope together into a unified mass.

Non-living approaches use rigid structures, like gravity retaining walls and rock buttresses to retain soil. Plants can be used in conjunction with these structures to create vegetated structures. The plants enhance the structures and help to reduce surface erosion.

When and Where to Use Soil Bioengineering

Soil bioengineering techniques are generally appropriate for immediate protection of slopes against surface erosion and shallow mass wasting (landslides), and provide cut and fill slope stabilization, earth embankment protection, and small gully repair treatment. These techniques are used when vegetative stabilization alone is not feasible. The use of soil bioengineering practices is limited on rocky or gravelly slopes that lack sufficient soil or moisture to support plant growth. Soil-restrictive layers, such as hardpans, may also prevent root growth.

What to Consider

Soil bioengineering is often a useful alternative for small, highly sensitive, or steep sites where the use of machinery is not feasible and hand labor is a necessity. However, rapid vegetative establishment may be difficult on extremely steep slopes. The soil bioengineering system selected should fit the site. The slope, soils, geology, hydrology and existing vegetation should be taken into account when designing the system. Existing vegetation should be retained whenever possible to provide protection against surface erosion and shallow slope failures. This vegetation can also be a source of cuttings to use in the practice. Native plant species that root easily should be used (turpentine tree (*Bursera simaruva*), white manjack (*Cordia sulcata*), hog plum (*Spondias mombin*), orchids, bromeliads, anthuriums – see USDA-NRCS *Common Planting Table*) or contact the USDA Natural Resources Conservation Service, UVI Cooperative Extension Service, or the V.I. Department of Agriculture for information on appropriate plants. The following soil bioengineering practices are most appropriate for conditions in the

Virgin Islands, although other practices may be applicable (consult the USDA-NRCS for further information on soil bioengineering practices).

Vegetated Rock Gabions: Rock gabions are rectangular baskets made from triple-twisted, hexagonal mesh of heavily galvanized steel wire placed in position, wired to adjoining gabion baskets, filled with large stone, and then folded shut and wired at the ends and sides. Live branches (or seeds) are then placed on each consecutive layer between the rock-filled baskets. These branches will take root inside the gabion basket and in the soil behind the baskets, binding the gabions to the slope (Figure 3.14).

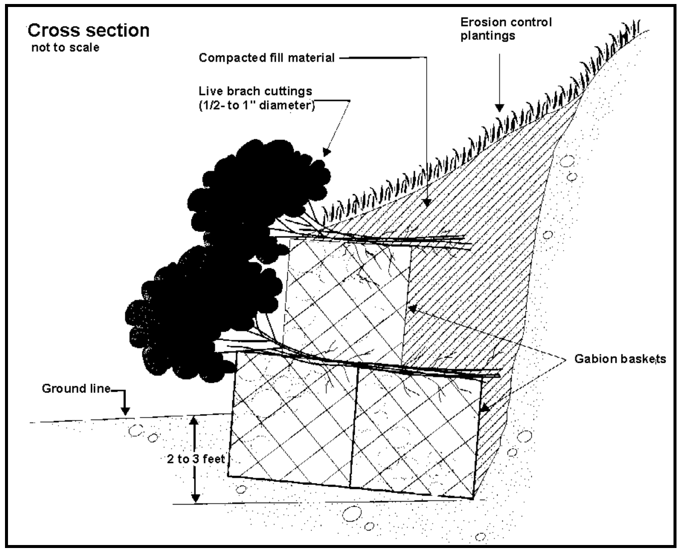

Figure 3.14. Vegetated rock gabion details (*USDA-SCS, 1992*). (Note: rooted/leafed condition of the living plant material is not representative of the time of installation).

This practice is used at the base of a slope where a low wall may be needed to stabilize the toe of the slope and reduce its steepness. It is not designed to resist large, lateral earth stresses. Vegetated rock gabions should be built a maximum of 5 feet in height, overall, including the excavation needed for a stable foundation. This practice is useful where space is limited and a more vertical structure is needed.

Vegetated Rock Wall: A vegetated rock wall is a combination of rock and live branch cuttings used to stabilize and protect the toe of steep slopes. Vegetated rock walls are different from retaining walls because they are placed against relatively undisturbed earth and are not intended to resist large lateral earth pressures (Figure 3.15). Vegetated rock walls are used where a low wall may be needed to stabilize the toe of the slope and reduce its steepness. This practice is especially useful where space is limited and natural rock is available.

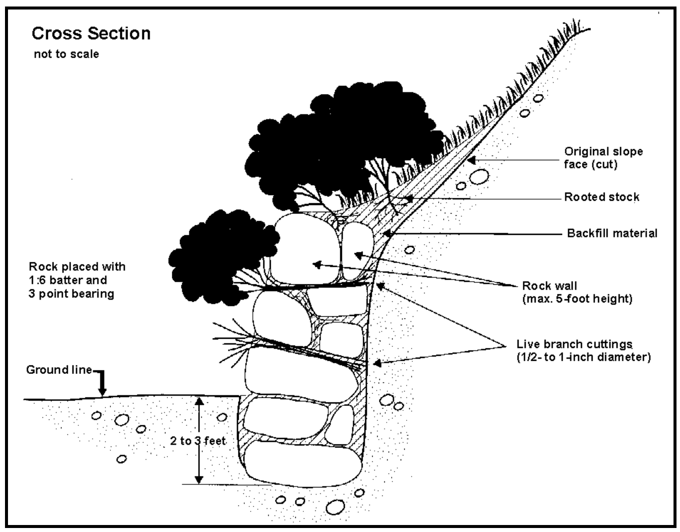

Figure 3.15. Vegetated rock wall details *(USDA-SCS, 1992*). (Note: Rooted/leafed condition of the living plant material is not representative of the time of installation).

Low wall/slope face plantings: This practice consists of a low retaining wall placed at the foot of a slope so that the slope can be flattened for planting. Vegetation established on the face of the slope protects against both surface erosion and shallow land slides (Figure 3.16). Different types of retaining walls can be used as low walls, the simplest being a gravity wall that resists lateral earth movement with its weight or mass. This includes masonry and concrete walls as well as reinforced earth or geogrid walls.

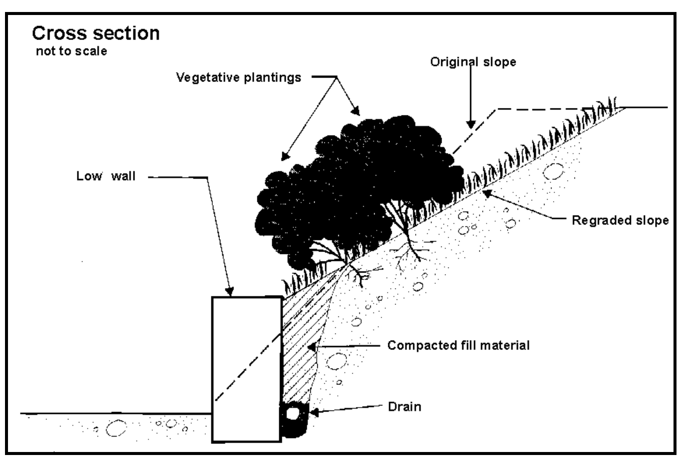

Figure 3.16. A low wall with plantings established on the slope above (*USDA-SCS, 1992*).

Tiered wall/bench plantings: An alternative to a low wall with a face planting is a tiered retaining wall, or terrace, system. This alternative effectively allows vegetation to be planted on slopes that would otherwise be too steep. Shrubs and trees planted on the benches screen the structure behind them and lend a more natural appearance while their roots protect the benches. Virtually any type of retaining structure can be used in a tiered wall system. A tiered wall system allows plant propagation on steep slopes and embankments.

ADVANTAGES OF SOIL BIOENGINEERING
• Soil bioengineering systems generally require minimal access for equipment and workers and cause relatively minor site disturbance during installation.
• Combined slope protection systems can be more cost-effective than the use of either vegetative treatments or structural practices alone, especially when using indigenous plant material.
• Are exceptionally effective in preventing erosion and landsliding from unstable slopes and soils that cannot be stabilized using vegetative methods alone.
• Can withstand heavy rainfalls immediately after installation.
• Is self-repairing by regeneration and growth once vegetation is established.
• Requires little maintenance.
DISADVANTAGES OF SOIL BIOENGINEERING
C May be expensive to design and install, depending upon site constraints, size and materials used.
C Depending on the species of plant material used, may be difficult to get adequate vegetation establishment.
C Requires periodic inspections until vegetation is established.

