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Rainfall, Runoff, and Land Use Change

Supplementary Information

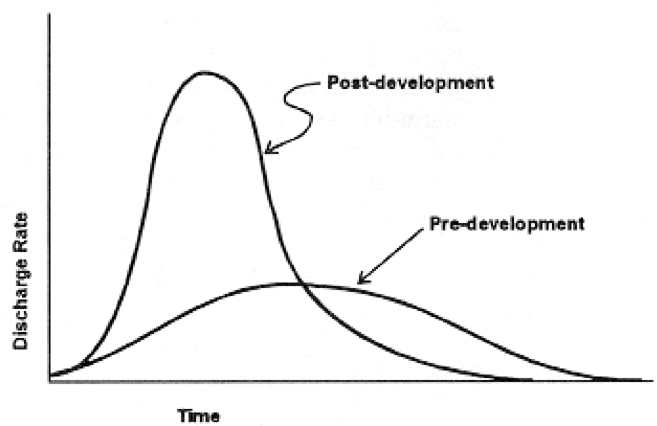
Effects of Development

There are two main effects that urbanization has on stormwater. First, an increase in the volume and rate of runoff as development takes place in a watershed. Second, an increased risk of degrading water quality; both surface water and ground water.

Hydrologic Changes

Undeveloped land that is in woods, grass, and/or agriculture, has an ability to absorb rainfall. Rainfall is infiltrated into the soil, used by vegetation, or runs off. Water reaches the earth's surface by rain and snow. Some water is retained on the upper surface of the soil and is either evaporated or transpired into the atmosphere by grass, plants and trees. Some water infiltrates into the soil and becomes groundwater which eventually reaches streams, lakes and oceans.

The remainder of the water falling to the earth becomes runoff and flows into the streams, lakes and oceans as surface flow. Evaporation takes place on these bodies of water and sends the moisture back into the atmosphere as vapor.



Pre- and Post-development Hydrographs

When development takes place, vegetation may be removed and replaced with impervious surfaces. These surfaces include roads, streets, parking lots, roof tops, driveways, walks, etc. which reduce the amount of rainfall that can infiltrate into the soil and therefore create more runoff into the surface water system.

In addition to the increase in impervious surfaces, urbanization creates a significant amount of ground surface modification. Natural drainage patterns are modified and runoff is transported via road ditches, storm sewers, drainage swales, and constructed channels. These modifications increase the velocity of the runoff; which in effect decreases the time that it takes for runoff to travel through the watershed. This decreased time creates higher peak discharges.

Increase In Pollution Potential

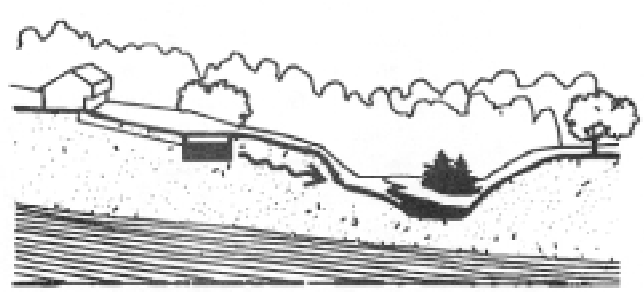
The largest urban non-point pollution source is sediment and the nutrients and trace metals attached to it. In addition, the runoff from urban areas may carry bacteria, toxic chemicals, hydrocarbons and organic substances.

Sediment is a major pollutant from urban areas. Runoff from construction sites during the urbanization process is the largest source of sediment. Sediment fills road ditches, streams, rivers, lakes and wetlands. A good erosion and sediment control plan can substantially decrease the amount of sediment being produced from urban areas and transported off site.

Nutrients from urban areas are a major concern to surface water quality because of their effects on water bodies. The two major nutrients are nitrogen and phosphorous. Nutrient enrichment can cause an increase in algal growth. Nitrogen consumes large amounts of oxygen in the nitrification process within the water. Both conditions can impair the use of our surface waters for water supply, recreation, and fish and wildlife habitat.

Main sources of nutrients in urban areas include improper use of fertilizers, and organic matter from lawn clippings and leaves. Auto emissions can also contribute phosphorous in areas of heavy traffic.

Trace metals can degrade water quality because of the effect they may have on aquatic life. The most common trace metals found in urban runoff are lead, zinc and copper, however other trace metals such as chromium, nickel and cadmium are frequently found.

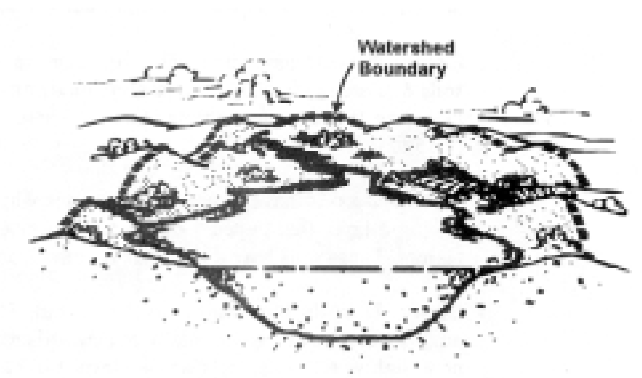


Bacteria levels can increase due to urbanization. Fecal coliform bacteria are found in the intestinal tract of warm-blooded animals and can be associated with animal wastes and failed septic systems.

Hydrocarbons from petroleum are commonly found in urban runoff. The hydrocarbons attach to fine sediment and are then transported and deposited throughout the surface water system. Common sources of hydrocarbons are from roads, streets, and parking lots. Other sources include gasoline stations, fuel storage facilities, and improper disposal of motor oil.

Factors affecting surface runoff

Surface runoff is the volume of excess water that runs off a drainage area, or watershed. Peak discharge is the peak rate of runoff from a drainage area for a given rainfall.



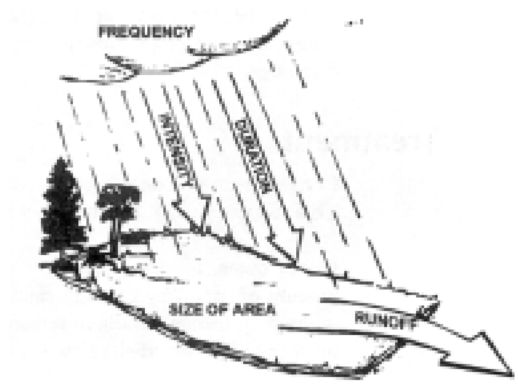
A watershed is a drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation. The term watershed is synonymous with drainage area; the contributing area, in acres, square miles, or other unit is usually expressed as drainage area.

General

Rainfall is the primary source of water that runs off the surface of small watersheds. The main factors affecting the volume of rainfall that runs off are the kind of soil, type of vegetation and amount of impervious area in the watershed. Factors that affect the rate at which water runs off are watershed topography and shape along with man-made features in a watershed.

Rainfall

The peak discharge from a small watershed is usually caused by intense rainfall. The intensity of rainfall affects the peak discharge more than it does the volume of runoff. The melting of accumulated snow may result in a greater volume of runoff, but usually at a lesser rate than runoff caused by rainfall. The melting of a winter's snow accumulation over a large area may cause major flooding along rivers. Intense rainfall that produces high peak discharges in small watersheds usually does not extend over a large area. Therefore, the same intense rainfall that causes flooding in a small tributary is not likely to cause major flooding in a main stream that drains 10 to 20 square miles.



Hydrologic soil groups

Soils may be classified into four hydrologic soil groups, defined as follows:

Group A soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of sands and gravels that are deep, well drained to excessively drained, and have a high rate of water transmission (greater than 0.30 in/hr).

Group B soils have moderate infiltration rates when thoroughly wetted and consist chiefly of soils that are moderately deep to deep, moderately well drained to well drained, and have moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15 to 0.30 in/hr).

Group C soils have low infiltration rates when thoroughly wetted and consist chiefly of soils having a layer that impedes downward movement of water and soils of moderately fine to fine texture. These soils have a slow rate of water transmission (0.05 to 0.15 in/hr).

Group D soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0 to 0.05 in/hr).

Cover Type

"Cover type" describes conditions at the soil surface; e.g. vegetation, bare soil, impervious surfaces such as parking areas, roofs, streets, or roads. Cover type affects runoff in several ways. The foliage and its litter maintain the soil's infiltration potential by preventing the impact of the raindrops from sealing the soil surface. Some of the raindrops are retained on the surface of the foliage, increasing their chance of being evaporated back into the atmosphere. Some of the intercepted moisture takes so long to drain from the plant down to the soil that it is Withheld from the initial period of runoff.

Ground cover also allows soil moisture from previous rains to transpire, leaving a greater void in the soil to be filled. Vegetation, including its ground litter, forms numerous barriers along the path of the water flowing over the surface of the land. This increased surface roughness causes water to flow more slowly, lengthening the time of concentration and reducing the peak discharge.

Treatment

Conservation practices reduce erosion and help maintain an "open structure" at the soil surface. This reduces runoff, but the effect diminishes rapidly with increases in storm magnitude.

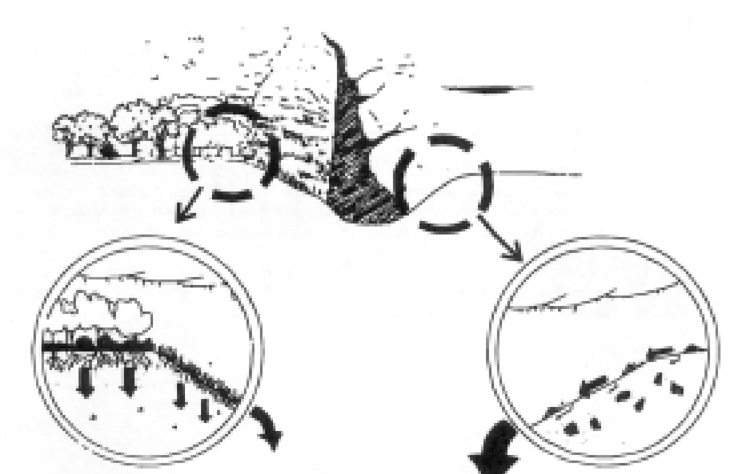
Check dams, terraces, detention ponds, and similar practices reduce erosion and decrease the amount of runoff by creating small reservoirs. Closed-end level terraces act as storage reservoirs without spillways. Gradient terraces, surface roughening, vegetation increase the distance water must travel or impede its flow - and thereby increase the time of concentration.

Hydrologic conditions

Hydrologic condition indicates the effects of cover type and treatment on infiltration and runoff rates. It is generally estimated from the density of plant and crop residue on the area. Good hydrologic condition indicates that the soil usually has low runoff potential for that specific hydrologic soil group, cover type and treatment. Some factors to consider in estimating the effect of cover on infiltration and runoff are: canopy or density of leaves, amount of year-round cover, percent of residue cover, and the degree of surface roughness.

In most cases, the hydrologic condition of the site affects the volume of runoff more than any other single factor. The hydrologic condition considers the effects of cover type and treatment on infiltration and runoff and is generally estimated from density of plant cover and residue on the ground surface. Good hydrologic condition indicates that the site usually has a lower runoff potential.

A grass cover is "good" if the vegetation covers 75 percent or more of the ground surface. Cover is "poor" if vegetation covers less than 50 percent of the ground surface. Grass cover is evaluated on the basal area of the plant, whereas trees and shrubs are evaluated on the basis of canopy cover.



Vegetated slope yields minimal, filtered runoff. Trees and vegetation absorb most of the erosive power of rain.

Bare slope yields a large volume of sediment-laden runoff.

Topography

The slopes in a watershed have a major effect on the peak discharge at downstream points. Slopes have little effect on how much of the rainfall will run off. As watershed slope increases, velocity increases, time of concentration decreases, and peak discharge increases. An average small watershed is fan-shaped. As the watershed becomes elongated or more rectangular, the flow length increases and the peak discharge decreases.

Potholes may trap a small amount of rain, thus reducing the amount of expected runoff. If potholes and marshland areas make up one-third or less of the total watershed and do not intercept the drainage from the remaining two-thirds, they will not contribute much to the peak discharge. These areas may be excluded from the drainage area for estimating peak discharge. If potholes constitute more than one-third of the total drainage or if they intercept the drainage, a “pond and swamp adjustment factor” can be applied.

Runoff

“Runoff” is the water leaving the watershed during and after a storm. It may be expressed as the average depth of water that would cover the entire watershed. The depth is usually expressed in inches. The volume of runoff is computed by converting depth over the drainage area to volume and is usually expressed in acre-feet.

Hydrologic Methods

Hydrologic methods are well-covered in literature such as Soil Conservation Service (SCS) Technical Release 55, Urban Hydrology for Small Watersheds, other technical documents of various state and federal agencies, commercial publishing houses, and numerous computer programs.

In order to assist designers preparing development plans and local Conservation Commissions reviewing such plans; checklists for reviewing reports prepared using SCS technical releases TR-20, Computer Program for Project Formulation - Hydrology, and TR-55, Urban Hydrology for Small Watersheds, have been included in this section. Natural Resources Conservation Service (formerly Soil Conservation Service) engineers often receive queries about technical details of hydrologic procedures, and a summary of common questions and answers has also been included.

Note: Technical Releases issued prior to November 1994 are referred to as Soil Conservation Service Technical Releases. After November 1994, they are referred to as Natural Resources Conservation Service Technical Releases.

Checklist for Reviewing Reports Using SCS TR-55 Analysis

☑ Watershed map at a scale of 1 inch = 500 feet or larger. Show watershed boundary, sub-area boundaries, and sub-area names or numbers. Show time of concentration, curve number, and drainage area for each sub-area on the map. Contour maps must include some additional area outside the property line boundaries.

☑ Large scale map showing different soils within each sub-area boundary. May also be used to delineate drainage areas. Show the flow route used for calculating time of concentration for each sub-area.

☑ Tabulation sheet or computer printout showing runoff curve number and time of concentration calculations for each sub-area. Drainage areas, hydrologic soils groups, and land use areas should be documented and supported from soils maps or other references.

☑ Tabulation sheet showing calculations and equations used for any storage estimates to design a detention basin.

☑ Narrative explanation and documentation for any sheet flow lengths used that exceed 50 feet.

☑ TR-55 printout showing graphical or tabular peak discharge calculations. include printouts for both pre-development and post-development conditions. The printout showing the design of a detention basin should be included. These printouts should document any claim of zero discharge increase for all required storms.

☑ The written report should state the initial conditions and storm frequencies to be analyzed. Include a summary table showing the pre-development, post-development, and designed system peak discharges for all design frequencies.

☑ Show a sketch of the structure outlet system with elevations and dimensions.

Checklist for Reviewing Reports Using SCS TR-20 Analysis

☑ TR-20 watershed map at a scale of 1 inch = 500 feet or larger. Show sub-area boundaries, cross section locations and numbers, structure locations and numbers, and sub-area names or numbers. Show time of concentration, curve number, and drainage area for each sub-area on the map. Contour maps must include some additional area outside the property line boundaries.

☑ Large scale map showing different soils within each sub-area boundary. May also be used to delineate drainage areas. Show time of concentration calculation path used for each sub-area.

☑ Tabulation sheet or computer printout showing runoff curve number and time of concentration calculations for each sub-area. Drainage areas, hydrologic soils groups, and land use areas should be documented and supported from soils maps or other references.

☑ Tabulation sheet showing calculations and equations used for structure stage, discharge, and storage volumes, and cross-section elevation, discharge, area calculations. Include sketches of structures and cross sections showing elevations and dimensions used in the calculations.

☑ Narrative explanation and documentation for any sheet flow lengths used that exceed 50 feet.

☑ TR-20 printout showing input listing and a minimum output of the summary tables. The minimum required output is listings and summary tables for the pre-development, post-development, and post-development-with-control for all required storms. These printouts should document any claim of zero discharge increase for all required storms.

☑ The written report should state the initial conditions and storm frequencies to be analyzed. Include a summary table showing the pre-development, post-development, and designed system peak discharges for all design frequencies.

Common Questions and Answers About Urban Hydrology for Small Watersheds, TR-55

General

Q. What is the minimum acceptable drainage area for the procedure?
A. The procedure does not have a drainage area limit. It is governed by a minimum time of concentration of 0.1 hours.

Q. What rainfall distribution should be used for Massachusetts?
A. All of Massachusetts is covered by the Type III rainfall distribution. This distribution represents the influence of thunderstorms and tropical storms (e.g. hurricanes) along the coast.

Q. What is the difference between the Type II and Type III rainfall distributions?
A. The Type III distribution is a little less intense than the Type II distribution. The Type III distribution reduces the peak discharges by 34 percent for short time of concentrations of 0.1 hours, by 17 percent for a Tc of 1.0 hours, by 8 percent for a Tc of 3 hours, and approximately the same for time of concentrations of 7 to 10 hours.

Time of Concentration

Q. How do you handle time of concentrations less than 0.1 hours?
A. The procedure has a minimum time of concentration of 0.1 hour. If the computed Tc is less than 0.1 hour, use the minimum value of 0.1 hour. The lower limit is consistent with the available rainfall intensity information from the National Weather Service. The rainfall distribution curve incorporates the high intensity rainfall storm having a 5-minute duration.