3.3 STRUCTURAL PRACTICES

Structural practices are used in sediment and erosion control to divert stormwater runoff away from exposed areas, to convey runoff, to prevent sediment from moving offsite, and to reduce the erosive forces of runoff waters. These controls can be either permanent or temporary practices, depending on how they are used. The structural practices described in this chapter include:

- Perimeter Dike/Swale
- Drainage Swale
- Temporary Storm Drain Diversion
- Silt Fence
- Gravel/Stone Filter Berm
- Stabilized Construction Entrance
- Check Dams/Triangular Dikes/Berms
- Sediment Traps
- Temporary Sediment Basin
- Storm Drain Inlet Protection
- Outlet Protection
- Gabion Inflow Protection

Temporary structural practices are used during construction to prevent sediment from moving offsite. The length of time that temporary practices are functioning varies since the sediment control strategy may change as construction activities progress. Permanent structural practices are used to convey stormwater runoff to a safe outlet away from erodible areas and/or to treat stormwater runoff to remove sediment. Permanent structural practices remain in place and continue to be used after construction is completed.

In general, structural sediment control practices are less effective that erosion control – i.e., it is much easier and more cost effective to keep the soil in place than it is to attempt to remove soil from stormwater. This is particularly true in the Virgin Islands since predominant soil types have high clay content. Clays are particularly difficult to remove from stormwater because of their very small particle size and propensity to stay suspended in stormwater for long time periods. **Most practices, such as silt fences, sediment traps, and gravel/stone filter berms, are not effective in removing clays from stormwater runoff.**

Perimeter Dike/Swale

A perimeter dike is a ridge of compacted soil. A swale is an excavated trench or channel. These two practices are used together to prevent stormwater runoff generated outside a construction site from entering and crossing the site and eroding bare soils or disturbed areas. Perimeter dikes and swales reduce the volume and speed of runoff on a site and channel stormwater to a stabilized discharge area or sediment trap (see sections on ***Sediment Traps*** and ***Temporary Sediment Basins***). The dike is built using the soil dug from the adjoining swale placed along the perimeter of the construction site or disturbed area. Dikes and swales can be either temporary or permanent stormwater control structures.

When and Where to Use Perimeter Dikes/Swales

Perimeter dikes/swales are generally built around the edge of the site before any earth change activity takes place. They may also be used to protect existing buildings, topsoil stockpiles, or other small areas that have not yet been fully stabilized. They are appropriate for sites less than or equal to two (2) acres in size.

What to Consider

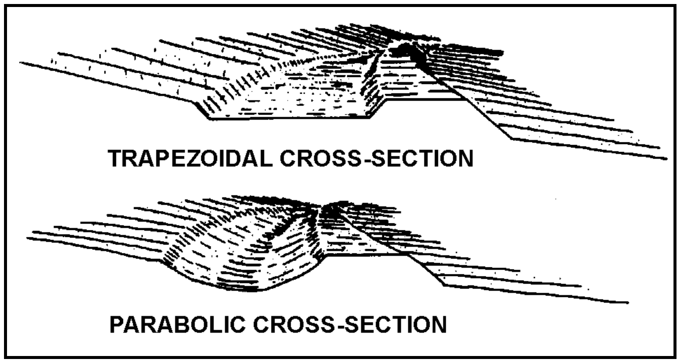

Figure 3.17. Examples of perimeter dikes/swales (*U.S. EPA, 1992*).

If temporary dikes and swales are to remain in place longer than 10 days they must be stabilized using either vegetation, erosion control matting, geotextile, rip-rap, or some other material. The distance from the bottom of the swale to the top of the dike should not be less than 18 inches. The bottom width of the dike and width of the swale should be a minimum of three (3) feet. The maximum allowable grade should **NOT** exceed 20 percent. Figure 3.17 shows two different types of perimeter dike/swale.

Stormwater runoff diverted by a perimeter dike/swale should be directed to an appropriate area for sediment removal (a sediment trap, basin, or filter area: see sections on ***Sediment Traps, Sediment Basins***, and ***Filter Strips***). Temporary perimeter dikes/swales may stay in place as long as 12 to 18 months, provided they are properly stabilized and inspected and maintained on a regular basis. They should remain in place until the area they were built to protect is permanently stabilized. Temporary and permanent control practices should be inspected once a week on a regular schedule and after every large or intense rain storm. Repairs should be made promptly.

ADVANTAGES OF PERIMETER DIKES/SWALES
• Are easy to install and are effective for channeling stormwater runoff away from areas subject to erosion.
• Can handle flows from large drainage areas.
• Are inexpensive because they use materials and equipment normally found onsite.
DISADVANTAGES OF PERIMETER DIKES/SWALES
• Can cause erosion and sediment transport downstream if they are not properly designed, built or stabilized.
• If water flows too fast, vegetation may be difficult to establish – slopes less than 20% are recommended.
• Require frequent maintenance, inspections and repairs.

Drainage Swale

A drainage swale is a channel excavated and located to convey runoff to a desired location. It typically has a lining of vegetation, erosion control matting, geotextile, rip-rap, concrete, or some other material.

When and Where to Use Drainage Swales

A drainage swale is used to route stormwater around or through an area without causing erosion. A swale can convey runoff from an undisturbed area surrounding the construction site to a stabilized outlet, where runoff is discharged at non-erosive rates. It can also be used to divert sediment-laden runoff away from a disturbed area, across disturbed areas to shorten overland flow distances, or from the base of a slope to a sediment trapping device.

What to Consider

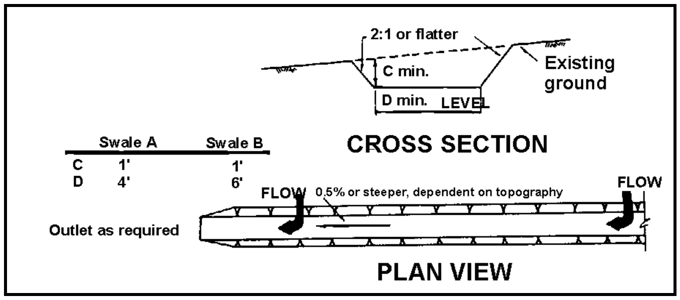

Figure 3.18. Temporary swale design example (*Empire State Chapter, Soil and Water Conservation Society, 1997*).

Swales should be lined with grass, sod, erosion control mats, geotextiles, rip-rap, or concrete. The type of liner used is dependent on the volume and velocity of the stormwater runoff to be conveyed. The swale should have a positive grade and should have no dips or low points where stormwater can collect. Figure 3.18 shows an example of swale design and Table 3.1 provides an example of how to design two different sized drainage swales.

Table 3.1. Example drainage swale designs (*Empire State Chapter, Soil and Water Conservation Society, 1997*).

	Swale A	Swale B
Maximum Drainage Area Contributing Runoff	< 5 Acres	5 - 10 Acres
Bottom Width of Flow Channel	4 feet	6 feet
Depth of Flow Channel	1 foot	1 foot
Side Slopes	2:1 (50% or 26°)or flatter	2:1 or flatter
Grade	0.5% minimum 20% maximum	0.5% minimum 20% maximum

ADVANTAGES OF DRAINAGE SWALES
• Swale excavation can be easily performed with earth moving equipment. • Can transport large volumes of runoff.
DISADVANTAGES OF DRAINAGE SWALES
• Stabilization and design costs can make construction expensive. • Effective use is restricted to areas with relatively flat slopes (< 8% for most designs).

Temporary Storm Drain Diversion

A temporary storm drain diversion is a pipe that redirects an existing storm drain system or outfall channel so that it discharges into a sediment trap or basin.

When and Where to Use Temporary Storm Drain Diversions

Storm drain diversions should be used to temporarily divert stormwater runoff flow going to a permanent outfall. This diverted flow should be directed to a sediment trapping device (see ***Sediment Traps*** or ***Temporary Sediment Basins*** section). A temporary storm drain diversion should be used for as long as the area draining to the storm drain remains disturbed.

What to Consider

Since the existing storm drain system will be modified, careful consideration needs to be given to the pipe configuration and the resulting impact of installation. The temporary diversions will need to be removed once construction is completed and the original storm drain system is restored. Therefore, appropriate restoration measures should be taken, such as flushing the storm drain before removing the sediment trapping device, and stabilizing the outfall and restoring grades.

ADVANTAGES OF TEMPORARY STORM DRAIN DIVERSIONS
• Requires little maintenance once installed.
DISADVANTAGES OF TEMPORARY STORM DRAIN DIVERSIONS
• Disturbs existing storm drain patterns.