Q. What is the acceptable limit for the length of sheet flow?
A. The procedure designates a maximum limit of 300 feet for sheet flow. Considering the definition of sheet flow as flow on a plane surface, a more practical limit in the northeast is 50 to 100 feet.

A good example of sheet flow is flow from the crown of a football field to the edge of the field, where the flow becomes concentrated in a grass swale. In woods the sheet flow length is also short because flow can be diverted by stonewalls, fallen trees, and tree roots. Considering the contributing area represented by sheet flow in proportion to the total drainage area, the travel time for sheet flow should be a small part of the total time of concentration. If the sheet flow length is greater than 10 percent of the total hydraulic length for the watershed or subarea, re-evaluate the sheet flow and travel time calculations.

Q. For sheet flow, should a surface cover of "woods with dense underbrush" be used?
A. This surface cover should be avoided, because the "n" value for this cover type is extrapolated from research data and does not represent typical conditions in the Northeast.

Q. Does shallow concentrated flow need to be used in the time of concentration calculations?
A. The method for shallow concentrated flow is used to calculate the travel time for the transition between sheet flow and open channel flow. If cross section information is available for the shallow concentrated flow segments, they can be treated as open channel flow for calculating travel time.

Q. How can USGS quad sheets be used to calculate time of concentrations?
A. The first segment can be a 50-foot length for sheet flow at the top of the watershed. Shallow concentrated flow will represent segments across parallel contour lines and defined watercourses on the maps. Open channel flow will be used for streams indicated by blue lines on the maps. A field visit of the area should be made to check the flow path and obtain information on the hydraulic characteristics of the channel. This information should include measuring the top width and depth of the channel for bank-full conditions.

Q. Can the upland method (Figure 15.2 in NEH-4) be used to calculate time of concentrations?
A. This method was originally developed for estimating time of concentrations in small rural watersheds. Based on more recent research and analyses, the sheet flow equation in TR-55 has superseded the upland method.

Q. Can other methods be used to calculate time of concentration?
A. The recommended method for calculating time of concentration is the stream hydraulics method. Travel times are calculated based on flow characteristics for each segment in the flow path. Other methods can be used, but they should be checked to see if the results are realistic for the site conditions. The same method should be used when analyzing existing and developed situations.

Hydrographs

Q. Can the hydrograph developed by the Tabular Method be used for detention basin routing?
A. The composite hydrograph developed by the Tabular Method is only a partial hydrograph at the design point based upon rounded time of concentration and travel time values in the tables. The partial hydrograph can be extrapolated to get a total hydrograph for routing by other methods, but this is still an approximation of the entire

hydrograph. If hydrographs are needed within the drainage basin or a more precise hydrograph is needed, another hydrologic method should be used such as TR-20.

Q. Does the Tabular method consider reach routing?
A. The subarea hydrograph is translated downstream based on the travel time for the reach. The method does not consider storage routing in the reach. Floodplain storage in a reach will reduce the peak flow similar to reservoir routing, as well as lag the timing of the peak. If reach storage routing needs to be considered, use the TR-20 hydrology model.

Storage Effects

Q. Can you account for pond and swamp storage within the drainage basin?
A. The Graphical Method has an adjustment factor to account for ponds and swarms spread throughout the basin and not in the time of concentration flow path. In both the Graphical and Tabular Methods, the storage effects within the time of concentration flow path can partially be accounted for by increasing the travel time for the segment, based upon typical pond routings.
The TR-20 hydrology model should be used in order to analyze the actual effects of pond and swamp storage within the basin by routing each storage area.

Q. Can you get a hydrograph with the TR-55 storage routing method?
A. The method just determines the peak outflow or total storage volume required for a detention basin. It is based on average storage and routing effects for many structures and is on the conservative side. If an outflow hydrograph or a more refined storage analysis is needed, the inflow hydrograph needs to be routed by other procedures. The Tabular Method can be used to create an approximate inflow hydrograph. The TR-20 hydrology model can be used to create an inflow hydrograph, conduct storage routings of a detention basin, and calculate the outflow hydrograph.

References

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U.S. Department of Agriculture, , Washington, DC, Engineering Field Handbook, Chapter 2, ***Estimating Runoff and Peak discharge***.

U.S. Department of Agriculture, Soil Conservation Service, Washington, DC, ***Urban Hydrology for Small Watersheds, Technical Release 55***, June, 1986.

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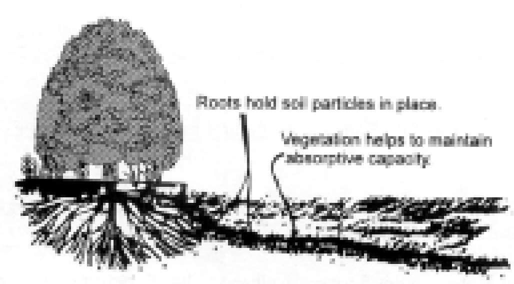
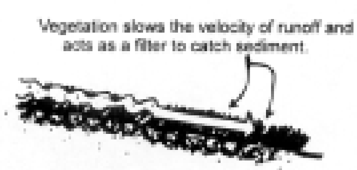
Plants, Vegetation, Soil Covers

Vegetation protects the soil surface from raindrop impact, a major force in dislodging soil particles and moving them downslope. It also shields the soil surface from the scouring effect of overland flow and decreases the erosive capacity of the flowing water by reducing its velocity. Vegetative cover is relatively inexpensive to achieve and tends to be self-healing; it is often the only practical, long-term solution to stabilization and erosion control on most disturbed sites in Massachusetts.

The shielding effect of a plant canopy is augmented by roots and rhizomes that hold the soil, improve its physical condition, and increase the rate of infiltration, further decreasing runoff. Plants also reduce the moisture content of the soil through transpiration, thus increasing its capacity to absorb water.





Planning from the start for vegetative stabilization reduces cost, minimizes maintenance and repair, and makes erosion and sediment control measures more effective and less costly to maintain. Final landscaping is also less costly where soils have not been eroded, slopes are not too steep, and weeds are not allowed to proliferate.

Design projects so that only the area that is totally necessary is disturbed. The existing natural areas provide low-maintenance landscaping, shade, and screening, and soil stability. Large trees increase property value, but must be properly protected during construction.

Besides preventing erosion, healthy vegetative cover provides a stable land surface that absorbs rainfall, cuts down on heat reflectance and dust, restricts weed growth, and complements architecture. It creates a pleasant environment, and an attractive site. Property values can be increased dramatically by small investments in erosion control. Vegetative cover and landscaping represent only a small fraction of total construction costs and contribute greatly to the marketing potential of a development.

Site Considerations

Species selection, establishment methods, and maintenance procedures should be based on site characteristics including soils, slope, aspect, climate, and expected management.

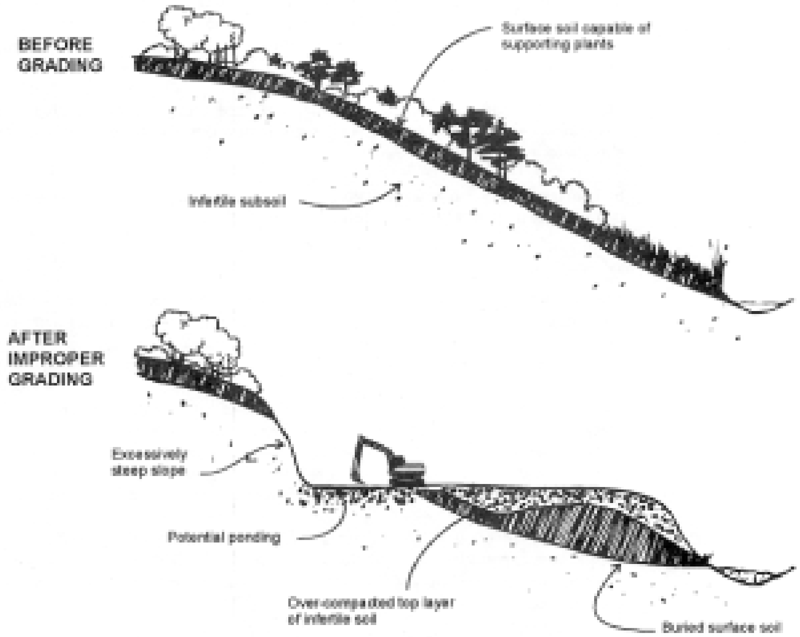
Soils

Many soil characteristics - including texture, organic matter, fertility, acidity, moisture retention, drainage, and slope - influence the selection of plants and the steps required for their establishment.

Nature of Disturbed Soils

Most disturbed sites end up, after grading, with a surface consisting of acid, infertile subsoil materials that lack nutrients necessary for supporting plant growth. Such soils may not be capable of supporting the dense growth necessary to prevent erosion.

Construction activities further decrease soil productivity by increasing compaction, making slopes steeper, and altering drainage patterns. Topsoiling, addition of soil amendments, and special seedbed preparation are generally required. Some native plant species are better suited to these conditions.



Soils Investigation

The vegetative plan should be based on thorough soil sampling and testing in the area of planned construction. Different soils should be sampled separately. Contact the local Conservation District office for suggestions on providers of these services. Test results should include lime and fertilizer recommendations. Fertilizing according to the soil test ensures the most efficient expenditure of money for fertilizer and a minimum of excess fertilizer to pollute streams or groundwater. Soil sampling should begin well in advance of planting because 1 to 6 weeks are required to obtain soil test results.

Information on the soil type is useful in selecting the plants to be used. Native plants growing on similar soils will be good candidates for revegetation.

Wet and dry areas should be checked at the time of maximum wetness and when the dry areas can be differentiated from the wet ones; making it possible to place plants in the microsites for which they are best adapted.

Soil Limitations

Certain soil factors are difficult to modify and can impose severe limitations on plant growth. These include such things as rooting depth, stoniness, texture, and properties related to texture such as organic matter content, and water- and nutrient-holding capacity.

Extremely coarse (gravelly) textures result in droughtiness and nutrient deficiencies. Fine textures, on the other hand, impede infiltration and decrease permeability, thereby increasing the volume of runoff. Light sandy soils may need special treatment with mulches or tackifiers to stabilize them sufficiently to allow plant establishment. Other soils may have a hardpan that limits water and root penetration.

Toxic levels of elements such as aluminum, iron, and manganese are limiting to plant growth. These become less soluble as the pH is raised, however, so that toxicity problems can usually be eliminated by liming.

Soil survey reports may refer to “poor,” “severe,” and “droughty,” soils. These are soils that require special treatment beyond routine tillage and fertilization.

Slope

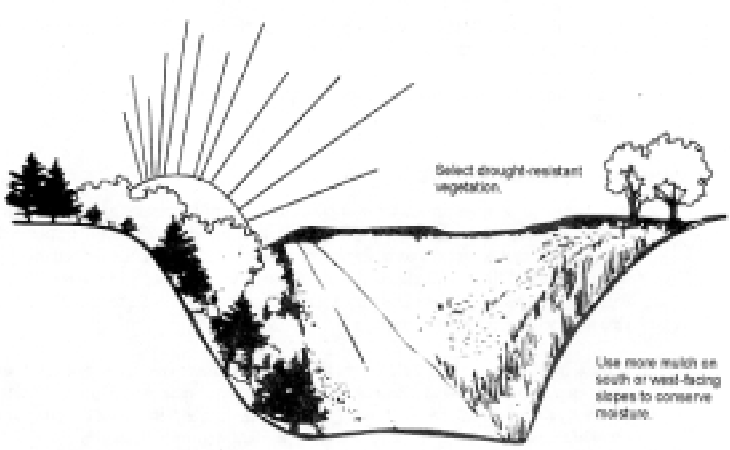
The steeper the slope, the more essential a vigorous vegetative cover is. Good establishment practices, including seedbed preparation, quality seed, lime, fertilizer, mulching and tacking are critical. The degree of slope may limit the equipment that can be used in seedbed preparation, planting, and maintenance; steep slopes also increase costs.

The severity of past erosion will indicate the degree of mechanical stabilization and slope preparation necessary for plant establishment. Shallow surface erosion will indicate the need for maximum surface plant cover. More deep-seated erosion will indicate the need for a high percentage of deep-rooted species. Relatively small rills and gullies will be smoothed as a matter of course during construction, whereas large gullies may need to be reworked with heavy equipment.

Slope angles steeper than 30-34 percent are difficult to revegetate. Steep slopes should be laid back whenever possible. Vegetation establishment is difficult at best on the tops of cuts. Rounding improves the chances of successful revegetation and minimizes chances of future undercutting.

Aspect

Aspect affects soil temperature and available moisture. South- and west-facing slopes tend to be hotter and drier, and often require special treatment. For example, mulch is essential to retain moisture, and drought-tolerant plant species should be added to the seed mixture. South- and west-facing slopes also may be subject to more frost heaving due to repeated cycles of freezing and thawing.



Temperatures are lower on north- and northeast-facing slopes than on south- and west-facing slopes. Colder temperatures lead to lower evapotranspiration values which result in more available water for plant growth. The effective growing season is reduced somewhat, however; soil temperatures are lower, affecting seed germination, and the possibility of frost damage is greater.

Climate

Climatic differences determine the appropriate plant selections based on such factors as cold-hardiness, tolerance to high temperatures and high humidity, and resistance to disease. Native plant lists give historic information on plants known to have survived in regions over centuries.

Microclimate

Valleys, draws, and low spots will have different microclimates from immediately adjacent higher areas. They will tend to have higher soil moisture because of higher water tables. They will be colder than adjacent higher ground. These conditions will affect plant performance in the same way that they do on slopes of different aspects.

Exposure to winds will vary from site to site in a general area. The winds may occur in either summer or winter or both. Wind increases evapotranspiration and reduces the effective water availability. Summer winds will make plant establishment more difficult, and winter winds may increase winter damage.

Soil pH

Soil pH may limit choices of plant species. Some plants require acid soils, some alkaline, and some are tolerant of a wide range of pH. High soil pH (7.5 and above) or low pH (4.5 or below) may restrict availability of plant nutrients or may make toxic ions available. Extremely low pH levels will increase availability of aluminum, and manganese and other metal ions that are toxic to plants. The pH in surface soils may be satisfactory for plant growth, but highway cuts may expose strata with abnormally high or low pH levels.

Management

When selecting plant species for stabilization, consider post-construction land use and the expected level of maintenance. In every case, future site management is an important factor in plant selection.

Where a neat appearance is desired, use plants that respond well to frequent mowing and other types of intensive maintenance.

At sites where low maintenance is desired, longevity is particularly important. Try to use native species.

Seasonal Considerations

Newly constructed slopes and other unvegetated areas should be seeded and mulched, or sodded, as soon as possible after grading. Where feasible, grading operations should be planned around optimal seeding dates for the particular region. The most effective times for planting perennials generally extend from April through May and from August through September. Outside these dates the probability of failure is higher. Late summer (August 15 - September 30) is the best period to establish grass/legume seedings.

If the time of year is not suitable for seeding permanent cover (perennial species), a temporary cover crop should be planted. Otherwise, the area must be stabilized with gravel or mulch. Temporary seeding of annual species (small grains, Sudangrass, or German millet) often succeeds at times of the year that are unsuitable for seeding permanent (perennial) species,

Dormant seeding can be made from the end of November through March. This type of seeding needs to be adequately protected with mulch, or better yet, erosion control fabric.

Seasonality must be considered when selecting species. Grasses and legumes are usually classified as “warm” or “cool” season in reference to their season of growth. Cool season plants produce most of their growth during the spring and fall and are relatively inactive or dormant during the hot summer months, therefore late summer into early fall is the most dependable time to plant them. Warm season plants greenup late in the spring, grow most actively during the summer, and go dormant at the first frost in fall. Spring and early summer are preferred planting times for warm-season plants.

Plant Species

Species selection should be considered early in the process of preparing the erosion and sedimentation control plan. For practical, economical stabilization and long-term protection of disturbed sites, species selection should be made with care. Many widely occurring plants are inappropriate for soil stabilization because they do not protect the soil effectively, or because they are not quickly and easily established. Plants that are preferred for some sites may be poor choices for others; some can become troublesome pests.

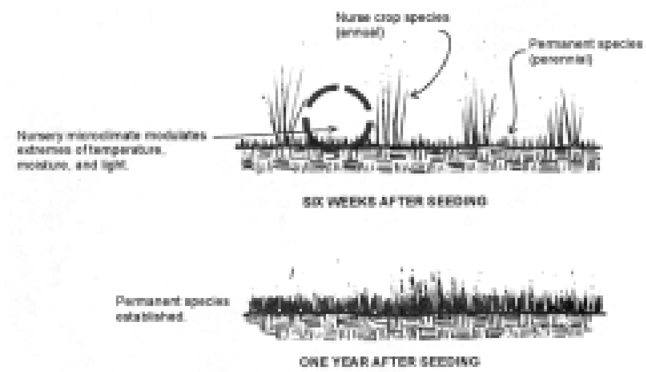
Initial stabilization of most disturbed sites requires grasses and legumes that grow together without gaps. This is true even where part or all of the site is planted to trees or shrubs. In landscape plantings, disturbed soil between trees and shrubs must also be protected either by mulching or by permanent grass-legume mixtures. Mulching alone is an alternative, but it requires continuing maintenance.

Mixtures vs. Single-Species Plantings

Single-species plantings are warranted in many cases, but they are more susceptible than mixtures to damage from disease, insects, and weather extremes. Also, mixtures tend to provide protective cover more quickly. The inclusion of more than one species should always be considered for soil stabilization and erosion control.

Addition of a quick-growing annual provides early protection and facilitates establishment of perennials. More complex mixtures might include a quick-growing annual, one or two legumes, and one or two perennial grasses.

Companion or “Nurse” Crops



The addition of a “nurse” crop (quick-growing annuals added to permanent mixtures) is a sound practice for soil stabilization, particularly on difficult sites - those with steep slopes; poor, stony, erosive soils; late seedings, etc. - or in any situation where the development of permanent cover is likely to be slow. The nurse crop germinates and grows rapidly, holding the soil until the slower growing perennial seedlings become established. Seeding rate of the nurse crop must be limited to avoid crowding, especially under optimum growing conditions.

Legumes: Nitrogen-Fixing Plants

Legumes should be used when practical because of their ability to improve sites by adding nitrogen. They should be inoculated at planting with appropriate bacteria. Commercial inoculants are available for many species. Native species for which no commercial inoculant is available should be inoculated by incorporating soil from native stands in the soils in which transplants are grown, or by topdressing with native soils.

Annuals

Annual plants grow rapidly and then die in one growing season. They are useful for quick, temporary cover or as nurse crops for slower-growing perennials.

Winter rye

Winter rye (grain) is usually superior to other winter annuals (wheat, oats, crimson clover, etc.) both for temporary seeding and as a nurse crop in permanent mixtures. It has more cold hardiness than other annuals and will germinate and grow at lower temperatures. By maturing early, it offers less competition during the late spring period, a critical time in the establishment of perennial species.

Rye grain germinates quickly and is tolerant of poor soils. Including rye grain in fall-seeded mixtures is almost always advantageous, but it is particularly helpful on difficult soils and erodible slopes or when seeding is late. Overly thick stands of rye grain will suppress the growth of perennial seedlings. Limit seeding rates to the suggested level. About 50 pounds per acre is the maximum for this purpose. Where lush growth is expected, that rate should either be cut in half, or rye grain should be eliminated from the mixture.

Annual ryegrass

Annual ryegrass provides dense cover rapidly, but may be more harmful than beneficial in areas that are to be permanently stabilized. Annual ryegrass is highly competitive, and if included in mixtures, it crowds out most other species before it matures in late spring or early summer, leaving little or no lasting cover. It can be effective as a temporary seeding, but if allowed to mature the seed volunteers and seriously interferes with subsequent efforts to establish permanent cover. Winter rye (grain) is preferable in most applications.

German millet

German millet is a fine-stemmed summer annual, useful for temporary seeding, as a nurse crop, and for tacking mulch. It is better adapted to sandy soils than are the Sudangrasses. Normal seeding dates are between the last frost in spring and the middle of August.

Sudangrass

Only the small-stemmed varieties of Sudangrass should be used. Like German millet, Sudangrass is useful for temporary seeding and as a nurse crop, but it is adapted to soils higher in clay content.

Perennials

Perennial plants remain viable over winter and initiate new growth each year. Stands of perennials persist indefinitely under proper management and environmental conditions. They are the principal components of permanent vegetative cover. Wherever possible, use native species for plantings

Native vs. Non-Native Species

In general, if a plant is indigenous to a given area of the country, it is a native. Some define “native” more narrowly, even to a plant indigenous to a given site.

Non-native plant species have been used to control erosion since the dust-bowl days of the 1930s. They are vigorous, establish their dense root systems in the soil, and stabilize bare earth.

These non-native plants, however, can be very competitive. Introduced, invasive plants can cause many more problems than they will solve. They crowd out native species and reduce plant diversity. They are capable of taking over landscapes, resulting in a monoculture. Natural ecosystems are degraded and the site may become vulnerable to disease and pest threats.

Even when non-natives are only a minor component of the seed mix, they tend to outperform and overrun natives for the first few years. Then, over the long term, 10 to 15 years, introduced species may weaken and die out. Native species generally have long-term superiority over non-native species.

Non-natives typically offer two features often lacking with native species; they are readily available and much cheaper than natives. Compared to earthmoving costs on most sites, however, the cost of seed is very small.

In addition to price and availability, project objectives can also affect the decision to plant native or introduced species. For example, an introduced species may be the only seed available that will establish soon enough to protect from a fast-approaching winter and its storms.

Native Species

Native plants evolved under local soil and climatic conditions and are best adapted to sites similar to those on which they grow. They are adapted to annual fluctuations in rainfall and temperatures. Natives often have minimal fungus and insect problems or exist in reasonable balance with such pests. At a proper site, they become established, reproduce, and perform satisfactorily without supplementary irrigation or maintenance. Native plants blend aesthetically with the surrounding vegetation.

Using native plants maintains the genetic integrity of plant populations in the area. Native plants have adapted to an environment; an important consideration in establishing environmentally-sound and low maintenance landscapes.

Native plants are especially adapted to poorer soils and may require no fertilizers or pesticides. Some of them, e.g. sweetfern, refuse to grow well, and sometimes not at all, if given fertilizer. Native plants are also adapted to the soils and require little or no watering.

Retaining native buffers produces great benefits for wildlife. Establishing islands of vegetation offers increased biotic diversity and helps produce wildlife benefits.

Native species maintain natural diversity providing an alternative to boring landscapes which routinely appear around shopping centers, industrial buildings and condominiums. Some people feel that disturbed land should reflect the natural plant systems in place before the site was disturbed.

Native species may be slow to establish, but this is not a significant drawback. Some sort of mulch is usually used anyway to control erosion on newly-seeded disturbed areas. Generally, it takes a year or so before native species can begin protecting the soil, but within two or three years they can provide as much cover as non-natives. Native species are becoming popular for highway embankments, utility corridors, and other development sites.

The availability of native planting stock, seeds or transplants, is sometimes limited because of lack of demand or limited knowledge about propagation methods and cultural requirements. There may be limited numbers of species adapted to artificially altered or disturbed sites. The use of introduced species may be necessary when the numbers of suitable plant species is limited. Increased demand for native plant materials, however, will encourage nursery suppliers to stock them.

Non-Native Species

Other terminology: "Introduced," "Exotic."

The number of introduced species with potential for revegetation of any particular site is usually greater than the number of native species. The commercial availability of introduced species is usually greater because they are the plants of our cultivated landscapes, and more information is usually available about their propagation and cultural requirements.

Introduced plants may sometimes be better adapted to an area than native plants. This may be so because of random chance in evolution or because evolutionary changes in the native plant spectrum have not occurred as rapidly as climatic changes. Introduced plants sometimes have fewer problems than natives because diseases and pests have been "left behind." Introduced species may be more pleasing, aesthetically, than many natives in urbanized areas because they blend with the surroundings.

There are now about 900 alien or introduced plant species in Massachusetts, about a third of the state's flora. In their native habitats, many of these plants were restrained by the pests and diseases that evolved with them over thousands of years. When brought into a new environment, however, they are not bound by natural restraints. The characteristics of disease resistance, fast growth, abundant reproduction, easy propagation, wildlife food production allow them to outcompete and overwhelm native plants.

Native Grasses

Big Bluestem* *Andropogon gerardii*
Big Bluestem is a long-lived perennial, warm-season native grass that has excellent drought resistance. It is being used in critical area seedings where cool season species cannot tolerate the high temperatures or coarse soils. It is selected for the Northeast for its standard durability. It grows from 5 to 7 feet tall and is very leafy.
Big Bluestem is an erosion control plant for sand and gravel pits, mine

spoil, and road sides. It is also excellent cover for wildlife.
Seed Big Bluestem in the early spring, taking care to compact the soil after seeding. Seed at 15 to 20 pounds per acre. It is slow to germinate and establish the first year but will produce fair to good cover by the end of the second year.
Big Bluestem grows well on hot, droughty sites. It tolerates medium to low fertility, acid, sandy, loamy, and clayey soils, has poor shade tolerance and prefers well-drained sites.

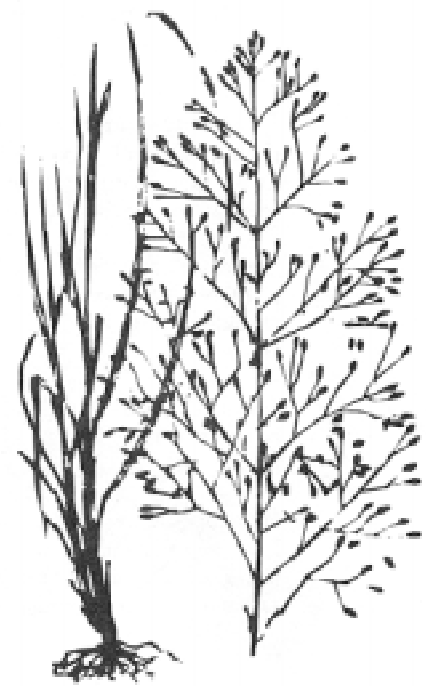
Little Bluestem* *Schizachryrium scoparium*
Little Bluestem is a persistent, low maintenance, warm-season bunch type perennial grass. As a native grass, Little Bluestem is almost always incorporated into mixes used to produce longliving native stands. Used as a cover plant on slopes and road banks.
Grows well on either uplands or lowlands. It is drought tolerant and adapted to wide variety of soil types, but is not very shade tolerant. Its russet-red color in fall and winter make it desirable for landscaping.
Height: 1 - 3’
Seedling vigor is weak, and control of competition is necessary. For best results, soil pH should be between 5.5 to 6.5.

Deertongue *Dichanthelium clandestinum*
Deertongue is a native warm-season bunch grass that grows to a height of 1-1/2 to 3 feet. It has broad, short leaves and a strong, fibrous root system. It will tolerate sites with a pH as low as 3.8 and aluminum concentrations which limit growth of other species.
Deertongue is excellent for revegetating acid mine spoil and ground cover for erodible sandy areas, such as road banks, ditch banks, and gravel pits. The seeds are eaten by many species of birds.
Deertongue grows in low-fertility, acid, loamy, and sandy soils. It has excellent drought tolerance, poor shade tolerance, and tolerates moderately well drained soil.
Establish by seeding early in spring. Seed 12 to 15 pounds per acre. It can be seeded with 10 to 15 pounds of tall fescue or perennial ryegrass for quick cover. It will produce complete cover in 2 years.

Eastern Gamagrass* *Tripsacum dactyloides*
A native, warm-season, perennial, tall grass that grows in large clumps from 1 - 4 feet in diameter on stems 3 - 9 feet tall. Regrows vigorously after mowing. Height: 3 - 9’

Indiangrass* *Sorghastrum nutans*
Indiangrass is a native, perennial warm season bunch type grass that grows 3 to 5 feet in height and produces most heavily from July through September.
Indiangrass is excellent for wildlife habitat, critical area seeding and as roadside beautification and erosion control. Indiangrass is winter hardy. It grows best in deep, well-drained soil, but is tolerant of moderately wet soil.

Tumble Lovegrass*Eragrostis Spectabilis*
Fine-leaved bunch grass; tan, purplish, dainty, feathery seed heads. Grows best in sandy soil. Height: 10 - 12"



Annual Ryegrass *Lolium multiflorum*
Annual Ryegrass is a short lived, annual grass useful for obtaining quick ground cover for lawns, slopes, and mine spoils. It usually germinates in 4 to 7 days, making it very effective for soil erosion. It is adapted to a wide range of soil conditions. Seed in mixtures at a rate of 20 to 30 pounds per acre.

Switchgrass* *Panicum virgatum*
Switchgrass is a medium height to tall perennial grass that grows native in nontidal marshes, stream banks, lake shores, moist woods, and fresh tidal marshes.
Grows under a wide range of soils: low-fertility, acid, sandy, clayey, and loamy soils. Winterhardy, and has excellent heat and drought tolerance, low shade tolerance. Does well on moderately well drained soils. Feathery, open heads; orange-yellow in winter.
Switchgrass is a valuable soil stabilization plant on strip mine spoil, sand dunes, dikes, and other critical areas. It is also suitable for low windbreak plantings in truck crop fields and provides food and excellent nesting and fall and winter cover for wildlife.
Switchgrass requires 1 to 2 years to become totally established. Little or no management is required after establishment.
Height: 4 - 5’
Varieties:
“Blackwell” - reclamation (performs better under low maintenance and wet soils), 4 to 5 feet tall.
“Shelter” - Plant Material Center released variety, wildlife cover, 4 to 6 feet tall. Besides being a good plant for revegetation of surface mine spoil, sand and gravel pits, and steep, sandy roadside cuts, Shelter is an excellent wildlife plant that provides year-round cover and food during the fall and winter. Its stiff stems resist lodging and will recover to an upright position after winter snowstorms.

Canada Wildrye *Elymus canadensis*
A cool season, native grass that prefers moist sites. This perennial bunch grass has very good seedling vigor and early spring growth, which make it easy to establish and cover ground rapidly. (See also Wetland Grasses.)

Riverbank Wild Rye *Elymus riparius*
This rye grows along nontidal shores, wet woods, meadows, prairies and also fresh tidal marshes. With the exception of having a somewhat nodding spike, this perennial grass has very similar characteristics to Virginia Wild Rye. (See also **Wetland Grasses**.)

Virginia Wildrye *Elymus virginicus*
A cool-season, native grass that tolerates both moist and dry sites, shade and full sun. Medium height perennial. While it can be planted alone, it makes an excellent component in a flood plain mix or a habitat mix. (See also **Wetland Grasses**.)

Broomsedge *Andropogon virginicus*
Broomsedge is a very hardy perennial which will tolerate both low pH and fertility. It is a clump type grass that will grow to a height of 1 to 3 feet. Mainly found in upland wet areas, an excellent ground cover, and provides feed for game and songbirds.
**Denotes warm-season grass.*

Other Grasses

Kentucky bluegrass
Kentucky bluegrass has higher lime and fertility requirements than some other perennial grasses. Bluegrass spreads by strong rhizomes and, where adapted, is an excellent soil stabilizer, readily filling in damaged spots. It has undergone intensive breeding activity in recent years, resulting in varieties with more heat tolerance and resistance to hot-weather diseases.

Creeping Red Fescue *Festuca rubra*
Creeping Red Fescue grows in medium fertility, slightly acid, clayey and loamy soils. It has fair drought tolerance, excellent shade tolerance and requires well drained soils. It will produce a complete cover of attractive, uniform sod in one year.
It is a cool season, fine textured, lawn grass that has narrow, bright green leaves. Similar to bluegrass.

It spreads by short underground stems to produce a tight, dense sod for stabilizing road banks and north facing slopes. Above-ground stems have a reddish tint and grow to a height of 18 inches. Red fescue may turn brown in hot, dry summer weather but will recover in the fall.

Red fescue is established by seeding on a firm seed bed in spring or early fall. It is usually used in a mix constituting 25 to 60 percent of the total and seeded at 3 to 5 pounds per thousand square feet. 'Pennlawn' is the most popular variety available.

Red Top *Agrostis alba*

Redtop is a tough, cool-season perennial grass tolerant of infertile, droughty, somewhat acid soils.

Red Top will provide quick cover for critical areas such as grassed waterways, road banks, diversions, and strip mine spoils. Other uses include erosion control, and temporary grass in turf seedings. It can be a useful component of mixtures on dry, stony slopes.

It is a fast-starting, sod-forming grass that is about 18 inches tall at maturity. It will produce effective ground cover the first year. Because it is fast starting and tolerates cold temperatures and poorly drained soils, red top is widely used as a component in mixtures planted on disturbed sites in Northeast.

Red Top grows in clayey, loamy, and sandy soils. It has poor shade tolerance.

Perennial Ryegrass *Lolium perenne*

Perennial Ryegrass is a fast growing, short term grass used for soil stabilization and improvement and lawns. Rapid growth rate is the primary conservation value, producing complete cover in a few months.

It grows in medium fertility, acid, clayey and loamy soils. It has fair drought tolerance, poor shade tolerance and will tolerate somewhat poorly drained soil. It grows to a height of 1 to 2 feet. Many long, narrow leaves extend from the base of the plant.

Oftentimes, seeding mixtures containing red fescue, redtop, Canada bluegrass, or perennial ryegrass are used; as they provide good short term erosion protection, but will allow indigenous plants to eventually naturalize the site.

When used in mixes, ryegrass should not exceed 20% of the mix. The turf varieties are longer lived and include 'Manhattan II,' 'Pennant' and 'Pennfine.'

Native Legumes

Roundhead lespedeza *Lespedeza capita*

Roundhead lespedeza is common on sand dunes, dry fields, sandy woods, and roadsides. It is important for soil stabilization. It flowers from June to September. The foliage is eaten by deer and turkeys. Seeds are consumed by upland birds and rodents.

Roundhead lespedeza seed is commercially available. The seed should be scarified to assure high rates of germination. Life span: perennial.

Panicled tickclover *Desmodium paniculatum*
Panicled tickclover is infrequent to locally common in dry woods, especially if the soil is rocky or sandy. It occasionally is found on roadsides. It flowers from July to September. It is consumed by domestic livestock and deer while it is immature. Rodents and birds utilize the seeds.
Seed is not commercially available. Panicled tickclover has no value for landscaping or erosion control. Life span: perennial.