Silt Fence

A silt fence, or filter fabric fence, is a temporary practice for sediment control. A silt fence is made of geotextile or filter fabric stretched across wood posts, rebar or a wire support fence. The lower edge of the material is vertically trenched into the ground and covered by backfill. Silt fences are most effective for removing sediment from overland flow. They reduce sediment loads entering receiving waters. They are also used to catch wind blown sand and to create an anchor for sand dune creation. Along with the typical wooden post and filter fabric method, there are several variations of filter fabric fence installation including fencing that can be purchased with pre-sewn pockets for use with steel rebar fence posts. ***(Use of steel rebar for fence posts is recommended in the Virgin Islands, especially on slopes greater than 20% or in stony or clayey soils).***

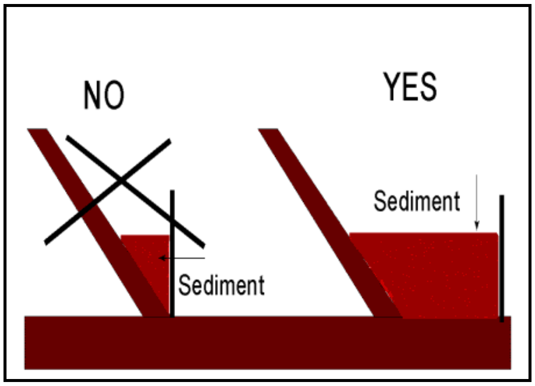

Figure 3.19. Poor silt fence placement (left) vs. proper silt fence placement (right) (*Fifield, 1996*).

When and Where to Use Silt Fences

Silt fences are the most widely and most incorrectly used sediment control practice in the Virgin Islands.

Silt fences should only be used to detain sediment on small construction sites, such as individual home sites. Silt fences should be installed **prior to** earth change activities. The fence should be placed away from the bottom of the slope (to increase holding capacity), along a line of uniform elevation perpendicular to the direction of flow (Figure 3.19). Silt fence material **MUST** be trenched into the ground to work properly (Figure 3.20). Fencing can also be placed across the direction of stormwater flow at the outer boundary of the work area. **Silt fences should NEVER be installed in guts or swales.**

Figure 3.20. Properly installed reinforced silt fence - note trenching, wire mesh and steel bars *(Estate Caret Bay, St. Thomas, 1999)*.

Silt fences used on slopes greater than 20% (5:1 or , or installed in rocky or clayey soils, should use $^3/_8$" - ½" steel rebar stakes instead of wooden posts (Figure 3.21). Silt fences installed on slopes greater than 40% should use $^3/_8$" - ½" steel rebar and wire mesh backing to prevent the fence from being knocked down by heavy stormwater flows. Double the height of the silt fence on slopes steeper than 1:1 or with a greater than recommended slope length (see Table 3.2). Attach the top and bottom of the second layer of geotextile to the rebar and wire mesh so that it overlaps the first layer by 6 inches. Staple the two layers together.

Figure 3.21. Properly installed silt fence (*Estate St. George's Hill, St. Croix, 1998*).

What to Consider

A silt fence is **NOT** appropriate for controlling runoff from a large area (greater than 5 acres). However, this type of fence is much more effective than a straw bale barrier if properly installed and maintained. (Straw bale barriers are **NOT** recommended for use in the Virgin Islands). Silt fences **MUST** be anchored and trenched into the ground or else they will fail. They should always be used in combination with other erosion and sediment control practices, such as temporary seeding, perimeter dikes and swales, drainage swales, sediment traps, etc. **The area below a silt fence should be undisturbed ground.**

The effective life span for a silt fence depends on the material and maintenance. Silt fences require frequent inspection and prompt maintenance to maintain effectiveness. The fence should be inspected after each rainfall. Check for areas where runoff has eroded a channel beneath the fence, or where the fence has sagged or collapsed from runoff flowing over the top. Remove sediment when it is one-third to one-half the height of the fence, or after each storm. (Accumulated sediment can be used for landscaping purposes once construction is completed.) Table 3.2 lists maximum **slope lengths** (distance down-slope between silt fences) for a silt fence depending upon steepness.

Table 3.2. Maximum allowable slope lengths contributing runoff to a silt fence (*Empire State Chapter, Soil and Water Conservation Society, 1997*).

Slope Steepness	Maximum Slope Length (feet)
2:1 (50% or ~26°)	50
3:1 (33% or ~19°)	75
4:1 (25% or ~14°)	125
5:1 (20% or ~11°)	175
Flatter than 5:1	200

Maximum drainage area for overland flow to a silt fence should not exceed ½ acre per 100 feet of fence. Also, **do not** use silt fences to retain sediment from concentrated stormwater flow (such as in a channel, gully, gut or other drainage way), the material is not designed and manufactured to withstand the force of concentrated flows.

ADVANTAGES OF SILT FENCING

- Reduces the speed of stormwater runoff and removes some sediment from runoff, protecting downstream areas from sedimentation.
- Is inexpensive and easy to install.
- Is suitable for smaller developments (such as individual home sites or those less than 5 acres).
- Requires minimal clearing and grubbing for installation.

DISADVANTAGES OF SILT FENCING

C Is not suitable for larger developments (greater than 5 acres).
C Un-reinforced (no steel rebar, wire netting) silt fences are not suitable for slopes greater than 20%.
C Fences with wood stakes are difficult to install in stony or clayey soils - use steel rebar stakes instead.
C **WILL FAIL IF IT IS NOT PROPERLY ANCHORED AND TRENCHED INTO THE GROUND!**
C Requires frequent inspection and maintenance to ensure effectiveness.

Gravel/Stone Filter Berm

A gravel, stone or rock berm is a temporary barrier of loose gravel, stone, or rock built across the bottom of a slope to slow runoff from leaving a site. They can also be used to divert flow from an exposed traffic area. These berms can also be used for directing runoff from a right-of-way to a stabilized outlet.

When and Where to Use Filter Berms

Gravel or stone filter berms are used where roads and other rights-of-way under construction accommodate vehicular traffic. They are meant for use in areas with gentle slopes. They also may be used at traffic areas within a construction site. **Berms should be used in conjunction with other temporary sediment control practices, such as diversion dikes and swales, drainage swales, silt fences, temporary seeding, and/or sediment traps.**

What to Consider

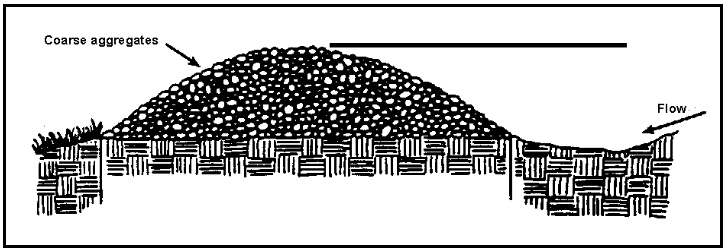

Figure 3.22. Example of a gravel filter berm (*U.S. EPA, 1992*).

Berm spacing depends on the steepness of the slope – berms should be placed closer together as the slope increases. The berm should be inspected regularly after each rainfall, or if breached by construction or other vehicles. All needed repairs should be performed immediately. Accumulated sediment should be removed and properly disposed of and the geotextile or filter material replaced, as necessary (Figure 3.22).

ADVANTAGES OF FILTER BERMS
• Reduce the speed of stormwater runoff.
• Berms are fairly inexpensive and easy to install, and work well on slopes up to 40%.
DISADVANTAGES OF FILTER BERMS
• Have a limited life span.
• Can be difficult to maintain due to clogging with mud.
• Frequent inspection and maintenance is necessary to ensure effectiveness.

Stabilized Construction Entrance

A stabilized construction entrance is a section of the construction road adjacent to a paved road that is stabilized with geotextile and large stone or gravel. A stabilized construction entrance is designed to reduce the amount of soil tracked off of the construction site by vehicles leaving the site. The rough surface of the stone or gravel shakes and pulls the soil off of vehicle tires as they drive over the entrance. The stone also reduces erosion and rutting on the portion of the road that it is installed on by protecting the soil below. Filter fabric or geotextile separates the stone from the underlying soil, preventing the stone from being ground into the soil. The fabric also reduces rutting caused by vehicle tires by spreading the weight of the vehicles over a larger soil area than the tire width.

When and Where to Use Stabilized Construction Entrances

A stabilized construction entrance should be installed at every point where traffic enters or leaves a construction site **before** construction begins on the site. For individual home sites, the construction entrance should be located where the permanent driveway will be sited. Stabilized construction entrances should not be used on existing pavement.

What to Consider

Stabilized construction entrances should be wide and long enough so that the largest construction vehicle will fit in the entrance with overlap available. A good rule of thumb is for the entrance to be a minimum of 50 feet long (30 feet for an individual home site) and 10 feet wide with a flare at the existing road to provide turning radius. Stone, rock or gravel (2" - 3") should be placed at least 6 inches deep on top of geotextile over the length and width of the entrance (Figure 3.23).