Canada tickclover *Desmodium canadense*
Canada tickclover is infrequent to common in prairies and thickets and along rivers and roads. It is most common in sandy soil. It flowers from July to September. Foliage is eaten by deer and rabbits. Many kinds of rodents and birds eat the seeds.
Canada tickclover is poor for erosion control. It has no value for landscaping. Life span: perennial.

Yellow wildindigo *Baptisia tinctoria*
Yellow wildindigo is scattered to common in open woods and clearings. It flowers from late May through July. Life span: perennial.
Seed is seldom commercially available. Most seed is destroyed in the legume by weevils. Germination may be improved by scarification and stratification. It is an attractive landscape plant.
Caution must be taken, because it may be poisonous to humans.

Groundnut *Apios americana*
Groundnut is infrequent to locally common in moist soils of ravines, pond and stream banks, and thickets. Life span: perennial.
Seeds are eaten by upland game birds and song birds. Tubers are eaten by mice, rabbits, and squirrels.
Seed is not commercially available. The plant has no potential for landscaping, although it holds promise as a tangle vine for erosion control.

Beach pea *Lathyrus japonicus*
Native to coastal Massachusetts. Adapted to beach/dune sites. Life span: perennial.
Seeded in moist, inter-dune areas.

Bush clover *Lespidesa capitata*
Bush clover may be used in locations where Sericea Lespedeza would previously have been recommended.

Native Ground Covers

Wintergreen *Gaugtheria paceumbens*
6" (Height) x 3' (Spread)
Acid, average/dry soil. Partial shade. Evergreen, reddish in winter, pinkish-white flowers, red berries.

Bearberry *Artostaphylus uva-ursi*
9" x 3'
Sandy soil. Full sun to partial shade. Evergreen, bronze in fall, urn-shaped flowers, red berries, sturdy and reliable.

Cranberry *Vaccinium macrocarpon*
4" x 3'
Cool, moist soil. Full sun. Evergreen, dense, glossy, red edible fruit.

Bunchberry *Cornus Canadensis*
6"
Moist, acid soil. Partial/full shade. Excellent under pines, broad-leaved evergreens, lovely fruit, whorled leaves, beautiful.

Trailing arbutus *Epigaea repens*
5" x 2'
Acid, sandy soil with oak leave/pine needle mulch. Evergreen; dainty, fragrant flowers, does not tolerate disturbance. State flower of Massachusetts.

Virginia creeper *Parthenocissus quinequefolia*
35'
Vine/ground cover. Tolerant as to soil. Sun/shade. Excellent low-maintenance cover, does not need support, red in fall, blue berries.

Coastal Dune Vegetation

Revegetation of construction sites requires special attention to selection of plant species. In the foredune area there are only a few plants that tolerate the stresses of the beach environment. They must be able to survive salt spray, sand blasting, burial by sand, saltwater flooding, drought, heat, and low nutrient supply.

'Cape' American beachgrass

American beachgrass is a cool-season perennial dune grass; for dune building and as a stabilizer in the foredune zone. Easy to propagate, it establishes and grows rapidly, and is readily available from commercial nurseries.

It is an excellent sand trapper capable of growing upward with four feet of accumulating sand in one season. New plantings are usually effective at trapping wind-blown sand by the middle of the first growing season. Beachgrass is also a good plant for interior dune zones as well as other droughty, sandy sites inland.

American beachgrass is extremely valuable for initial stabilization and dune building in disturbed areas. It is severely affected by heat and drought and tends to deteriorate and die behind frontal dunes as the sand supply declines.

It is also susceptible to a fungal disease (Marasmius blight) and a soft scale insect (Eriococcus carolinae). Beachgrass plantings should, therefore, be reinforced with plantings of woody species such as beach plum or barberry. Interior dune areas are candidates for a wider variety of coastal woody shrubs.

Saltmeadow cordgrass

A warm-season perennial useful for transplanting on low areas subject to saltwater flooding. It is a heavy seed producer and is often the first plant on moist sand flats. It collects and accumulates blowing sand, creating an environment suitable for dune plants.

Saltmeadow cordgrass is easy to transplant on moist sites but does not survive on dry dunes. Plants should be dug from young, open stands. Survival of transplants from older, thick stands is poor. Nursery production from seed is relatively easy, and the pot-grown seedlings transplant well. Propagation by seed is possible, but the percentage of viable seed varies.

Beach plum

A shrub of the New England coastal areas, of special interest for its edible fruit. It grows well in sandy, dry, windswept sites, and produces a profusion of white flowers in early May. Beach Plum grows to about 6 feet in height and makes an excellent massed seaside planting or a hedge to prevent erosion because it can tolerate salt spray. Nursery grown plants are recommended, as transplanting from the wild is not often successful. Produces flowers and fruit in 3 to 4 years; matures in 7 to 8 years.

Beach Plum requires cross-pollination to insure fruit production so it is necessary to have more than one plant if plums are desired. Beach plum can be grown in areas other than coastal dunes. Grows in medium-fertility, acid, loamy, and sandy soils; excellent drought tolerance; fair shade tolerance; tolerates moderately well-drained soil.

Bayberry

Bayberry is a semi-evergreen shrub that grows to a height of 6 to 8 feet. Ideal for sunny, coastal sites. Grows in low-fertility, acid, clayey, loamy, and sandy soils; excellent drought tolerance, poor shade tolerance; tolerates moderately well-drained soil. Versatile for landscaping and revegetating, sand dunes and inland areas; berries provide food for birds. It can also help stabilize dry slopes prone to erosion.

Produces fruit in 3 to 4 years; matures in 7 to 8 years. Fruit appears only where both male and female shrubs are planted in the same area. Roots fix nitrogen, which helps bayberry grow in low-fertility soil. Establish by planting bare-root or container-grown seedlings 2 years old.

Bayberry does best in open sites. It can be rejuvenated by cutting it back hard, which stimulates underground lateral stem growth. Stems root at the nodes where new leaves form, and new plants can be established by pinning down a prostrate stem node tightly against the soil.

Rugosa Rose

Rugosa Rose produces large bushy masses of greenery topped by red and white blossoms from soil that is little more than loose sand. Spreading and sprawling, its six-foot branches covered with spines, the plant is a formidable barrier that deters trampling feet and anchors dunes.

It is useful for roadside and dunes, replacing plants which could not tolerate the abuse of pedestrian traffic.

Intertidal Vegetation

In saltwater areas, smooth cordgrass is transplanted in the intertidal zone from mean sea level to mean high water, and saltmeadow cordgrass from mean high water to the storm tide level. In brackish water areas (10 parts per thousand or less of soluble salts), giant cordgrass may be used in the intertidal zone. Greenhouse-grown seedlings of these plants can be obtained from commercial sources, but usually only on special order. Transplants may be dug from young, open natural stands of smooth and saltmeadow cordgrass.

Smooth cordgrass

Smooth cordgrass is the dominant plant in the regularly flooded intertidal zone of saltwater estuaries along the Atlantic and Gulf Coast of North America. It is adapted to anaerobic, saline soils that may be clayey, sandy, or organic. It will tolerate salinities of 35 parts per thousand (ppt) but grows best from 10 to 20 ppt.

Plant height varies from 1 to 7 ft depending on environmental conditions and nutrient supply. It produces a dense root and rhizome mat that helps prevent soil movement. Transplants can be obtained by digging from new, open stands of the grass or may be grown from seed in pots. Seed are collected in September and stored, covered with seawater, and refrigerated. The plants and seedlings grow rapidly when transplanted on favorable sites.

Saltmeadow cordgrass

A fine-leaved grass, 1 to 3 ft in height, that grows just above the mean high tide line in regularly flooded marshes, and throughout irregularly flooded marshes. It can be propagated in the same way as smooth cordgrass except that seed may be stored dry under refrigeration. A stand of saltmeadow cordgrass provides good protection from storm wave erosion.

Giant cordgrass

Grows in brackish, irregularly-flooded areas. Stems are thicker and taller than in the other cordgrasses, growing to a height of 9 to 10 feet. Seedlings are easy to produce in pots and these can be successfully transplanted, but survival of plants dug from existing stands is poor.

Salt grass *Distichlis spicata*

Salt grass is another appropriate plant for intertidal zones.

Native Shrubs

Bayberry *Myrica pensylvanica*
9’ (Height) x 9’ (Spread)
Sandy/clay soils. Full sun to half-shade. Excellent for massing, borders, foundation plantings.

Mountain Laurel *Kalmia latifolia*
11’ x 11’
Acid, moist, well-drained soil. Sun/shade. Evergreen, magnificent in flower, exquisite in mass.

Common Buttonbush *Cephalanthus occidentalis*
9’ x 16’
Moist soil. Sun. Loose in appearance; white, fragrant flowers; best for naturalizing in wet areas.

Pinxterbloom Azalea *Rhododendron nudiflorum*
9’ x 9’
Dry, sandy, acid soil. Bright green foliage, yellow in fall, fragrant light-pink flowers, deciduous.

Roseshell Azalea *Rhododendron noxeum*
9’ x 9’
Moist/dry soil. Deciduous, much-branched, bright pink flowers with clove-like scent.

American Elder *Sambucus canadensis*
9’x 6’
Moist/dry soil. White profuse flowers, edible fruit, good for naturalizing.

Hardhack Spirea *Spiraea tomentosa*
5’ x 5’
Moist soil. Sun. Pink spike-like flowers, thicket of wand-like stems.

Canada Yew *Taxus canadensis*
5’x 7’
Moist, sandy soil. Needs winter shade. Evergreen, hardy; suitable for underplanting in cool, shaded situations.

Lowbush Blueberry *Vaccinium augustifolium*
2'x 2'
Dry, acid soil. Sun/partial shade. White flowers, sweet berry, lustrous blue-green foliage.

Highbush Blueberry *Vaccinium corymbosum*
9' x 10'
Dry, acid soil. Sun/partial shade. Excellent fall color, rounded, compact, edible fruit, white flower.

American Cranberrybush *Viburnum Viburnum milobum*
9' X 9'
Well-drained, moist soil. Sun/partial shade. Informal hedges; excellent flower, fruit, foliage.

Summersweet Clethra *Clethra alnifolia*
6' x 5'
Moist, acid soil. Sun/shade. White fragrant flowers, handsome foliage, pest-free.

Grey Dogwood *Cornus racerosa*
12' x 12'
Moist, well-drained soil. Sun/shade. (***See also Wetland Shrubs***.)

Beaked Filbert *Corylus cornuta*
6'x 6'
Well-drained, loamy soil. Sun/light shade. Interesting beaked fruits, refined, edible fruit.

Common Winterberry *Ilex verticillata*
8'x 8'
Moist, acid soil. Sun/partial shade. Shrub borders, massing waterside planting, male and female required for fruit, red fruit framed by snow. (***See also Wetland Shrubs***.)

Common Juniper *Juniperus communis*
7' x 10"
Dry soil. Sun. Useful for undergrowth and naturalized plantings, extremely hardy, evergreen.

Common Spicebush *Lindera benzdin*
9' x 9'
Moist, well-drained soil. Sun/half shade. Splendid plant in flower and fall color, ornamental fruit. (***See also Wetland Shrubs***.)

Bush Cinquefoil *Potentilla pruticosa*
3’ x 3’
Moist, well-drained soil. Sun/partial shade. Low hedge, perennial border, yellow flowers, graceful appearance.

Blackhaw Viburnum *Viburnum prunifolium*
13’x 10’
Tolerant as to soil. Sun/shade. Massing, shrub border, stiffly branched, red in fall, white flowers.

Rugosa Rose (naturalized) *Rosa rugosa*
5’x 5’
Well-drained soil. Sun. Beautiful in foliage, flower, fruit, hedging, low maintenance, hardy, fragrant flowers.

Native Trees

Red maple *Acer rubrum*
50’ (Height) x 50’ (Spread)
Acid, moist soil. One of first trees to color in fall, dazzling fall color.

Sugar maple *Acer saccharum*
70’ x 50’
Well-drained, slightly acid soil. Beautiful fall color, pleasing growth habit.

Shadblow *Amelanchier canadensis*
20’ x 20’
Average/moist soil. White flowers, edible sweet fruit, yellow in fall.

Sweet birch *Betula lenta*
50’x 40’
Rich, moist, well-drained soil. Reddish-brown bark, best of birches for fall color.

Paper birch *Betula papyrifera*
60’x 30’
Well-drained, acid soil. Full sun. Handsome for bark and fall color, splendid in winter with evergreens.

Common choke cherry *Prunus virginiana*
25’ x 22’
Well-drained soil. Sun to partial shade. Rounded crown, red/purple edible fruit, white fragrant flowers.

White oak *Quercus alba*
75’ x 75’
Moist, well-drained acid soil. Sun. Majestic tree for large areas.

Northern red oak *Quercus borealis*
75'x 60'
Acid, well-drained soil. Shade tolerant. High wildlife value, ascending branches, globular.

Rosebay rhododendron *Rhododendron maximum*
20'x 10'
Moist, acid soil. Shade. Loose, open habit; large, evergreen leaves; rose flowers.

Pussy willow *Salix discolor*
25' x 6'
Moist soil. Sun. Multiple trunks, leggy, high wildlife value.

Canada hemlock *Tsula canadensis*
50' x 30'
Moist, well-drained, acid soil. Sun/shade. Evergreen hedges, graceful, does not tolerate wind or drought.

Nannyberry viburnum *Viburnum lentago*
20' x 15'
Moist/dry soil. Sun/shade. Durable naturalizing or shrub borders, white flowers, handsome fruit, good winter food for birds. (***See also Wetland Trees.***)

Shagbark hickory *Carya ovata*
70'x 35'
Adaptable to wide range of soils. Edible nuts, "shaggy" bark, picturesque. Use chips for barbecues.

Pagoda dogwood *Cornus alternifolia*
20'x 30'
Moist, acid, well-drained soil. Partially shaded. Horizontal, low-branched, excellent textural effects.

Flowering dogwood *Cornus florida*
40' x 40'
Acid, well-drained soil. Four-season character; flower, foliage, fruit, winter habit.

Witchhazel *Hamamelis virginiana*
25' x 20'
Moist soil. Sun/shade. Shrub border, fragrant flowers, yellow in fall. (***See also Wetland Trees***.)

Eastern red cedar *Juniperus virginiana*
45' x 14'
Moist soil. Sun. Windbreaks, hedges, reddish-brown bark, evergreen.

Eastern larch *Larix laricina*
60' x 25'
Moist, well-drained acid soil. Sun. Excellent in groves, horizontal, drooping branches, deciduous.

Eastern white pine *Pinus strobus*
70'x 30'
Tolerant as to soil. Sun/some shade. Handsome, beautiful hedge, graceful, plume-like branches.

Quaking aspen *Populus tremuloides*
40' x 25'
Tolerant as to soil. Narrow leaves flutter in breeze, yellow in fall.

Black cherry *Prunus serotina*
50'x 25'
Moist/dry soil. Sun. Oval-headed; lustrous, dark-green leaves, edible fruit.

Native Wetland Herbs and Grasses

Sweet flag *Acorus calamus*
Sweet Flag is a perennial herb usually 1 to 4 feet tall. It flowers from May to August and has a very pleasant aroma. It grows in shallow waters, nontidal marshes, wet meadows, and fresh tidal marshes.

Swamp Aster *Aster puniceus*
Swamp Aster is a popular wetland perennial herb. It differs from New England Aster in that it often has hairy, purplish stems. It blooms from July to October sporting a bluish, daisy-like flower. The Swamp Aster, also known as the Red Stalk or Purple Stemmed Aster, prefers very moist, swampy areas.

Nodding Bur Marigold *Bidens cernua*
Bur Marigold is an annual herb that reaches up to 3-1/2 feet tall. Its large, yellow, daisy-like flowers, which contain six to eight "petals," will nod as their maturity increases from July into October. It grows in freshwater marshes and along stream banks.

Beggar Ticks *Bidens frondosa*
Beggar-Ticks, also known to many as the Stick-Tight, is an annual herb reaching up to 4 feet. It produces small yellow to orange flowers from June to October. It is found in many wet areas including ditches, pastures, and wet meadows and fields.

Fringed Sedge *Carex crinita*
Fringed Sedge is a perennial grass like plant growing up to 4-1/2 feet high. It flowers from May through June and grows in fresh water marshes, wet meadows, forested wetlands, pond borders, and ditches.

Lurid Sedge *Carex lurida*
This sedge will reach up to 3-1/2 feet tall. It flowers from June into October and grows in freshwater marshes, wet meadows, forested wetlands, ditches, and pond borders.

Fox Sedge *Carex vulpinoidea*
Fox Sedge is very hardy, an ideal pioneer plant when establishing new wetlands. It is a perennial grass like plant reaching up to 3-1/2 feet tall. It flowers from June through August. It grows in fresh water marshes, wet meadows, and other wet places.

Grass-Leaved Goldenrod *Solidago graminifolia*
Grass Leaved Goldenrod is a perennial herb growing up to 4 feet tall. Small yellow flowers appear on the top of the stem from July through October. It grows in nontidal marshes and meadows, various open, moist or dry inland habitats and brackish tidal marshes.

Hop Sedge *Carex lupulina*
These sedges are perennial grasslike plants very common to wetlands. They add beauty as well as seed for ducks and other wildlife. They reach heights between 1- ½ to 3 feet tall and bloom from May to October. They grow well in open woodlands, seasonally flooded areas, standing water, and saturated soils.

Riverbank Wild Rye *Elymus riparius*
This rye grows along nontidal shores, wet woods, meadows, prairies and also fresh tidal marshes. With the exception of having a somewhat nodding spike, this perennial grass has very similar characteristics to Virginia Wild Rye.

Virginia Wild Rye *Elumus virginicus*
Virginia Wild Rye is an excellent pioneer species to use when establishing a new wetland. A cool season perennial, it is good for wildlife cover and food and grows up to 5 feet tall. It is also good for forage. It is found in flood plains, thickets, along road sides, and many other wet areas. It is shade and drought tolerant and can handle wet areas better than Riverbank Wild Rye.

Canada Wild Rye *Elymus canadensis*
Canada Wild Rye is a cool season perennial bunch grass. It is good for wildlife food and cover, growing up to 6 feet tall. It is also good for forage. It grows in dry or moist soils and is drought tolerant.

Joe-Pye Weed (Spotted Flat-Topped) *Eupatoriadelphus maculatus or Eupatorium maculatum*
A very common wetland plant in the northeastern United States. It grows in forested wetlands, saturated fields or meadows, and in shrub swamps. It can be identified by its purple or purplespotted stems and a flat-topped inflorescence with small pinkish or purplish flowers that bloom from July through September.

Boneset *Eupatorium perfoliatum*
Boneset is a perennial herb reaching up to 5 feet high. It flowers in late July through October. Nontidal and fresh tidal marshes, wet meadows, shrub swamps, low woods, shores and other moist areas.

Arrow Arum *Peltandra virginica*
Arrow Arum is a fleshy perennial herb that grows up to 2 feet tall. Inconspicuous flowers on a spike enclosed within a pointed leaf-like structure will appear from May through July. Arrow Arum grows in shallow waters of ponds, lakes, swamps, and marshes.

Pennsylvania Smartweed *Polygonum pennsylvanicum*
Smartweed is an annual herb reaching a height of 6-1/2 feet tall. It grows well in fresh water marshes and wet fields and meadows. Its pink or purple flowers are very small and are arranged in dense clusters.

Blue Flag *Iris versicolor*
A member of the Iris family, Blue Flag is an eye-catching wetland perennial herb that grows in many wet areas including nontidal and tidal marshes, wet meadows, and shores. A blue flower can be seen on the Blue Flag from May through July.

Rattle Snake Grass *Glyceria canadensis*
This perennial grass grows to a height up to 3-1/2 feet tall. It blooms from June through August in forested wetlands, wet meadows, and bogs.

Fowl Manna Grass *Glyceria striata*
A perennial grass that will reach 4 feet in height. It prefers freshwater marshes, open forested wetlands, and other saturated soils. It blooms from June on into September.

Soft Rush *Juncus effusus*
Soft Rush is a perennial grass-like plant that grows up to 3-1/2 feet tall. It flowers from July into September. It grows in nontidal marshes, wet meadows, shrub swamps, wet pastures, and fresh tidal marshes.

Sensitive Fern *Onoclea sensibilis*
Sensitive Fern grows up to 3-1/2 feet tall. It flowers from June into October. It grows in nontidal marshes, meadows, forested wetlands, and fresh tidal marshes, and moist woodlands.

Rice Cutgrass *Leersia oryzoides*
Rice Cutgrass is a medium height to tall perennial grass growing up to 5 feet high. It flowers from June into October. It grows in nontidal marshes, wet meadows, ditches, muddy shores, and fresh tidal marshes.

Wool Grass *Scirpus cyperinus*
Wool Grass is a medium height to tall perennial grass like plant that grows up to 6-1/2 feet high. It flowers from August through September. It grows in nontidal marshes, wet meadows, swamps, and fresh tidal marshes.

Soft-Stemmed Bulrush *Scirpus validus*
This perennial herb grows to a height of up to 10 feet. It flowers from June into September. It grows in inland shallow waters, shores, nontidal marshes, and brackish and fresh tidal marshes.

Canada Goldenrod *Solidago canadensis*
Canada Goldenrod is a medium to tall perennial herb, sporting small yellow flowers in August through October. It grows well along stream banks, and in upland wet areas.

Eastern Bur-Weed *Sparganium americanum*
Eastern Bur-Weed is a perennial growing up to 3-1/2 feet tall. It flowers from May through August. It grows in muddy shores, shallow waters and nontidal marshes.

Prairie Cordgrass *Spartina pectinata*
Prairie Cordgrass is a native perennial that grows from 2 to 7 feet tall. It flowers from July through September and grows in wet spots.

Narrow-Leaved Cattail *Typha angustifolia*
Narrow-Leaved Cattail provides food and shelter for wildlife and is used to control erosion. It has narrow leaves (1/2" wide) and reaches up to 6 feet tall.

Cattail *Typha latifolia*
The Cattail is a perennial herb growing to 10 feet high. It flowers from May through July. It grows in nontidal marshes, ponds, ditches, and fresh tidal marshes.

Blue Vervain *Verbena hastata*
Blue Vervain is a perennial herb that grows up to 5 feet tall. The flowers are bluish to violet and are borne on several dense spikes. Its blooms begin in June and continue through October. It does well in nontidal marshes, wet meadows, open shrub swamps, and moist fields.

Turtlehead *Chelone glabra*
Turtlehead is a perennial herb growing up to 3 feet tall. The flowers, which bloom from July to September, resemble turtle heads as the petals are two-lipped and tubular. It can be found growing along stream banks, forested wetlands, swamps and fresh water marshes.

Native Wetland Shrubs and Trees

Red Osier Dogwood *Cornus stolonifera*
Has red stems, green leaves, and white fruit. Its ability to spread by layering and its tolerance of wet soils makes it an excellent choice for stream bank erosion control. It is also a useful upland plant, providing food and cover for wildlife and color for shrub borders and landscaping. Grows in medium-fertility, slightly acid, clayey, loamy, and sandy soils. It has moderate shade tolerance and poor drought tolerance.
When planting along stream banks, plant at the waters edge, using rooted cuttings or fresh hardwood unrooted cuttings that are at least 9 to 12 inches long and leaving 2 inches of the stem above ground. Spreads by layering where stems contact the ground. It is moderately fast growing, reaching a height of 6 to 10 feet.

Button bush *Cephalanthus occidentalis*
Button Bush is a broad leaved, deciduous, tall shrub or small tree growing to 33 feet high. Its flowers are white and appear from May though June. It grows in nontidal and fresh tidal marshes and shrub swamps, forested wetlands, and borders of streams, lakes and ponds.

Grey Dogwood *Cornus racemosa*
Grey Dogwood is a shrub similar to Silky Dogwood, but possesses grey twigs and white berries. It grows in medium fertility, acid, clayey, loamy and sandy soils. Unlike Silky Dogwood it requires well-drained soil. It is best adapted along stream banks, in forested wetlands and shrub wetlands. It can be established by seed or unrooted cuttings.

Silky dogwood *Cornus amomum*
Silky Dogwood is a broad leaved deciduous shrub that grows to a height of 9 to 12 feet. White flowers and blue or white berries remain until late summer or early fall. It is used for stabilizing lower slopes of stream banks. It also provides food and cover for game birds, song birds, rabbits, raccoon, and other wildlife.

To establish on stream banks plant Silky Dogwood seedlings, rooted cuttings or unrooted cuttings 2 feet apart or broadcast seed. Silky Dogwood provides effective stream bank protection in 3 to 5 years and also produces fruit at this age. Silky Dogwood grows in forested wetlands, shrub wetlands, stream banks, and moist woods. It grows in medium fertility, acid, clayey, loamy, and sandy soils. It has fair drought tolerance, fair shade tolerance and tolerates poorly drained soil.

Witch Hazel *Hamamelis virginiana*
Witch Hazel is a broad-leaved deciduous shrub or low tree up to 30 feet tall. It flowers from September into November. It grows in seasonally flooded swamps and forested wetlands, and tidal swamps.

Common Winterberry *Ilex verticillata*
Winterberry is a broad leaved, deciduous shrub growing up to 16 feet tall. It flowers from May through July. It grows in seasonally flooded shrub swamps and forested wetlands. Showy red berries remain on the plant until spring.

Spicebush *Lindera benzoin*
Spicebush is a broad leaved, deciduous shrub growing up to 16 feet tall. It flowers from March through July. It grows in nontidal marshes, ponds, ditches and fresh tidal woodlands.

Swamp Rose *Rosa palustris*
Swamp Rose is a broad-leaved, deciduous thorny shrub growing up to 7 feet tall. It blooms pink five-petalled flowers from May through July. It grows in upland fields, thickets, and woods, and forested wetlands.

Black Willow *Salix nigra*
A broad-leaved deciduous shrub or tree that can reach a height of 70 feet tall or more. It grows well in nontidal forested wetlands, fresh tidal marshes, tidal swamps, and wet meadows. Identifying characteristics of the Black Willow is its brownish or blackish deeply grooved bark and its narrow leaves.

Common Elderberry *Sambucus canadensis*
Elderberry is a broad leaved deciduous shrub growing up to 12 feet tall. It flowers from June through July. It grows in nontidal and fresh tidal marshes and swamps, meadows, old fields, moist woods, and along road sides.

Arrowwood Viburnum *Viburnum dentatum*
Arrowwood is a broad leaved deciduous shrub growing up to 15 feet tall. It flowers from May through July. It grows in nontidal and fresh tidal marshes, shrub swamps, and forested wetlands. It also does well in moist woods, and various drier sites.

Nannyberry or Wild Raisin *Viburnum lentago*
Nannyberry is a broad leaved deciduous shrub or small tree growing up to 27 feet tall. It has long, pointed leaves with winged stalks. It flowers from April into May and produces berries in the fall that are eaten by wildlife. It grows in forested wetlands, open upland woods and thickets, fence rows and road sides.

Northern or Smooth Arrowwood *Viburnum recognitum*
Arrowwood is a broad leaved deciduous shrub growing up to 15 feet tall. It flowers from May through July. It grows in nontidal and fresh marshes, shrub swamps, forested wetlands, moist woods and various drier sites.

American Cranberrybush *Viburnum trilobum*
This shrub provides winter food for grouse, songbirds, and squirrels and is useful for hedges and borders. It grows in medium-fertility, acid, clayey, loamy and sandy soils. It has poor drought tolerance, fair shade tolerance and tolerates poorly drained soil.

Establishing Vegetation

Site Preparation

The soil on a disturbed site must be modified to provide an optimum environment for germination and growth. Addition of topsoil, soil amendments, and tillage are used to prepare a good seedbed. At planting the soil must be loose enough for water infiltration and root penetration, but firm enough to retain moisture for seedling growth. Tillage generally involves disking, harrowing, raking, or similar method. Lime and fertilizer should be incorporated during tillage.

Topsoiling

The surface layer of an undisturbed soil is often enriched in organic matter and has physical, chemical, and biological properties that make it a desirable planting and growth medium. Topsoil should be stripped off prior to construction and stockpiled for use in final revegetation of the site.

Topsoiling may not be required for the establishment of less demanding, lower maintenance plants, but it is essential on sites having critically shallow soils or soils with other severe limitations. It is also essential for establishing fine turf and ornamentals.

Soil Amendments

Liming

Liming is almost always required on disturbed sites to decrease the acidity (raise pH), reduce exchangeable aluminum, and supply calcium and magnesium. Even on the best soils, some fertilizer is required. Suitable rates and types of soil amendments should be determined through soil tests. Limestone and fertilizer should be applied uniformly during seedbed preparation and mixed well with the top 4 to 6 inches of soil.

Organic amendments

Organic amendments, in addition to lime and fertilizer, may improve soil tilth, structure, and water-holding capacity—all of which are highly beneficial to seedlings establishment and growth. Some amendments also provide nutrients. Examples of useful organic amendments include well-rotted animal manure and bedding, crop residue, peat, and compost.

Organic amendments are particularly useful where topsoil is absent, where soils are excessively drained, and where soils are high in clay. The application of several inches of topsoil usually eliminates the need for organic amendments.

Surface Roughening

A rough surface is especially important to seeding sloped areas. Contour depressions and loose surface soil help retain lime, fertilizer, and seed. A rough surface also reduces runoff velocity and increases infiltration.

Permanent Cover

A permanent type of vegetation should be established as soon as possible: to reduce damages from sediment and runoff to downstream areas; and to avoid severe erosion on the site itself.

Vegetation may be in the form of grass-type growth by seeding or sodding, or it may be trees or shrubs, or a combination of these. Establishing this cover may require the use of supplemental materials, such as mulch or jute netting.

Planting Methods

Seeding is the fastest and most economical method that can be used with most species. However, some grasses do not produce seed and must be established by planting runners or stems (sprigging) or plugs cut from sod (plugging). Seedbed preparation, liming, and fertilization are essentially the same regardless of the method chosen.

Seeding

Uniform seed distribution is essential. This is best obtained using a cyclone seeder (hand-held), drop spreader, conventional grain drill, cultipacker seeder, or hydraulic seeder. The grain drill and cultipacker seeders (also called grass seeder packer or Brillion drill) are pulled by a tractor and require a clean, even seedbed.

On steep slopes, hydroseeding may be the only effective seeding method. Surface roughening is particularly important when preparing slopes for hydroseeding. In contrast to other seeding methods, a rugged and even trashy seedbed gives the best results.

Hand-broadcasting should be considered only as a last resort, because uniform distribution is difficult to achieve. When hand-broadcasting of seed is necessary, minimize uneven distribution by applying half the seed in one direction and the other half at right angles to the first. Small seed should be mixed with sand for better distribution.

A “sod seeder” (no-till planter) is used to restore or repair weak cover. It can be used on moderately stony soils and uneven surfaces. It is designed to penetrate the sod, open narrow slits, and deposit seed with a minimum of surface disturbance. Fertilizer is applied in the same operation.

Inoculation of legumes

Legumes have bacteria, rhizobia, which invade the root hairs and form gall-like “nodules.” The host plant supplies carbohydrates to the bacteria, which supply the plant with nitrogen compounds fixed from the atmosphere. A healthy stand of legumes, therefore, does not require nitrogen fertilizer. Rhizobium species are host specific; a given species will inoculate some legumes but not others. Successful establishment of legumes, therefore, requires the presence of specific strains of nodule-forming, nitrogen-fixing bacteria on their roots. In areas where a legume has been growing, sufficient bacteria may be present in the soil to inoculate seeded plants, but in other areas the natural Rhizobium population may be too low.

In acid subsoil material, if the specific Rhizobium is not already present, it must be supplied by mixing it with the seed at planting. Cultures for this purpose are available through seed dealers.

Sprigging and Plugging

Sprigging refers to planting stem fragments consisting of runners (stolons) or lateral, belowground stems (rhizomes), which are sold by the bushel. This method can be used with most warm-season grasses and with some ground covers, such as periwinkle. Certain dune and marsh grasses are transplanted using vertical shoots with attached roots or rhizomes. Lawn-type plants are usually sprigged much more thickly.

Broadcasting is easier but requires more planting material. Broadcast sprigs must be pressed into the top ½ to 1 inch of soil by hand or with a smooth disk set straight, special planter, cultipacker, or roller.

Plugging differs from sprigging only in the use of plugs cut from established sod, in place of sprigs. It is usually used to introduce a superior grass into an old lawn. It requires more planting stock, but usually produces a complete cover more quickly than sprigging.

Sodding

In sodding, the soil surface is completely covered by laying cut sections of turf. A commercial source of high-quality turf is required and water must be available. Plantings must be wet down immediately after planting, and kept well watered for a week or two thereafter.

Sodding, though quite expensive, is warranted where immediate establishment is required, as in stabilizing drainage ways and steep slopes, or in the establishment of high-quality turf. If properly done, it is the most dependable method and the most flexible in seasonal requirements. Sodding is feasible almost any time the soil is not frozen.

Irrigation

Irrigation, though not generally required, can extend seeding dates into the summer and insure seedling establishment. Damage can be caused by both under and over-irrigating. If the amount of water applied penetrates only the first few inches of soil, plants may develop shallow root systems that are prone to desiccation. If supplementary water is used to get seedlings up, it must be continued until plants become firmly established.

Mulching

Mulch is essential to the revegetation of most disturbed sites, especially on difficult sites such as southern exposures, channels, and excessively dry soils. The steeper the slope and the poorer the soil, the more valuable it becomes. In addition, mulch fosters seed germination and seedling growth by reducing evaporation, preventing soil crusting, and insulating the soil against rapid temperature changes.

Mulch may also protect surfaces that cannot be seeded. Mulch prevents erosion in the same manner as vegetation, by protecting the surface from raindrop impact and by reducing the velocity of overland flow. There are a number of organic and a few chemical mulches that may be useful, as well as nets and tacking materials.

Maintenance

Satisfactory stabilization and erosion control requires a complete vegetative cover. Even small breaches in vegetative cover can expand rapidly and, if left unattended, can allow serious soil loss from an otherwise stable surface. A single heavy rain is often sufficient to greatly enlarge bare spots, and the longer repairs are delayed, the more costly they become. Prompt action will keep sediment loss and repair cost down.