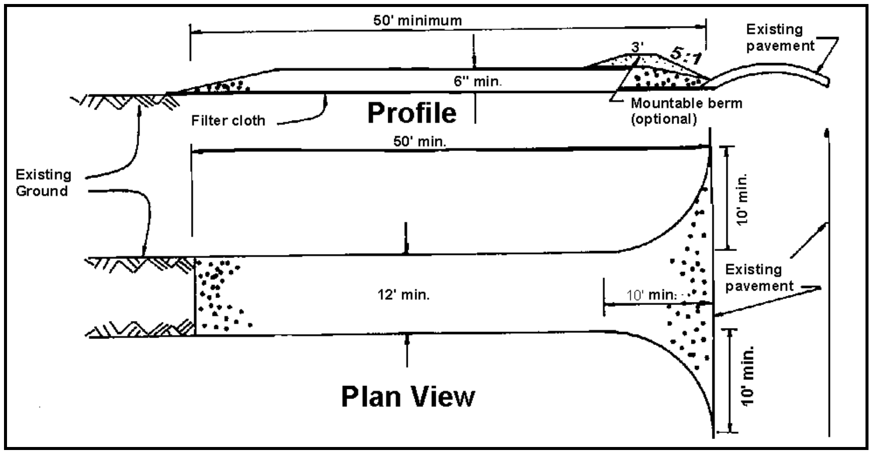

Figure 3.23. Stabilized construction entrance design *(Empire State Chapter, Soil and Water Conservation Society, 1997)*.

ADVANTAGES OF STABILIZED CONSTRUCTION ENTRANCES
• Are very effective in reducing the amount of soil tracked off of a construction site.
• Can improve the appearance of the construction site from the public's point of view.
DISADVANTAGES OF STABILIZED CONSTRUCTION ENTRANCES
• Only work if they are installed at every location where traffic leaves and enters the site.
• Cannot always remove all of the soil tracked off of disturbed areas by vehicles.
• Stone may have to be added to maintain effectiveness.

Check Dams/Triangular Dikes/Berms

A check dam is a small, temporary or permanent dam constructed across a drainage ditch, swale, or channel to reduce the speed of concentrated flows. Reduced runoff speed reduces erosion and gullying in the channel and allows sediments to settle out.

When and Where to Use Check Dams

A check dam should be installed in steeply sloped swales or channels, or in swales where adequate vegetation cannot be established. Check dams limit erosion by reducing flow in small open channels that are degrading or subject to erosion. A check dam may be built from stone, rip-rap, pea gravel-filled sand bags, or manufactured pervious berms or barriers such as a Triangular Silt Dike™ (Figure 3.24), EnviroBerm®, Geo-Ridge® berm, coir (coconut fiber) rolls or "logs," or other similar product.. **Check dams should NOT be built in streams or guts.** They block normal streamflow, altering drainage patterns, and can lead to channel bypass and dramatically increased erosion.

Figure 3.24. Installation of a triangular dike as a check dam in a drainage swale *(Estate St. George's Hill, St. Croix, 1998*).

What to Consider

Check dams should be used only in small open channels that will not be overtopped by flow once the dams are built. The maximum drainage area above the check dam should not be larger than two (2) acres. The center section of the check dam should be lower than the edges, and should not be higher than two (2) feet. Check dam side slopes should be 2:1 or flatter. Dams should be spaced so that the toe of the upstream dam is at the same elevation as the top of the downstream dam (Figure 3.24).

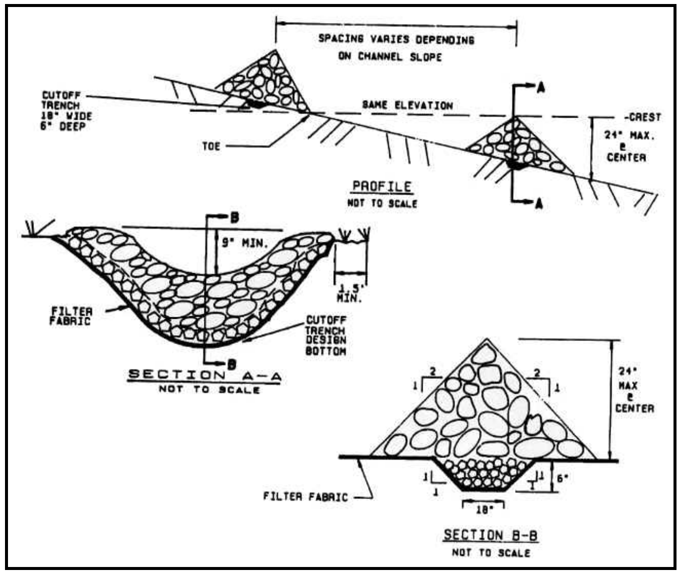

Figure 3.25. Check dam design example *(Empire State Chapter, Soil and Water Conservation Society, 1997*).

After each significant rainfall, check dams should be inspected for sediment and debris accumulation. Sediment should be removed when it reaches one half the original dam height. Check for erosion at edges and repair promptly. After construction is complete, all stone and rip-rap should be removed if vegetative erosion controls will be used for permanent stabilization. It is important to know expected erosion rates and runoff flow rate for the swale or channel in which this practice is to be installed. Contact DPNR's Division of Environmental Protection, USDA Natural Resources Conservation Service, the UVI Cooperative Extension Service, or a licensed engineer for assistance in designing this practice.

ADVANTAGES OF CHECK DAMS
• Are inexpensive and easy to install.
• May be used permanently if designed properly.
• Allow a high proportion of sediment in stormwater runoff to settle out.
• Reduce velocity and may provide water aeration.
• May be used where it is not possible to divert runoff flow or otherwise stabilize the channel.
DISADVANTAGES OF CHECK DAMS
• May kill grass linings in channels if the water level remains high after it rains or if there is significant sedimentation.
• Can reduce the hydraulic capacity of the channel.
• May create turbulence that can erode channel banks.

Sediment Traps

A sediment trap is built by excavating a pond or by installing an earthen embankment across a low area or drainage swale. An outlet or spillway from the trap is built using large stones or aggregate to slow the release of stormwater runoff. Sediment traps are designed to retain runoff long enough to allow most of the sediment to settle out. There are six basic types of sediment traps: pipe outlet traps, grass outlet traps, storm inlet traps, swale traps, stone outlet traps, and rip-rap outlet traps.

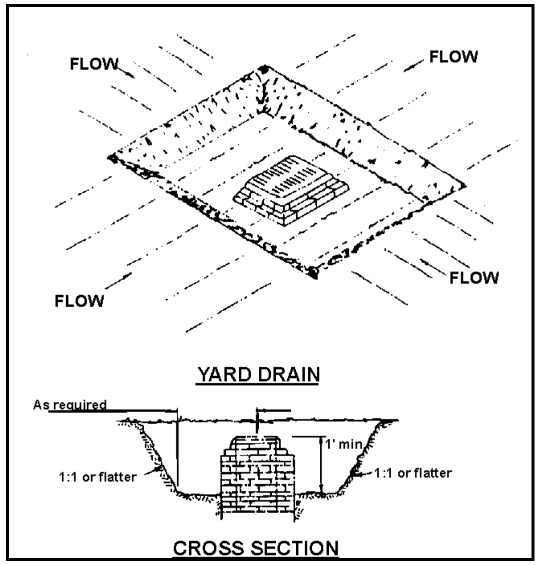

Figure 3.26. Storm inlet sediment trap design (Empire State Soil and Water Conservation Society, 1991).

When and Where to Use Sediment Traps

A temporary sediment trap should be used in conjunction with other temporary practices, such as gravel construction entrances, temporary seeding, silt fences, and diversion dikes, swales, or channels. Sediment traps are suitable for small drainage areas and should be installed at stormwater discharge points from a disturbed area. Pipe, stone and grass outlet sediment traps can handle maximum drainage areas of 5 acres or less; storm inlet traps can handle 3 acres or less; swale traps can handle 2 acres or less; and rip-rap outlet traps can handle 10-15 acres. Sediment traps should **NOT** be installed in guts or used to artificially break up a natural drainage area into smaller sections where a larger device (sediment basin) would be more appropriate. Figures 3.26 to 3.29 show the different types of outlets that can be used with sediment traps. Larger drainage areas require larger sediment traps, and larger traps require more detailed engineering design.