New seedlings should be inspected frequently and maintenance performed as needed. If rills and gullies develop, they must be filled in, re-seeded, and mulched as soon as possible. Diversions may be needed until new plants take hold.

Maintenance requirements extend beyond the seeding phase. Damage to vegetation from disease, insects, traffic, etc., can occur at any time. Herbicides and regular mowing may be needed to control weeds; dusts and sprays may be needed to control insects. Herbicides should be used with care where desirable plants may be killed. Weak or damaged spots must be relimed, fertilized, mulched, and reseeded as promptly as possible. Refertilization may be needed to maintain productive stands.

Vegetation established on disturbed soils often requires additional fertilization. Frequency and amount of fertilization can best be determined through periodic soil testing. A fertilization program is required for the maintenance of fine turf and sod that is mowed frequently. Maintenance requirements should always be considered when selecting plant species for revegetation.

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Native Grasses and Legumes for Eastern Massachusetts

Essex, Middlesex, Suffolk, Norfolk, Plymouth, Bristol, Barnstable, Dukes and Nantucket Counties

Dry Sites

Ticklegrass	Agrostis hyemalis	(no Essex) (no seed source)(cool season)
Upland Bentgrass	Agrostis prennans	(no seed source)(cool season)
Beachgrass	Ammophila brevigulata	(cool season)
Big Bluestem	Andropogon gerardii	(warm season)
Broomsedge	Andropogon virginicus	(warm season)
Common Hairgrass	Deschampsia flexuosa	(no seed source) (warm)
Deertongue grass	Dichanthehum clandestinum	(warm season)
Canada Wild Rye	Elymus canadensis	(no Cape and Islands) (cool season)
Tumble Lovegrass	Eragrostis spectabilis	(warm season)
Red Fescue	Festuca rubra	(cool season)
Nimblewill	Muhlenbergia schreberi	(no seed source)
Switchgrass	Panicum virgatum	(warm season)
Little Bluestem	Schizachyrium scoparium	(warm season)
Dropseed	Sporabolus cryptandrus	(no Cape and Islands) (warm season)
Poverty Dropseed	Sporobolus vaginiflorus	(Annual) (warm season)
Indiangrass	Sorghastrum nutans	(warm season)
Purple Sandgrass	Triplasis purpurea	(Annual) (cool season)
Wild Indigo	Baptisia tinctoria	
Showy Tick-Trefoil	Desmodium canadense	
Beach Pea	Lathyrus japonicus var. glaber	
Round Head Bush Clover	Lespideza capitata	

Moist Sites

Creeping/Marsh Bentgrass	Agrostis stolonifera var. palustris	(cool season)
Fringed Bromegrass	Bromus ciliatus	(cool season)
Deertongue Grass	Dichanthelium clandestinum	(warm season)
Canada Wild Rye	Elymus canadensis	(cool season)
Virginia Wild Rye	Elymus virginicus	(cool season)
Purple Lovegrass	Eragrostis pectinacea	(warm season)
Switchgrass	Panicum virgatum	(warm season)
Fowl Meadow Grass	Poa palustris	(cool season)
Salt Meadow Cordgrass	Spartina patens	(tidal)
Giant Cordgrass	Spartina cynocuroides	(brackish)
Eastern Gammagrass	Tripsacum dactyloides	(warm season)
Ground Nut	Apios americana	
Showy Tick-Trefoil	Desmodium canadense	

Wet Sites

Creeping Bentgrass	Agrostis stolonifera var. palustris	(cool season)
Fringed Bromegrass	Bromus ciliatus	(cool season)
Blue Joint Reed Grass	Calamagrostis canadensis	(cool season)
Stout Wood Reed	Cinna arundinacea	(cool season)
Canada Manna Grass	Glyceria canadensis	(cool season)
Fowl Meadow Grass	Glyceria striata	(cool season)
Rice Cut Grass	Leersia oryzoides	(cool season)
Marsh Mully	Muhlenbergia glomerata	(no Islands)
Smooth Cordgrass	Spartina altiniflora	(tidal)
Freshwater Cordgrass	Spartina pectinata	

Native Grasses and Legumes for Central and Western Massachusetts

Worcester, Franklin, Hampshire, Hampden and Berkshire Counties

Dry Sites

Big Bluestem	Andropogon gerardii	(warm season)
Broomsedge	Andropogon virginicus	(warm season)(no Berkshire or Franklin)
Common Hair Grass	Deschampsia flexuosa	(warm season)(no seed source)
Deertongue Grass	Dicanthelium clandestinum	(warm season)
Nodding Wild Rye	Elymus canadensis	(cool season)
Tumble Lovegrass	Erogrostis spectabolis	(warm season)
Red Fescue	Festuca rubra	(cool season)
Nimblewill	Muhlenbergia schreberi	(no seed source)
Switchgrass	Panicum virgatum	(warm season)
Little Bluestem	Schizachyrium scoparium	(warm season)
Yellow Indiangrass	Sorghastrum nutans	(warm season)
Sand Dropseed	Sporobolus cryptandrus	(no seed source)
Poverty Dropseed	Sprobolus vaginiflorus	(Annual)
Wild Indigo	Baptisia tinctoria	
Showy Tick Trefoil	Desmodium canadense	
Narrow-leafed Tick Trefoil	Desmodium paniculatum	
Round Head Bush Clover	Lespideza capitata	

Moist Sites

Creeping/Marsh Bentgrass	Agrostis stolonifera var. palustris	(cool season)
Fringed Bromegrass	Bromus Ciliatus	(cool season)
Wood Reed grass	Cinna arundinacea	(cool season)
Riverbank Wild Rye	Elymus riparius	(cool season)
Virginia Wild Rye	Elymus virginicus	(cool season)
Green Muhly	Muhlenbergia glomerata	
Switchgrass	Panicum virgatum	(warm season)
Ground Nut	Apios americana	
Showy Tick Trefoil	Desmodium canadense	

Wet Sites

Creeping/Marsh Bent Grass	Agrostis stolonifera var. palustris	(cool season)
Blue Joint Reed Grass	Calamagrostis canadensis	(cool season)
Wood Reed Grass	Cinna arundinacea	(cool season)
Canada Mannagrass	Glyceria canadensis	(cool season)
Fowl Meadow Grass	Glyceria striata	(cool season)
Rice Cut Grass	Leersia oryzoides	(cool season)
Fowl Meadow Grass	Poa palustris	(cool season)
Fresh Water Cordgrass	Spartina pectinata	

Courtesy of Natural Resources Conservation Service, Amherst, MA.
Source: Massachusetts Natural Heritage and Endangered Species Program

Tree and Shrub Plantings

Trees For Dry Soils

Scientific Name	Common Name	Mature Height
Acer Negundo	Box Elder	60’
Betula populifolia	Gray Birch	30’
*Pinus resinosa**	Red Pine	80’
*Pinus strobus**	Eastern White Pine	90’
*Pinus sylvestris**	Scotch Pine	60’
Populus tremuloides	Quaking Aspen	50’

Shrubs For Dry Soils

Scientific Name	Common Name	Mature Height
Acer ginnala	Amur Maple	20’
Ceanothus americanus	New Jersey Tea	2’
Comptonia peregrina	Sweet Fern	3’
Corylus americana	American Hazelnut	6’
Gaylussacia baccata	Black Huckleberry	3’
*Juniperus communis**	Common Juniper	3-30’
*Juniperus virginiana**	Red-cedar	10-90’
Myrica pennsylvanica	Bayberry	5’
Rhus aromatica	Fragrant Sumac	3’
Rhus copallina	Shining Sumac	30’
Rhus glabra	Smooth Sumac	9-15’
Rhus typhina	Stagborn Sumac	30’
Rosa rugosa	Rugosa Rose	6’
Rosa virginiana	Virginia Rose	3’
Viburnum lentago	Nannyberry	15’

**evergreen*

Trees For Moderately Moist Soils

Scientific Name	Common Name	Mature Height
Fraxinus pennsylvanica	Green Ash	50’
Picea abies*	Norway Spruce	150’
Picea pungens*	Colorado Spruce	100’
Pinus strobus*	Eastern White Pine	100-150’
Populus nigra ‘Italica’	Lombardy Poplar	90’
Pseudotsuga menziesii*	Douglas-fir	100-300’
Salix nigra	Black Willow	40’
Sorbus americana	American Mountain Ash	25’
Thuja occidentalis*	American Arbor-vitae	60’
Tilia americana	Basswood	60-80’
Tsuga canadensis*	Canada Hemlock	90’

Shrubs For Moderately Moist Soils

Scientific Name	Common Name	Mature Height
Cornus amomum	Silky Dogwood	6-10’
Cornus racemosa	Gray-stemmed Dogwood	6’
Corylus americana	American Hazelnut	6’
Corylus cornuta	Beaked Hazelnut	12’
Forsythia Z intermedia	Border Forsythia	9’
Hamemelis virginiana	Common Witchhazel	15’
Ilex glabra	Inkberry	5’
Myrica pennsylvanica	Bayberry	5’
Rhododendron maximum	Rhododendron	20’

**evergreen*

Trees For Very Moist Soils

Scientific Name	Common Name	Mature Height
Acer negunda	Box Elder	60’
Acer rubrum	Red Maple	60’
Acer saccharinum	Silver Maple	70’
Fraxinus pennsylvanica	Green Ash	40’
Fraxinus nigra	Black Ash	45’
Larix laricina	American Larch	60’
Platanus occidentalis	Sycamore	100’
Populus deltoides	Eastern Cottonwood	70’
Salix nigra	Black Willow	40’
Salix bebbiana	Bebb Willow	25’
Thuja occidentalis	White Cedar	60’

Shrubs For Very Moist Soils

Scientific Name	Common Name	Mature Height
Alnus rugosa	Speckled Alder	20’
Alnus serulata	Smooth Alder	20’
Aronia arbutifolia	Red Chokeberry	20’
Clethra alnifolia	Sweetpepper Bush	10’
Cornus amomum	Silky Dogwood	8’
Cornus stolonifera	Red Osier Dogwood	8’
Ilex verticillata	Winterberry	10’
Lonicera canadensis	Canada Honeysuckle	15’
Lyonia ligustrium	Maleberry	8’
Rhododendrum canadensis	Rhodora***	12’
Rubus odoratus	Purple Flowering Raspberry	8’
Salix discolor	Pussy Willow	10’
Salix lucida	Shining Willow	8’
Sambucus canadensis	Elderberry	10’
Vaccinium corymbosum	Highbush Blueberry	10’
Viburnum cassinoides	Wild Raisin	12’
Viburnum acerifolium	Mapleleaf Viburnum	6’
Viburnum dentatium/recognitum	Arrowwood	8’
Viburnum trilobum	Highbush Cranberry	15’

Spacing Distance

For water erosion control:

Small to medium shrubs	1’ x 1’ to 2’ x 2’
Medium to large shrubs	2’ x 2’ to 4’ x 4’
Trees	4’ x 4’ to 8’ x 8’

For wind erosion control:

Small to medium shrubs	2’ x 2’ to 4’ x 4’
Medium to large shrubs	4’ x 4’ to 6’ x 6’
Trees	6’ x 6’ to 10’ x 10’

References

Technical assistance provided by Natural Resources Conservation Service staff at Amherst, MA, Massachusetts Native Plant Advisory Committee, and the Massachusetts Natural Heritage and Endangered Species Program.

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North Carolina Sediment Control Commission, ***Erosion and Sediment Control Planning Design Manual***, Raleigh, NC, September, 1988.

Washington State Department of Ecology, ***Stormwater Management Manual for the Puget Sound Basin***, Olympia, WA, February, 1992.

Soil Bioengineering

Soil bioengineering methods use vegetative materials in combination with more traditional landshaping, rock placement, and structural techniques. Bioengineering techniques can be used for immediate protection of slopes against surface erosion, cut and fill slope stabilization, earth embankment protection, and small gully repairs.

Stems and branches of living plants are used as soil reinforcing and stabilizing material. Techniques include live staking, fascines, brushlayers, branchpacking, and live gully repair. Roots develop and foliage sprouts when the vegetative cuttings are placed in the ground. The resulting vegetation becomes a major structural component of the bioengineering system.

Bioengineering combines biological elements with engineering design principles. The requirements for both must be considered when planning and designing measures. Engineering requirements may call for highly compacted soil for fill slopes, for example, while plants prefer relatively loose soil. Using a sheepsfoot roller for compaction is a solution that would integrate biological and engineering requirements because it compacts the soil, but also allows plant establishment in resulting depressions in the slope.

Vegetation can be used with rigid construction such as surface armoring, gravity retaining walls, and rock buttresses to create vegetated structures. Vegetation enhances the structures and helps reduce surface erosion, but usually does not provide any reinforcement benefits.

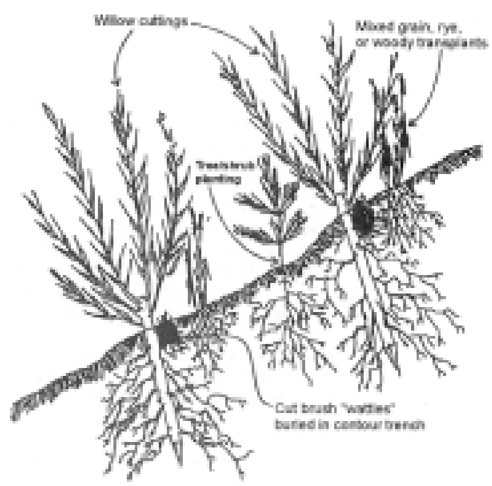
Vegetated cribwalls, gabions, and rock walls are bioengineering techniques that use porous structures with openings through which vegetative cuttings are inserted and established. The structural elements provide immediate resistance to sliding, erosion, and washout. As vegetation becomes established, roots develop, binding the slope together in a unified, coherent mass. Over time, the structural elements diminish in importance as the vegetation increases in strength and functionality.

Contact the local Conservation Commission regarding any stream crossing or other work conducted in a wetland resource area. The Massachusetts Wetland Protection Act requires that the proponent file a "Request for Determination of Applicability" or "Notice of Intent."

Material in this section is adapted from Chapter 18, *Soil Bioengineering for Upland Slope Protection and Erosion Reduction*, of the Natural Resources Conservation Service *Engineering Field Handbook,* and from *Stormwater Management Manual for the Puget Sound Basin*, Washington State Department of Ecology.

Vegetative Components

Vegetation offers long-term protection against surface erosion on slopes. It provides some protection against shallow mass movement. Vegetation helps to prevent surface erosion by:



- Binding and restraining soil particles in place,
- Reducing sediment transport,
- Intercepting raindrops,
- Retarding velocity of runoff,
- Enhancing and maintaining infiltration capacity,
- Minimizing freeze-thaw cycles of soils susceptible to frost.

Woody vegetation has deeper roots and provides greater protection against shallow mass movement by:

- Mechanically reinforcing the soil with roots,
- Depleting soil-water through transpiration and interception,
- Buttressing and soil arching action from embedded stems.

Examples

Fascines:

Woody species, such as shrub willow or shrub dogwood, are used for "live fascines" -long bundles of branch cuttings bound together into sausage-like bundles. The bundles are placed with the stems oriented generally parallel to the slope contour.

Live fascines dissipate the energy of flowing water by trapping debris and providing a series of benches on which grasses, seedlings, and transplants establish more easily. Portions of the live fascines root and become part of the stabilizing cover. Live fascines provide an immediate increase in surface stability and can further improve soil stability to depths of two to three feet as roots develop.

Brushlayering:

Live branches or shoots of such woody species as shrub willow, dogwood, or privet are placed in successive layers with the stems generally oriented perpendicular to the slope contour. This orientation is the optimal direction for maximum reinforcing effect in a slope. Brushlayering can improve soil stability to depths of 4 to 5 feet.

Structural Components

Structural measures help stabilize a slope against shallow mass movement and protect the slope against rill and gully formation. Structures also help establish vegetation on steep slopes or in areas subject to severe erosion. They may make it feasible to establish plants on slopes steeper than would normally be possible. Structures stabilize slopes during critical seed germination and root growth. Without this stabilization, vegetative plantings would fail during their most vulnerable time.

Materials

Structures can be built from natural or manufactured materials. Natural materials, such as earth, rock, stone, and timber, usually cost less, are environmentally more compatible, and are better suited to vegetative treatment or slight modifications than are manufactured materials. Natural materials may also be available onsite at no cost.

Some structures are comprised of both natural and manufactured materials. Examples include concrete cribwalls, steel bin walls, gabion walls or revetments, welded wire or polymeric geogrid walls, and reinforced earth. In these cases steel and concrete mostly provide rigidity, strength, and reinforcement, whereas stone, rock, and soil provide mass. These types of structures have spaces that are often planted with herbaceous or woody vegetation.

Retaining Structures

A retaining structure of some type is usually required to protect and stabilize extremely steep slopes. Low retaining structures at the toe of a slope make it possible to grade the slope back to a more stable angle that can be successfully revegetated without loss of land at the crest. Structures are generally capable of resisting much higher lateral earth pressures and shear stresses than vegetation.

Grade Stabilization Structures

Grade stabilization structures are used to control and prevent gully erosion. A grade stabilization structure reduces the grade above it and dissipates the excess energy of flowing water within the structure itself. Debris and sediment tend to be deposited and trapped upstream of the structure. This, in turn, permits establishment of vegetation behind the structure, which further stabilizes the ground. Grade stabilization structures may range from a series of simple timber check darns to complex concrete overfall structures and earth embankments with pipe spillways.

Gully control is an example of the integration of structures and vegetation. Structural measures may be required in the short term to stabilize critical locations. The long-term goal is to establish and maintain a vegetative cover that prevents further erosion. Vegetation alone will rarely stabilize gully headcuts because of the concentrated water flow, overfalls, and pervasive forces that promote gully enlargement in an unstable channel system. Initially, the vegetation and the structure work together in an integrated fashion. The ultimate function of these structures, however, is to help establish vegetation which will provide longterm protection.

Factors to Consider

Bioengineering integrates the characteristics of vegetative components with those of structural components. The resulting systems and their components have benefits and limitations that need to be considered prior to selecting them for use.

Bioengineering is not appropriate for all sites and situations. In some cases, conventional vegetative treatment (e.g., grass seeding and hydro mulching) works satisfactorily at less cost. in other cases, the more appropriate and most effective solution is a structural retaining system alone or in combination with bioengineering.

Environmental Compatibility

Bioengineering systems generally require minimal access for equipment and workers and cause relatively minor site disturbance during installation. These are generally important considerations in environmentally sensitive areas, such as parks, woodlands, and scenic corridors where aesthetic quality, wildlife habitat, and similar values may be critical.

Cost Effectiveness

Combined slope protection systems are more cost effective than the use of either vegetative treatments or structural solutions alone in some instances. Where construction methods are labor intensive and labor costs are reasonable, the combined systems may be especially cost effective. If labor is scarce or costly, however, bioengineering systems may be less practical than structural measures.

Using native plant materials accounts for some of the cost effectiveness because plant costs are limited to labor for harvesting and handling and direct costs for transporting the plants to the site.

Planting Times

Bioengineering systems are most effective when they are installed during the dormant season, usually the late fall winter, and early spring. This often coincides with the time that other construction work is slow.

Constraints on planting times or the availability of the required quantities of suitable plant materials during allowable planting times may limit the usefulness of bioengineering methods.

Difficult Sites

Bioengineering may be an alternative for small, sensitive, or steep sites where the use of machinery is not feasible and hand labor is a necessity. Rapid vegetative establishment may be difficult, however, on extremely steep slopes.

Suitable soils are needed for plant growth. Rocky or gravelly slopes may lack sufficient fines or moisture to support plant growth. Restrictive layers in the soil, such as hardpans, may restrict root growth.

Vegetation would be of limited use on slopes that are exposed to high velocity water flow or constant inundation.

Harvesting Local Plant Material

Vegetation can often be obtained as dormant cuttings from local stands of willows and other suitable species. This stock is already well suited to the climate, soil conditions, and available moisture and is a good candidate for survival. Using local plant materials and gathering in the wild could result in short supplies or unacceptable depletion of site vegetation. Some localities have prohibitions against gathering native plants and materials must be purchased from commercial sources.

Biotechnical Strengths

Bioengineering systems are strong initially and grow stronger with time as vegetation becomes established. In some instances, the primary role of the structural component is to give the vegetation a better chance to become established. Bioengineering systems can usually withstand heavy rainfalls immediately after installation. Even if established vegetation dies, the plant roots and surface residue still furnish protection during reestablishment.

Design Considerations

Consider site topography, geology, soils, vegetation, and hydrology. Avoid extensive grading and earthwork in critical areas. Perform soil tests to determine if vigorous plant growth can be supported.

Topography and Exposure

Note the degree of slope in stable and unstable areas. Also note the presence or lack of moisture. The potential for success of bioengineering treatments can best be determined by observing existing stable slopes in the vicinity of the project site.

Note the type and density of existing vegetation in areas with and without moisture and on slopes facing different directions. Certain plants grow well on east-facing slopes, but will not survive on south-facing slopes.

Look for areas of vegetation that may be growing more vigorously than other site vegetation. This is generally a good indicator of excess moisture, such as seeps and a perched water table, or it may reflect a change in soils.

Geology and Soils

Note evidence of past sliding. If site evidence exists, determine whether the slide occurred along a deep or shallow failure surface. Leaning or deformed trees may indicate previous slope movement or downhill creep. In addition to site evidence, check aerial photos, which can reveal features that may not be apparent from a site visit.

Determine soil type and depth. Use the soil survey report, if available.

Hydrology

Determine the drainage area. Note whether water can be diverted away from the problem area.

Are there concentrated discharges?

Calculate peak flows through the project area.

If a seep area is noted, locate the source of the water. Determine whether the water can be intercepted and diverted away from the slope face.

Vegetation

Retain existing vegetation, limit the removal of vegetation. Vegetation provides excellent protection against surface erosion and shallow slope failures.

Bioengineering measures are designed to aid or enhance the reestablishment of vegetation.

Limit cleared area to the smallest practical size.

Limit duration of disturbance to the shortest practical time.

Remove and store existing woody vegetation that may be used later in the project.

Schedule land clearing during periods of low precipitation whenever possible.

Earthwork

Sites usually require some earthwork prior to the installation of bioengineering systems. A steep undercut or slumping bank, for example, requires grading to flatten the slope for stability. The degree of flattening depends on the soil type, hydrologic conditions, geology, and other site factors.

Scheduling and Timing

Planning and coordination are needed to achieve optimal timing and scheduling. The seasonal availability of plants or the best time of year to install them may not coincide with the construction season or with tight construction schedules. In some cases, rooted stock may be used as an alternative to unrooted dormant season cuttings.

Vegetative Damage to Inert Structures

Vegetative damage to inert structures may occur when inappropriate species or plant materials that exceed the size of openings in the face of structures are used. Vegetative damage does not generally occur from roots. Plant roots tend to avoid porous, open-faced retaining structures because of excessive sunlight, moisture deficiencies, and the lack of a growing medium.

Moisture Requirements and Effects

The backfill behind a stable retaining structure needs specific mechanical and hydraulic properties. Ideally, the fill is coarse-grained, free-draining, granular material. Excessive amounts of clay, silt, and organic matter are not desirable. Free drainage is essential to the mechanical integrity of an earth retaining structure and also important to vegetation, which cannot tolerate waterlogged soil conditions.

Establishing and maintaining vegetation, however, usually requires some fine-grained soils and organic matter in the soil to provide adequate moisture and nutrient retention. These requirements can often be satisfied without compromising the engineering performance of the structure. With cribwalls, for example, adequate amounts of fine-grained soils or other amendments can be incorporated into the backfill. Gabions can have the spaces between rocks filled with and soil to facilitate growth of vegetation. Woody vegetative cuttings can be placed between the baskets during filling and into the soil or backfill beyond the baskets. The needs of plants and the requirements of structures must be taken into account when designing a system.

Construction Materials and Techniques

General Considerations

Bioengineering measures have certain requirements and capabilities. Plant species must be suitable for the intended use and adapted to the site's climate and soil conditions. Species that root easily, such as willow, are required for such measures as live fascines, brushlayer, and live staking or where unrooted stems are used with structural measures. See the end of this section for a list of plant species suitable for use in bioengineering applications in Massachusetts.

Rooted plants and live dormant cuttings are living materials and must be handled properly to avoid excess stress, such as drying or exposure to heat. They must be installed in moist soil and adequately covered. The soil must be compacted to eliminate or minimize air pockets around the buried stems. If soils are not at or near moisture capacity, the installation should be delayed unless deep and regular irrigation can be provided during and following installation.

Bioengineering systems are best installed in the late fall at the onset of plant dormancy; either in the winter, as long as the ground is not frozen, or in early spring before growth begins. Installation after initial spring growth may be successful in some cases, but the risks of failure are high. Summer installation is not recommended. Rooted plants can be used, but they are sometimes less effective and more expensive.

All installations should be inspected regularly and provisions made for prompt repair if needed. Initial failure of a small portion of a system normally can be repaired easily and inexpensively. Neglect of small failures, however, can often result in the failure of large portions of a system.

Properly designed and installed vegetative portions of systems will become self-repairing to a large extent. Periodic pruning and replanting may be required to maintain healthy and vigorous vegetation. Structural elements, such as cribwalls, rock walls, and gabions, may require maintenance and/or replacement throughout their life. Where the main function of structural elements is to allow vegetation to become established and take over the role of slope stabilization, the eventual deterioration of the structures is not a cause for concern.

Bioengineering Materials

Plant tolerances to deposition, flooding, drought, and salt should be considered in selecting species for adverse site conditions.

Locating and Selecting Plant Materials

Commercial Sources

Commercially grown plant materials are suitable sources of vegetation for use in bioengineering systems; however, it is necessary to allow adequate lead time for their procurement and delivery.

Native Species

Correctly selected live dormant cuttings harvested from existing stands of living woody vegetation are the preferred bioengineering materials. The use of indigenous live materials requires careful selection, harvesting, handling, and transporting. They should result in plants that have deep and strong root systems, are relatively inexpensive, are usually effective, and can be installed quickly.

Live plant materials can be cut from existing native or naturalized stands found near the project site or within practical hauling distance. The source site must contain plant species that will propagate easily from cuttings. Cuttings are normally ½ to 2 inches in diameter and range in length from 2 to 6 feet.

Chain saws, bush axes, loppers, and prunners are recommended for cutting living plant material. Safety precautions must be followed when using these tools. Onsite plant material should be harvested with great care. In some places a large area can be cut, but other sites require selective cutting. Cuts should be made at a blunt angle, 8 to 10 inches from the ground, to assure that the source sites will regenerate rapidly and in a healthy manner.

The harvesting site should be left clean and tidy. Remnant materials that are too large for use in bioengineering projects should be chipped or left in piles for wildlife cover. A site may be needed again for future harvesting and should be left in a condition that will enhance its potential for regeneration.

Binding and Storage

Live cuttings should be bundled together securely at the collection site for easy loading and handling and for protection during transport. Side branches and brushy limbs should be kept intact.

Transporting

The bundles of live cuttings should be placed on the transport vehicles in an orderly fashion to prevent damage and facilitate handling. They should be covered with a tarpaulin during transportation to prevent drying and additional stress.

Handling

Live cuttings should arrive on the job site within eight hours of harvest and should be installed immediately. This is especially critical when the ambient temperature is 50 degrees F or above.

Live cuttings not installed on the day they arrive should be placed in controlled storage conditions and protected until they can be installed. When in storage, the cuttings must receive continuous shade, must be sheltered from the wind, and must be continuously protected from drying by being heeled into moist soils or stored in uncontaminated water. All live cuttings should be removed from storage and used within 2 days of harvest.

Installing Plant Materials

Timing

Installation of live cuttings should begin concurrently with earth moving operations if they are carried out during the dormant season. All construction operations should be phased together whenever possible. The best time for installation of bioengineering systems is during the dormant season.

Planting Medium

Bioengineering projects ideally use onsite stockpiled topsoil as the planting medium of choice. Gravel is not suitable for use as fill around live plant materials. A planting medium is needed that includes fine-grained soil and organic material, and is capable of supporting plant growth.

Muddy soils that are otherwise suitable should not be used until they have been dried to a workable moisture content. Heavy clays should be mixed with organic soils to increase porosity. Select soil backfill does not need to be organic topsoil but it must be able to support plant growth.

Soil samples should be taken of the onsite materials prior to planting live woody cuttings. Soil samples should also be taken of all fill materials that are brought to the site prior to use. Nutrient testing should include analyses for plant nutrients, metal contents, and pH. Laboratory reports should include recommended fertilizer and lime amendments for woody plant materials.

All fill soil around the vegetative cuttings should be compacted to densities approximating the surrounding natural soil densities. The soil around plants should be free of voids.

Establishment Period

Bioengineering measures should be checked periodically after installation. Recommended schedule:

First two months:

Inspect biweekly. Check for insect infestations, soil moisture, and other conditions that could lead to poor survivability. Take action, such as the application of supplemental water, to correct any problems.

Next six months:

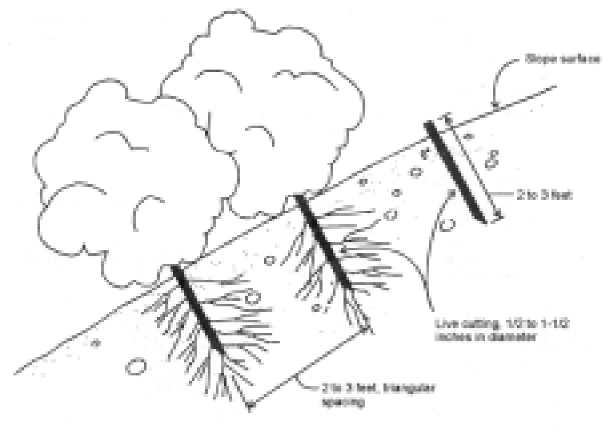
Inspect monthly. Systems not in acceptable growing condition should be noted and, as soon as seasonal conditions permit, should be removed from the site and replaced with materials of the same species and sizes as originally specified.

Initial 2-year establishment period:

Perform reestablishment work as needed every six months. This will usually consist of replacing dead material.

Make additional inspections during periods of drought or heavy rains. Damaged sections should always be repaired immediately.

Live Staking



Live staking involves the insertion and tamping of live, rootable vegetative cuttings into the ground. If correctly prepared and placed, the live stake will root and grow. Stakes create a living root mat that stabilizes the soil by reinforcing and binding soil particles together and by extracting excess soil moisture.

Live staking increases the opportunity for natural invasion and establishment of other plants from the surrounding plant community.

Recommended Uses

Most willow species root rapidly and begin to dry out a slope soon after installation. Live staking is appropriate for repair of small earth slips and slumps that frequently are wet.

May be used for pegging down surface erosion control materials.

Can be used to stabilize intervening area between other bioengineering techniques, such as live fascines.

Well-adapted to relatively uncomplicated site conditions when construction time is limited and an inexpensive method is necessary.

Construction Recommendations

Select cuttings ½ to 1 ½ inches in diameter and 2 to 3 feet long.

The cuttings must have side branches cleanly removed and the bark intact.

The ends should be cut at an angle for easy insertion into the soil. The top should be cut square.

Cuttings should be installed the same day that they are prepared.

Installation

Tamp the live stake into the ground at right angles to the slope. The installation may be started at any point on the slope face.

The live stakes should be installed 2 to 3 feet apart using triangular spacing. The density of the installation will range from 2 to 4 stakes per square yard.

The buds should be oriented up.

About four-fifths of the length of the live stake should be installed into the ground. Pack soil firmly around stakes after installation.

Be careful not to split the stakes during installation. Stakes that do split should be replaced.

An iron bar can be used to make a pilot hole in firm soil. Drive the stake into the ground with a dead blow hammer (hammer head filled with shot or sand).

Dormant Woody Plantings

This involves the use of live, dormant-stem cuttings of woody plant species from ½ to 3 inches or more in diameter. The plantings create a living root mat that stabilizes the soil by reinforcing and binding soil particles together and by extracting excess soil moisture.

Recommended Uses

Dormant plantings are appropriate for repair of small earth slips and slumps that frequently are wet.

Can be used to stabilize intervening area between other bioengineering techniques, such as live fascines.

A technique for relatively uncomplicated site conditions when construction time is limited and an inexpensive method is necessary.

Materials and Preparation

Cuttings, stakes and posts to be used as live dormant woody materials should be obtained from moisture-loving species that will either root naturally or respond to treatment with rooting hormones. Always select healthy materials native or adaptable to the planting site.

The proper preparation and handling of selected materials is very important. Make clean cuts and avoid split ends.

Always plant materials with the butt end down. The butt end should be tapered to mark it for proper orientation as well as facilitate driving it into the soil if done so manually. The top end should be flat, especially on stakes and posts, to facilitate manual driving.

Trim lateral branches to leave the bark ridge and branch collar intact.

The diameter and length of the plant materials varies with the type:

Dormant "cutting" - The diameter of cuttings should be a minimum of one-half inch and a maximum of less than one (1) inch. Cuttings should be at least 12 inches but less than 18 inches in length.

Dormant "stake" - Stakes should be one to three inches in diameter at the top and 18 inches to six feet in length.
Dormant "post" - Posts should be greater than three inches in diameter at the top end. Length will vary with the depth to saturated soil and the difference in feet between the channel bottom and low bank elevation. However, posts should be a minimum length equal to the difference in feet between the lowest point of channel scour and the low bank elevations or 7 feet, whichever is less.

All "stakes" and "posts" should extend a minimum of two feet below the maximum depth of the streambed scour.

There should be at least two lateral buds and/or terminal bud scars above the ground on "cuttings." A terminal bud scar should be within 1 to 4 inches of the top. Cuttings put out the largest number and strongest shoots just below a terminal bud scar (annual growth scar).

Planting materials must not be allowed to dry out. They should be kept moist and covered during transport to the planting site and during planting operations. Material should be kept submerged in water up to the time of planting. It is best to plant materials the same day they are cut and prepared. One exception is Eastern Cottonwood, which has exhibited increased survival rates if soaked in water for 1 to 2 days prior to planting.