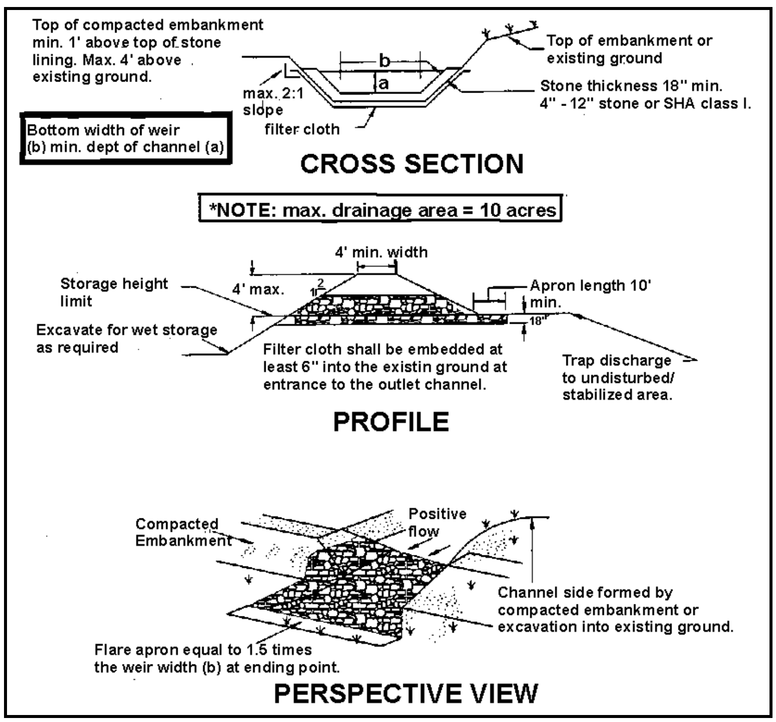

Figure 3.27. Rip-rap outlet sediment trap example *(Maryland Department of the Environment, 1994*).

What to Consider

The sediment trap should be large enough to allow soil particles to settle out of stormwater and should have enough capacity to store collected sediment until it is removed. The volume of sediment storage that the sediment trap provides depends upon the amount and intensity of expected rainfall and on estimated quantities of sediment in stormwater runoff. However, storage capacity should allow for an average of 3600 cubic feet per acre of drainage area contributing stormwater to the trap. This sizing is used in areas where the soils have high clay contents in order to allow for greater settling of fine particles. Due to the predominance of clayey soils in the Virgin Islands, sizing basins to 3600 ft^3 per acre of drainage area will allow for greater sediment removal through longer retention of sediment-laden stormwater. However, larger sediment traps need more detailed engineering design and may not be practical for small sites.

Sediment traps should be installed **prior** to grading or filling, and they must be located at least 20 feet away from an existing building foundation. Sediment trap embankment height should not exceed 5 feet and should have a minimum 4 foot wide top and side slopes of 2:1 or flatter. The trap embankment should be compacted during construction. The sediment trap outlet should be designed so that sediment does not leave the trap and so that erosion at or below the outlet does not occur. Sediment traps must outlet water onto stabilized (preferably undisturbed) ground, or into a stabilized channel, drainage, or storm drain system (Maryland Department of the Environment, 1994). Contact DPNR's Division of Environmental Protection, USDA Natural Resources Conservation Service, the UVI Cooperative Extension Service, or a licensed engineer for assistance in designing this practice.

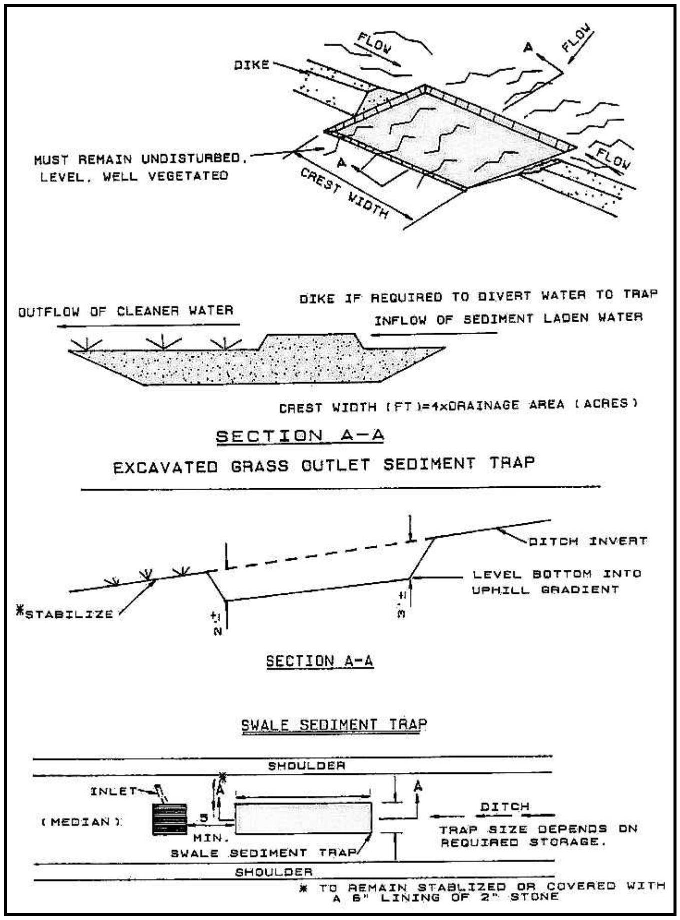

Figure 3.28. Grass outlet and swale outlet sediment trap designs (*Empire State Chapter, Soil and Water Conservation Society, 1997*).

The effective life of a sediment trap depends on proper maintenance. The trap should be easily accessible for regular maintenance and sediment removal. Traps should be inspected after each rainfall and cleaned when one-third (⅓) to one-half (½) the design volume has been filled with sediment. The trap should continue to be used and maintained until the site is permanently stabilized by vegetation and other permanent practices. After completion of construction and site stabilization, all sediment traps should be removed and the trap areas should be graded and vegetatively stabilized.

ADVANTAGES OF SEDIMENT TRAPS
• Protect downstream areas from sedimentation.
• Are relatively inexpensive and easy to install.
• Are suitable for individual home sites or smaller developments (up to 10 acres, depending upon the type of sediment trap (see Appendix B).
DISADVANTAGES OF SEDIMENT TRAPS
C Are not suitable for large developments or steep slopes.
C Are only effective if properly maintained.
C Will not remove very fine silts and clays from stormwater runoff.
C Must be removed after construction and stabilization are completed, unless converted to a permanent retention basin (see Chapter 4).

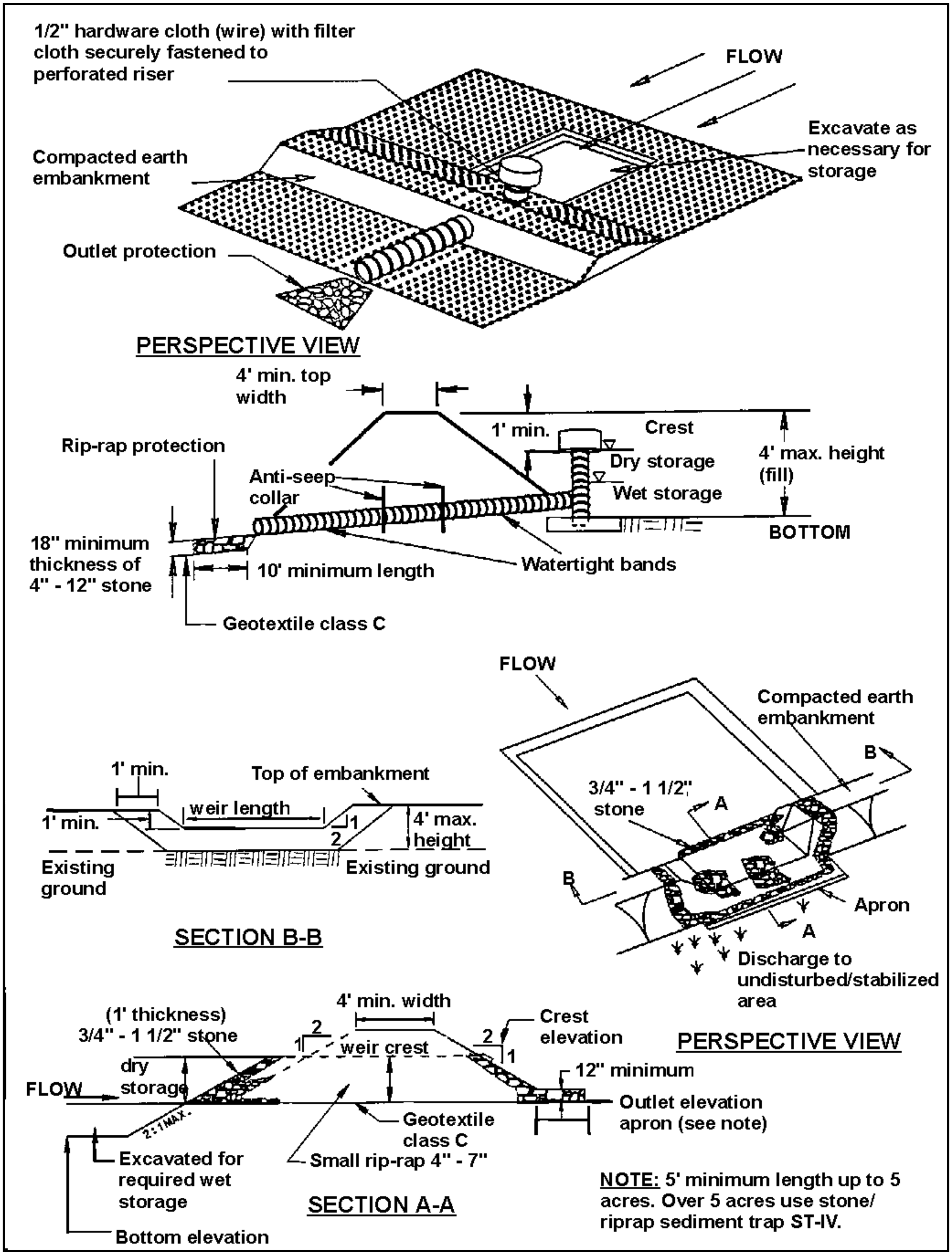

Figure 3.29. Examples of pipe and stone outlet sediment traps *(Maryland Department of the Environment, 1994)*.

Temporary Sediment Basin

A temporary sediment basin is a settling pond with a controlled stormwater release structure used to collect and store sediment produced by construction activities. A sediment basin can be constructed by excavation and/or by placing an earthen embankment across a low area or drainage swale or channel. Sediment basins can be designed to maintain a permanent pool or to drain completely dry. The basin detains sediment-laden runoff from larger drainage areas long enough to allow most of the sediment to settle out.

The pond has a riser and pipe outlet with a gravel outlet or spillway to slow the release of runoff and provide some sediment filtration. By removing sediment, the basin helps prevent clogging of offsite conveyance systems and sediment-loading of receiving waters.

When and Where to Use Temporary Sediment Basins

Temporary sediment basins are usually designed for disturbed areas larger than 5 acres. A sediment basin should be installed before clearing and grading is undertaken. It should **NOT** be built in a stream or gut. The creation of a dam at these sites may result in destruction of aquatic and moist forest habitats and flooding may result from dam failure. A temporary sediment basin should only be used at sites where there is sufficient space and appropriate topography. A temporary sediment basin used in combination with other control practices such as temporary seeding, diversion dikes and swales, drainage swales, and/or mulching and matting is especially effective in removing sediment.

What to Consider

The pond area in a temporary sediment basin should be large enough to hold runoff long enough for sediment to settle out. Sufficient space should be allowed for collected sediments. Sediment trapping efficiency is improved by providing the maximum surface area possible. Because finer silts and clays may not settle out completely, additional erosion control measures should be used to minimize release of fine silt. Runoff should enter the basin as far from the outlet as possible to provide maximum retention time (i.e., the flow path, or length of flow in the sediment basin should be maximized. Appendix B has detailed specifications and criteria to follow in designing a sediment basin to fit each specific site. Figure 3.30 depicts a sample sediment basin design.

The useful life of a sediment basin depends on regular maintenance. Sediment basins should be readily accessible for maintenance and sediment removal. They should be inspected after each rainfall event and be cleaned out when about half the

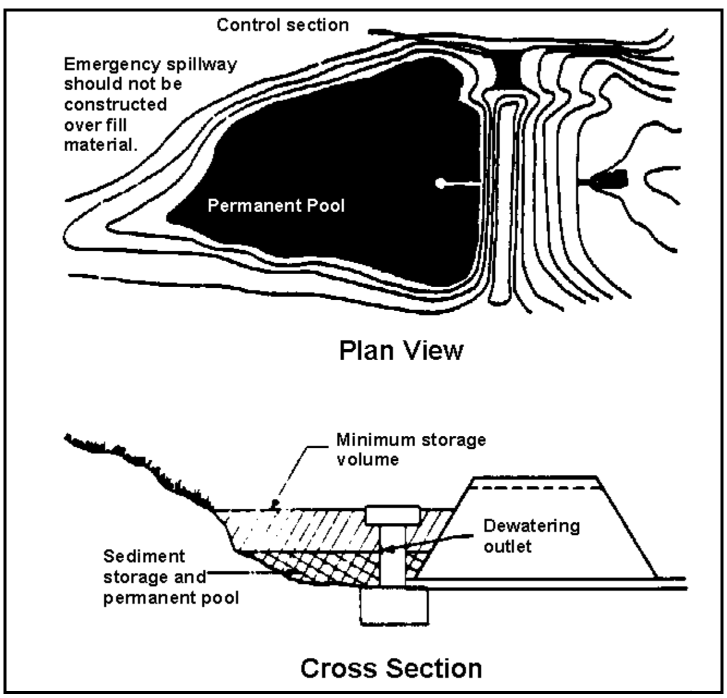

Figure 3.30. Temporary sediment basin design (*U.S. EPA, 1992*).

volume has been filled with sediment. The basin should remain in operation and be properly maintained until the construction site is permanently stabilized by vegetation. If the basin is located near a residential area, it is recommended for safety reasons that a sign be posted (child hazard, no playing) and that the area be secured by a fence. A well-built temporary sediment basin that is large enough to handle post-construction runoff volume may later be converted to use as a permanent stormwater management structure (see Chapter 4).

The outlet pipe and spillway of the sediment basin should be designed by an engineer based upon an analysis of the expected runoff flow rates from the site. Contact DPNR's Division of Environmental Protection, USDA Natural Resources Conservation Service, the UVI Cooperative Extension Service, or a licensed engineer for assistance in designing this practice.

ADVANTAGES OF TEMPORARY SEDIMENT BASINS
• Protects downstream areas from clogging or damage due to sediment deposits generated during construction activities.
• Can trap smaller sediment particles than sediment traps due to longer detention time.
• Can be converted to a permanent stormwater detention structure, once construction is complete.
DISADVANTAGES OF TEMPORARY SEDIMENT BASINS
• Requires regular maintenance and removal of accumulated sediment and debris.
• Will not remove very fine silts and clays unless used in conjunction with other sediment and erosion control practices.
• Is more expensive than other methods of sediment removal and requires larger area for installation.
• Requires careful adherence to safety practices since ponds may attract children.

Storm Drain Inlet Protection

Storm drain inlet protection consists of a permeable barrier placed around any inlet or drain to filter sediment out of stormwater. This practice prevents sediment from entering the storm drain inlet structures and getting into the storm drain system. It also prevents the silting-in of inlets, storm drainage systems, or receiving channels. Inlet protection may be composed of gravel and stone with a wire mesh filter, block and gravel, or geotextile (filter fabric). There are four basic types of inlet protection recommended in the V.I.: stone and block drop inlet protection, excavated drop inlet protection, curb drop inlet protection, and geotextile drop inlet protection (see Figures 3.32 and 3.33). Commercially manufactured inlet inserts (Beaver Dam™, Silt Sack™, etc., see Figure 3.31) that remove sediment and other pollutants from are also available, but have not been tested in the V.I.

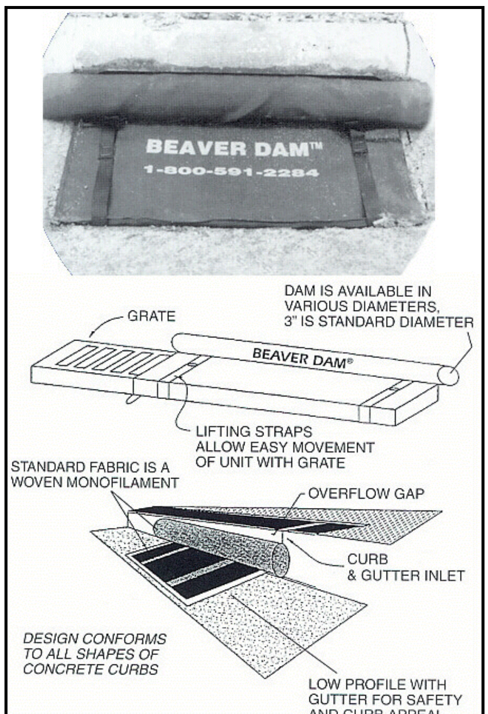

Figure 3.31. Example installation and diagram for Beaver Dam™ storm drain inlet protection (*Dandy Products, Inc., 2001*).

When and Where to Use Inlet Protection

This practice should be used where the drainage area to an inlet is disturbed, it is not possible to temporarily divert the storm drain outfall into a trapping device, for small drainage areas where storm drain inlets will be ready for use before final stabilization, where a

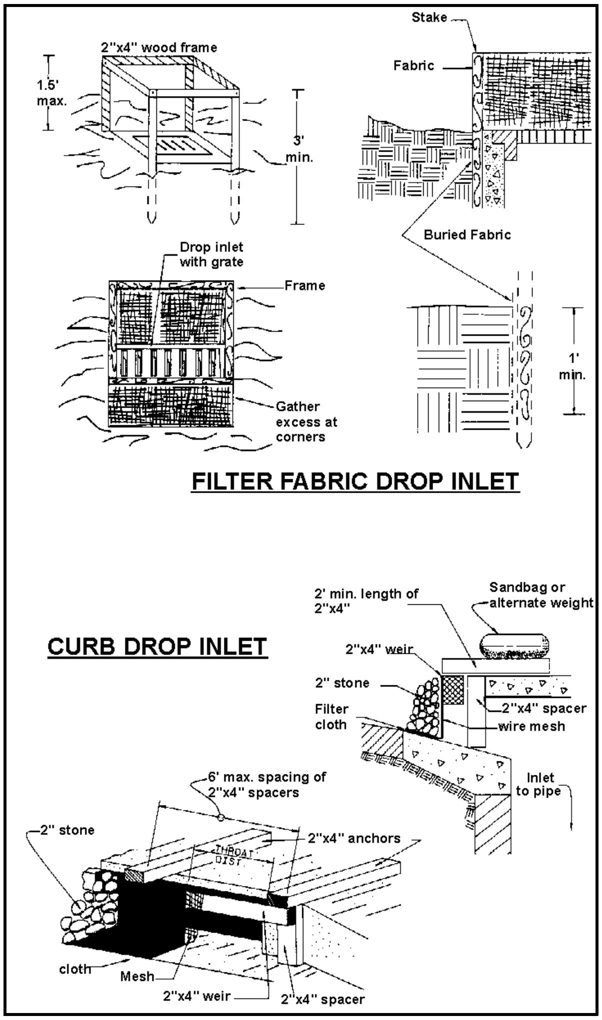

Figure 3.32. Examples of filter fabric drop inlet and curb drop inlet storm drain protection (*Empire State Chapter, Soil and Water Conservation Society, 1997*).

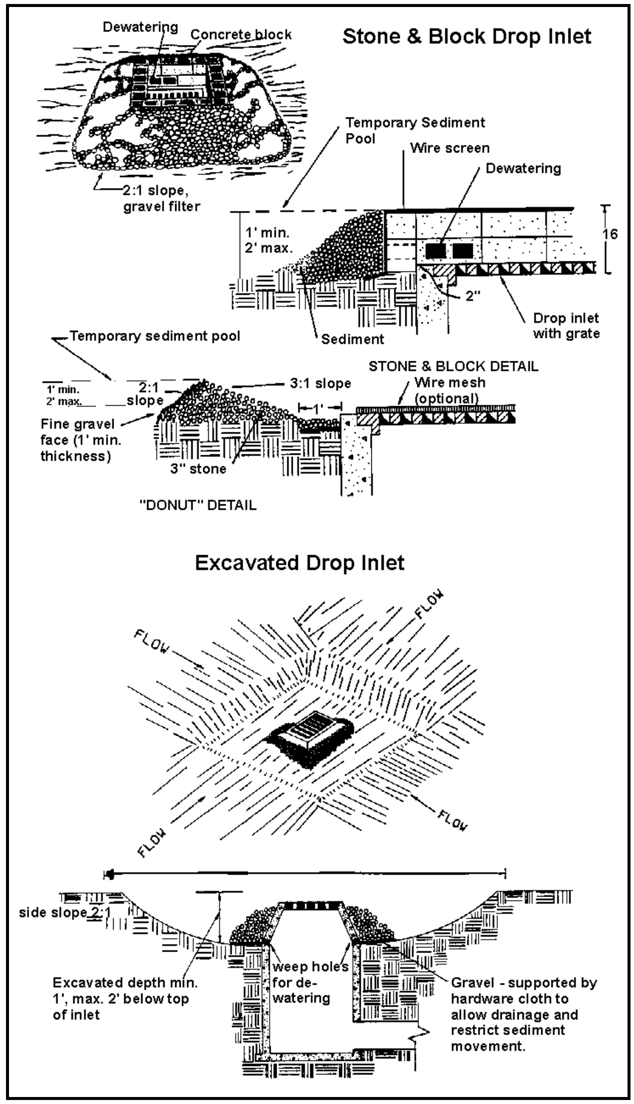

Figure 3.33. Examples of stone and block inlet and excavated drop inlet storm drain protection (*Empire State Chapter, Soil and Water Conservation Society, 1997*).

permanent storm drain structure is being constructed onsite, or where watertight blocking of inlets is not advisable. Straw bales are **NOT** recommended for this practice. It should **NOT** be used in place of sediment trapping devices.

Geotextiles are used for inlet protection when stormwater flows are relatively small with low velocities (Figure 3.32). This practice **cannot** be used where inlets are paved because the filter fabric must be staked into the ground. However, commercially manufactured inlet inserts (Beaver Dam™, Silt Sack™, etc., see Figure 3.31) can be used over flat grates, for curb and gutter inlets, or median barrier inlets. Block and gravel filters can be used where velocities are higher. Gravel and mesh filters can be used where flows are higher and subject to disturbance by site traffic (Figure 3.33).

What to Consider

Storm drain inlet protection is not meant for use in drainage areas that are larger than one acre or for large, concentrated stormwater flows. This practice should be installed before any soil disturbance takes place in the drainage area. The type of material used will depend on site conditions and the size of the drainage area.

Inlet protection should be used in combination with other practices, such as small sediment traps, to provide more effective sediment removal. Inlet protection structures should be inspected regularly, especially after a rainstorm. Repairs and sediment removal should be performed as necessary. This practice should be removed only after the disturbed areas are completely stabilized.

ADVANTAGES OF STORM DRAIN INLET PROTECTION
• Effective in preventing clogging of existing storm drainage systems and reduces receiving water siltation.
• Reduces the amount of sediment leaving the site.
DISADVANTAGES OF STORM DRAIN INLET PROTECTION
• May be difficult to remove collected sediment.
• Requires regular maintenance and cleaning.
• May cause erosion elsewhere if clogging occurs.
• Is practical only for low sediment, low volume flows (disturbed areas 1 acre or less).

Outlet Protection

Outlet protection reduces the depth, speed and energy of concentrated stormwater flows, reducing erosion and scouring at stormwater outlets of culverts, swale and drainage channels. Outlet protection also reduces the potential for downstream erosion. This protection can be achieved through a number of methods including stone or rip-rap, concrete aprons, paved sections, and settling basins installed below the storm drain outlet.

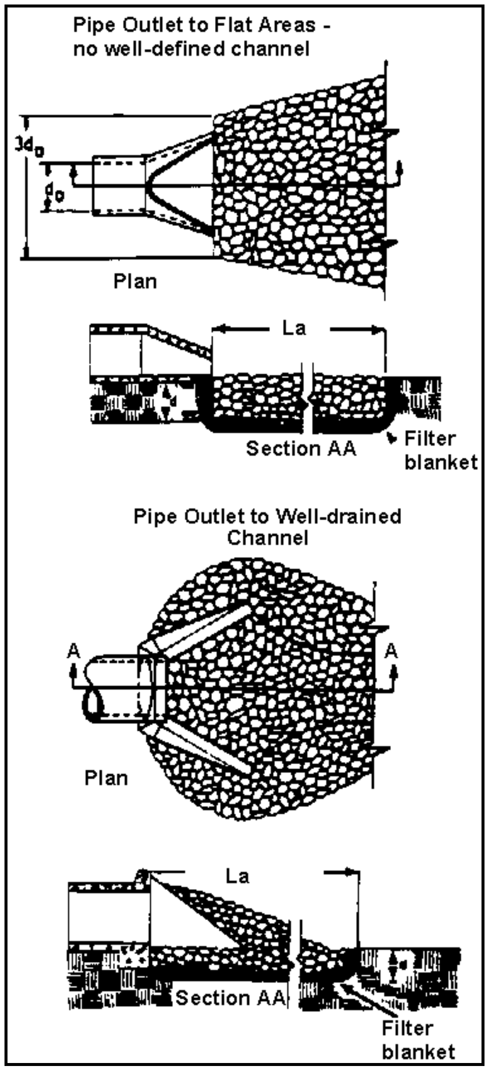

Figure 3.34. Examples of rock outlet protection designs (*U.S. EPA, 1992*).

When and Where to Use Outlet Protection

Outlet protection should be installed at all pipe, interceptor dike, swale, culvert or channel section outlets where the velocity of flow may cause erosion at the pipe outlet and in the receiving channel. This practice applies to culvert outlets of all types; pipe conduits from all sediment basins, dry stormwater ponds, and permanent ponds; and new channels built as outlets for culverts or other drainage ways. Outlet protection should also be used at outlets where the velocity of flow at the design capacity may result in plunge pools (small permanent pools located at the inlet to or the outfall from control practices). Outlet protection should be installed early during construction activities, but may be added at any time, as necessary.

What to Consider

The exit speed of runoff as it leaves the outlet protection structure should be reduced to levels that minimize erosion. The design of outlet protection depends on the location. Pipe outlets at the top of cuts or on slopes steeper than 10 percent cannot be protected by rock aprons or rip-rap sections because re-concentration of runoff flows and high velocities may occur after the flow leaves the apron. Contact DPNR's Division of Environmental Protection, USDA Natural Resources Conservation Service, the UVI Cooperative Extension Service, or a licensed engineer for assistance in designing for tailwater depth, apron size, bottom grade, alignment, materials, thickness, stone quality, and filter for this practice. Appendix B contains design specifications and example design procedure calculations (see example in Figure 3.34).

Once a rip-rap outlet has been installed, maintenance needs are usually low. Outlet protection should be inspected on a regular schedule to look for erosion and scouring and to check if any stones have been dislodged. Outlets must be kept clean of clogging debris. Repairs should be made promptly.

ADVANTAGES OF OUTLET PROTECTION
• Provides, with riprap-lined apron (the most common outlet protection), a relatively low-cost method that can be installed easily on most sites.
• Removes sediment in addition to reducing runoff speed.
• Can be used at most outlets where flow speed is high.
• Is an inexpensive but effective practice.
• Requires less maintenance than many other practices.
DISADVANTAGES OF OUTLET PROTECTION
• May cause problems in removing collected sediment (without removing and replacing the outlet protection structure itself).
• May require frequent maintenance for rock outlets with high velocity flows.
• May be unsightly.

Gabion Inflow Protection

Gabion inflow protection uses a temporary, lined drainage way installed to convey concentrated stormwater runoff into sediment traps and basins in order to prevent erosion of the flow channel. Gabions are constructed of rock or concrete within a flow channel to stabilize the channel. It should be used in conjunction with dikes, swales or other water control devices as warranted by site conditions.

When and Where to Use Gabion Mattresses

Gabion inflow protection should be used where stormwater runoff entering sediment basins or traps will cause erosion of the embankments or channels leading to them. Runoff can be directed to the entrance of the gabion using dikes or swales.

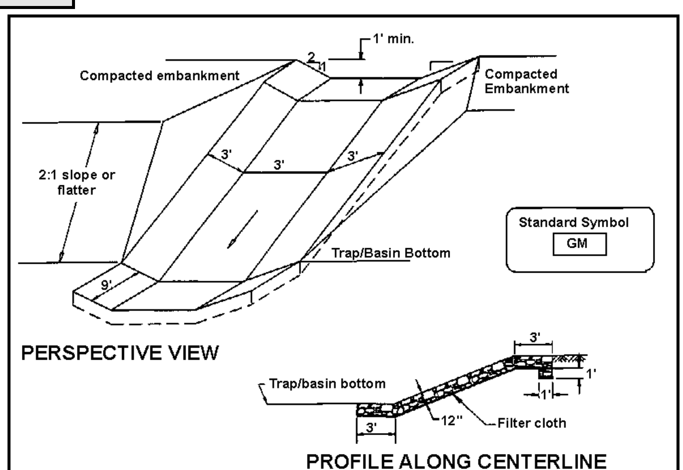

Figure 3.35. Gabion mattress inflow protection (*Maryland Department of the Environment, 1994*).

What to Consider

A gabion mattress should be constructed of 9'x3'x9' gabion baskets to form a cross-section one foot deep with 3:1 side slopes and a 3 foot bottom width (see Figure 3.35). The top mattress should be anchored into the ground at least one foot. Geotextile (or filter) fabric should be installed under all gabion baskets. The fabric used should be the same as that used for swale channel stabilization (see ***Drainage Swale*** and ***Silt Fence*** sections).

ADVANTAGES OF GABION INFLOW PROTECTION
• Removes sediment in addition to reducing runoff speed.
• Can be used at most inlets where flow speed is high.
• Requires less maintenance than many other practices.
DISADVANTAGES OF GABION INFLOW PROTECTION
• May cause problems in removing collected sediment (without removing and replacing the inlet protection structure itself).
• May require frequent maintenance for gabion inlets with high velocity flows.
• May be expensive.

3.4 REFERENCES

CWP. 2000a. *Stormwater Management Factsheet: Grassed Filter Strip*, Center for Watershed Protection, Stormwater Manager's Resource Center website www.stormwatercenter.net, Ellicott City, Maryland.

Dandy Products, Inc. 2001. *Sediment Control Solutions for All Stormwater Systems and Dewatering Projects*, Dandy Products, Inc., Grove City, Ohio, website: www.dandyproducts.com.

DPNR-DEP and USDA-NRCS. 1998. *Unified Watershed Assessment Report - United States Virgin Islands*, Virgin Islands Department of Planning and Natural Resources in cooperation with USDA Natural Resources Conservation Service, Caribbean Area, St. Croix, USVI.

Empire State Chapter, Soil and Water Conservation Society. 1997. *New York Guidelines for Urban Erosion and Sediment Control Update*, Syracuse, New York.

Empire State Chapter, Soil and Water Conservation Society. 1991. *New York Guidelines for Urban Erosion and Sediment Control*, Syracuse, New York.

Fifield, J.S. 1996. *Field Manual for Effective Sediment and Erosion Control Methods*, HydroDynamics, Inc., Parker, CO.

MacDonald, L.H., D.M. Anderson and W.E. Dietrich. 1997. "Paradise Threatened: Land Use and Erosion on St. John, U.S. Virgin Islands," *Environmental Management*, Vol. 21, No. 6, pp. 851-863.

Maryland Department of the Environment, Water Management Administration. 1994. *1994 Maryland Standards and Specifications for Soil Erosion and Sediment Control*, Annapolis, Maryland.

Sampson, R. 1997. *Precipitation, Runoff and Sediment Yield on St. John - A Review of the Data*, 319 Project Report to Island Resources Foundation, February, 1997, St. Thomas, U.S. Virgin Islands.

Schueler, T.R. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*, Metropolitan Washington Council of Governments, Department of Environmental Programs, Washington, DC. Publication Number 87703.

USDA-SCS. 1992. *Engineering Field Handbook, Chapter 18: Soil Bioengineering for Upland Slope Protection and Erosion Reduction*, U.S. Department of Agriculture Soil Conservation Service, Publication Number 210-EFH, 10/92, Washington, DC.

USDA-SCS. 1993a. *Conservation Choices: Your guide to 30 conservation and environmental farming practices*, USDA-SCS, Des Moines, Iowa.

U.S. EPA. 1993. *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*. U.S. Environmental Protection Agency, Office of Water, Publication Number 840-B-92-002, Washington, DC.

U.S. EPA. 1992. *Storm Water Management for Construction Activities: Developing Pollution Prevention Plans and Best Management Practices*. U.S. Environmental Protection Agency, Office of Water, Document Number EPA 832-R-92-005, Washington, DC.

Virgin Islands Department of Conservation and Cultural Affairs (DCCA). 1979. *Environmental Laws and Regulations of the Virgin Islands, Title 12, Chapter 3, Trees and Vegetation Adjacent to Watercourses, §123 Cutting or Injuring Certain Trees*, Equity Publishing Corporation, Oxford, New Hampshire.

Washington State. 1992. *Standards for Storm Water Management for the Puget Sound Basin*. Washington State Department of Ecology, Seattle, Washington.

Wernicke W., A. Seymour and R. Mangold. 1986. *Sediment Study in the St. Thomas, St. Croix, Areas of the United States Virgin Islands*. Donald E. Hamlin Consulting Engineers for the Virgin Islands Department of Conservation and Cultural Affairs, Division of Natural Resources Management, St. Thomas, Virgin Islands.