Select native or naturalized species that root readily with or without the use of rooting hormones. Rooting hormones, if used, should be applied according to manufacturers' recommendations.

Wood species with short, dense, flexible top growth and large, deep, fibrous root systems are recommended. Other desirable characteristics include rapid initial growth, ability to reproduce by seed or vegetatively, and resistance to insects and diseases.

Layout

Dormant "stakes" and "posts" should be placed in staggered rows at two-foot by two-foot, two-foot by four-foot, or four-foot by four-foot spacings. Dormant "cuttings" may be scattered between rows of "stakes" and "posts."

On eroding streambanks over 15 feet high, use a minimum of 4 rows of dormant "stakes" or "posts."

Installation

All materials should be cut and installed while in a dormant stage. The following periods are recommended for practice installation: November 1 until ground becomes frozen, or February 1 to April 1 provided ground is not frozen or buds have not broken dormancy.

Be sure that the planting material is right side up (butt end in the ground).

Set the materials as deep as possible with at least the bottom 12 inches into a saturated soil layer. Deep planting insures an adequate moisture supply for root development, minimizes water loss due to transpiration and prevents root breakage caused by movement between the planting material and the soil during high velocity water flows.

Avoid excessive damage to the bark of the planting material, especially stripping.

Be sure there is good contact between the soil and planting material. “Dormant cuttings” will have the soil tamped around them. Dormant materials may be installed using an iron bar for “cuttings” and a post hole digger, powered auger or a metal ram on a backhoe or similar equipment for “stakes” and “posts.”

In soft, nonrestricted soils, “stakes” or “posts” may be manually driven into place using a wooden maul. If a sledge is used, care must taken to avoid splitting the planting material. Extreme care is needed in driving the stakes or posts, and should be limited to soils such as sandy soils, where use of the other methods is not feasible.

Post lengths should be extended 4 to 6 inches to allow for a new flat cut to eliminate any damaged materials after manual driving. At least 40 percent, and preferably 50 percent or more, of the planting material should be below ground level after planting.

Where damage by beaver may occur, treating materials with a repellant, such as ropel, or enclosing them with chicken wire is recommended.

All “stakes” and “posts” located in the stream channel should have a minimum of 12 inches extending above the normal water level.

Recommended Species

Species selection should consider the position of the plant in the bank profile.

Zone 1

Below normal waterline to upper limit of saturation area kept moist by capillary water movement. This zone includes the greatest potential for periodic inundations and the least moisture stress.

Zone 2

Area from upper limit of Zone 1 to 2-3 feet from the top of the bank. This area may be subject to rapid drying and greater moisture stress.

Zone 3

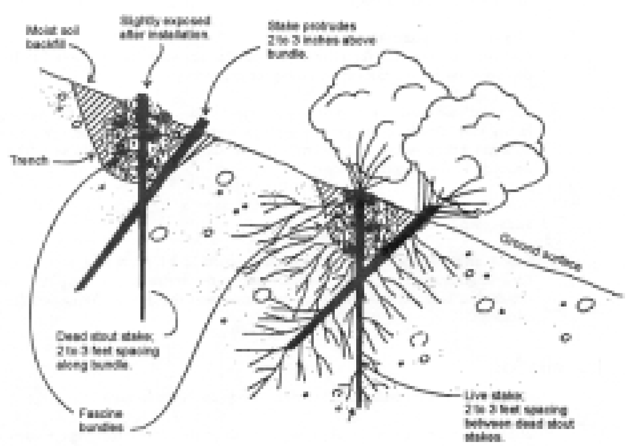
Area 2-3 feet below the top of the bank to a minimum of 30 feet into the floodplain.

Plant Zone	Common Name/Scientific Name	Growth Form
1	Black Willow* Salix nigra	Tree
1	Bankers Willow* Salix cottettii	Shrub
1	Purple-osier willow* Salix purpurea	Shrub
1	Sandbar Willow* Safix interior	Tree
1	Carolina Willow* Safix caroliniana	Tree
1	Peach-leaved Willow* Salix amycdaloides	Tree
1	Buttonbush* Cephalanthis occidetalis	Shrub
1,2,3	Red-osier Dogwood* Comus stolonifera	Shrub
2,3	Silky Dogwood Comus amomum	Shrub
2,3	Flowering Dogwood Comus florida	Tree
2,3	Green Ash Fraxinus pennsylvanica	Tree
2,3	Sycamore* Platanus occidentalis	Tree
1,2,3	Bald Cypress Taxodium distichum	Tree
1,2	River Birch Betula nigra	Tree
1,2,3	Eastern Cottonwood* Populus deltoides	Tree
1,2,3	Swamp Cottonwood* Populus heterophylla	Tree

**These species are suitable for use as dormant woody cuttings, stakes or posts. All species of willow and cottonwood do not require hormone treatment for rooting.*

Fascines

Fascines are long bundles of live branch cuttings bound together into sausage-like structures. When cut from appropriate species and properly installed with live and dead stout stakes, fascines will root and immediately begin to stabilize slopes.



Advantages

An effective stabilization technique for slopes.

Immediately reduces surface erosion or rilling.

Enhances vegetative establishment by creating a microclimate conducive to plant growth.

Capable of trapping and holding soil on the face of the slope, thus reducing a long slope, into a series of shorter slopes.

Recommended Uses

To protect slopes from shallow slides (1 to 2 foot depth).

On steep, rocky slopes, where digging is difficult.

Construction guidelines

Fascines should be placed in shallow contour trenches on dry slopes and at an angle on wet slopes to reduce erosion and shallow face sliding. This causes little site disturbance when installed by a trained crew.

Live materials

Cuttings must be from species, such as young willows or shrub dogwoods, that root easily and have long, straight branches.

Live material sizes and preparation

Cuttings tied together to form live fascine bundles may vary in length from 5 to 30 feet or longer, depending on site conditions and limitations in handling.

The completed bundles should be 6 to 8 inches in diameter, with all of the growing tips oriented in the same direction. Stagger the cuttings in the bundles so that tops are evenly distributed throughout the length of the uniform-sized bundle. Live stakes should be 2 ½ feet long in cut slopes and 3 feet long in fill slopes.

Inert materials

String used for bundling should be untreated twine.

Dead stout stakes used to secure the fascines should be 2 ½-foot long, untreated, 2 by 4 lumber. Each length can be cut again diagonally across the 4-inch face to make two stakes from each length. Use new, sound, unused lumber. Any stakes that shatter during installation should be discarded.

Installation

Prepare the fascine bundles and live stakes immediately before installation.

Beginning at the base of the slope, dig a trench on the contour just large enough to contain the live fascine. The trench will vary in width from 12 to 18 inches, depending on the angle of the slope to be treated. The depth will be 6 to 8 inches, depending on the individual bundle's final size. Place the live fascine into the trench.

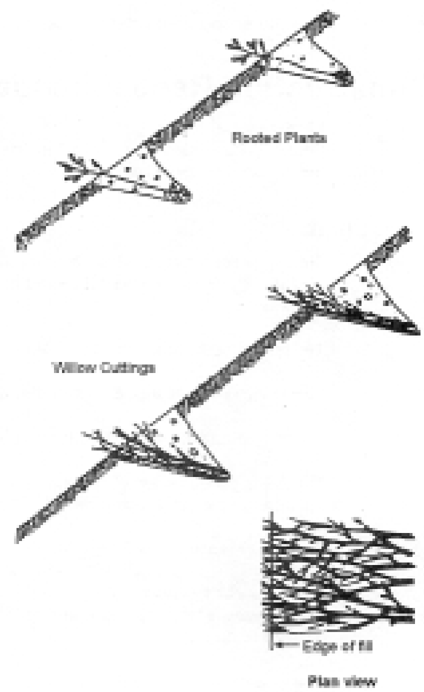
Drive the dead stout stakes directly through the live fascine every 2 to 3 feet along its length. Extra stakes should be used at connections or bundle overlaps. Leave the top of the stakes flush with the installed bundle.

Live stakes are generally installed on the downslope side of the bundle. Drive the live stakes below and against the bundle between the previously installed dead stout stakes. The live stakes should protrude 2 to 3 inches above the top of the live fascine. Place moist soil along the sides of the live fascine. The top of the fascine should be slightly visible when the installation is completed.

Repeat the preceding steps to the top of the slope; at intervals on the contour or at an angle up the face of the bank. When possible, place one or two rows over the top of the slope.

Long straw or similar mulching material should be placed between rows on 2.5:1 or flatter slopes, while slopes steeper than 2.5:1 should have jute mesh or similar material placed in addition to the mulch.

Brushlayer



Brushlayering consists of placing live branch cuttings in small benches excavated into the slope. The benches can range from 2 to 3 feet wide. These systems are recommended on slopes up to 2:1 in steepness and not to exceed 15 feet in vertical height.

Brushlayers are similar to fascine systems because both involve the cutting and placement of live branch cuttings on slopes. The two techniques differ principally in the orientation of the branches and the depth to which they are placed in the slope. In brushlayering, the cuttings are oriented more or less perpendicular to the slope contour. The perpendicular orientation is more effective for earth reinforcement and mass stability of the slope.

Brushlayer branches serve as reinforcing units. The portions of the brush that protrude from the slope face assist in retarding runoff and reducing surface erosion.

Purpose

Brushlayers perform several immediate functions in erosion control earth reinforcement, and mass stability of slopes:

- Breaking up the slope length into a series of shorter slopes separated by rows of brushlayer.
- Reinforcing the soil with the unrooted branch stems.
- Reinforcing the soil as roots develop, adding significant resistance to sliding or shear displacement.
- Providing slope stability and allowing vegetative cover to become established.
- Trapping debris on the slope.
- Aiding infiltration on dry sites.
- Drying excessively wet sites.
- Adjusting the site's microclimate, thus aiding seed germination and natural regeneration.
- Improving slope stability by acting as horizontal seepage drains.

Construction Recommendations

Live material sizes

Branch cuttings should be ½ to 2 inches in diameter and long enough to reach the back of the bench. Side branches should remain intact for installation.

Installation

Starting at the toe of the slope, benches should be excavated horizontally, on the contour, or angled slightly down the slope, if needed to aid drainage. The bench should be constructed 2 to 3 feet wide.

The surface of the bench should be sloped so that the outside edge is higher than the inside.

Live branch cuttings should be placed on the bench in a crisscross or overlapping configuration.

Branch growing tips should be aligned toward the outside of the bench.

Backfill is placed on top of the branches and compacted to eliminate air spaces. The brush tips should extend slightly beyond the fill to filter sediment.

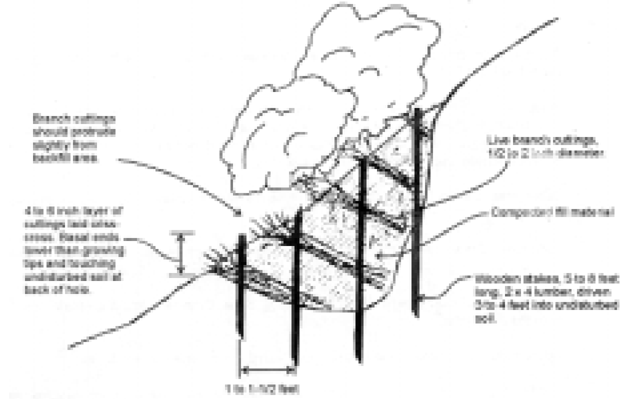
Each lower bench is backfilled with the soil obtained from excavating the bench above.

Long straw or similar mulching material with seeding should be placed between rows on 3:1 or flatter slopes, while slopes steeper than 3:1 should have jute mesh or similar material placed in addition to the mulch.

The brushlayer rows should vary from 3 to 5 feet apart, depending upon the slope angle and stability.

Branchpacking

Branchpacking consists of alternating layers of live branch cuttings and compacted backfill to repair small localized slumps and holes in slopes. Branchpacking provides immediate soil reinforcement.



Where Practice Applies

- Effective in earth reinforcement and mass stability of small earthen fill sites.
- Produces a filter barrier, reducing erosion and scouring conditions.
- Repairs holes in earthen embankments other than dams where water retention is a function.

Construction Recommendations

Live material

Live branch cuttings may range from ½ inch to 2 inches in diameter. They should be long enough to touch the undisturbed soil at the back of the trench and extend slightly from the rebuilt slope face.

Inert material

Wooden stakes should be 5 to 8 feet long and made from 3- to 4-inch diameter poles or 2 by 4 lumber, depending upon the depth of the particular slump or hole.

Installation

Starting at the lowest point, drive the wooden stakes vertically 3 to 4 feet into the ground. Set them 1 to 1 ½ feet apart.

A layer of living branches 4 to 6 inches thick is placed in the bottom of the hole, between the vertical stakes, and perpendicular to the slope face. They should be placed in a crisscross configuration with the growing tips generally oriented toward the slope face. Some of the basal ends of the branches should touch the back of the hole or slope.

Subsequent layers of branches are installed with the basal ends lower than the growing tips of the branches.

Each layer of branches must be followed by a layer of compacted soil to ensure soil contact with the branch cuttings.

The final installation should match the existing slope. Branches should protrude only slightly from the filled face.

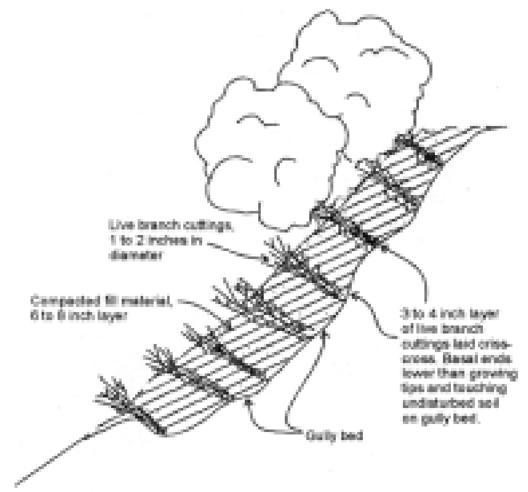
The soil should be moist or moistened to insure that live branches do not dry out.

The live branch cuttings serve as “tensile inclusions” for reinforcement once installed. As plant tops begin to grow, the branchpacking system becomes increasingly effective in retarding runoff and reducing surface erosion. Trapped sediment refills the localized slumps or holes, while roots spread throughout the backfill and surrounding earth to form a unified mass. Branchpacking is not effective in slump areas greater than 4 feet deep or 5 feet wide.

Live gully repair

A live gully repair utilizes alternating layers of live branch cuttings and compacted soil to repair small rills and gullies. Similar to branchpacking.

Limited to rills or gullies which are a maximum of 2 feet wide, 1 foot deep, and 15 feet long.



Advantages

The installed branches offer immediate reinforcement to the compacted soil and reduce the velocity of concentrated flow of water.

Provides a filter barrier that reduces rill and gully erosion.

Construction Recommendations

Live material sizes

Live branch cuttings may range from ½ inch to 2 inches in diameter. They should be long enough to touch the undisturbed soil at the back of the rill or gully and extend slightly from the rebuilt slope face.

Inert materials

Fill soil is compacted in alternate layers with live branch cuttings.

Installation

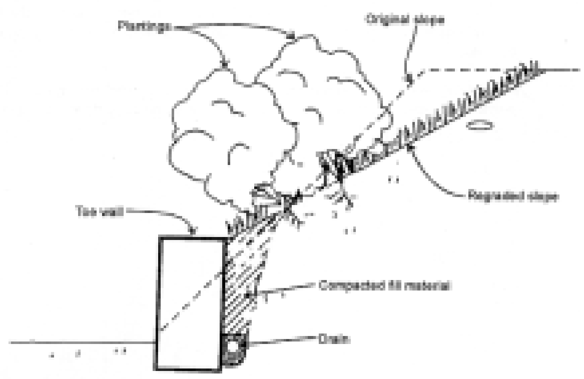
Starting at the lowest point of the slope, place a 3- to 4-inch layer of branches at lowest end of the rill or gully and perpendicular to the slope.

Cover with a 6 to 8 inch layer of fill soil.

Install the live branches in a crisscross fashion. Orient the growing tips toward the slope face with basal ends lower than the growing tips.

Follow each layer of branches with a layer of compacted soil to ensure soil contact with the live branch cuttings.

Vegetated Structures



Vegetated structures consist of either low walls or revetments (concrete or rock and mortar) at the foot of a slope with plantings on the interposed benches.

A structure at the foot of a slope protects the slope against undermining or scouring and provides a slight buttressing effect. In the case of low walls, it allows regrading of the slope face to a more stable angle without excessive retreat at the crest.

Vegetation planted on the crest of the wall and the face of the slope protects against, erosion and shallow sloughing. In the case of tiered structures, the roots of woody plants grow into the soil and backfill within the structure, binding them together. The foliage in front covers the structure and enhances its appearance.

Low Wall/Slope Face Plantings

A low retaining structure at the foot of a slope makes it possible to flatten the slope and establish vegetation. Vegetation on the face of the slope protects against both surface erosion and shallow face sliding.

Several types of retaining structures can be used as low walls. The simplest type is a “gravity wall” that resists lateral earth pressures by its weight or mass. The following types of retaining structures can be classified as gravity walls:

- Masonry and concrete walls
- Crib and bin walls
- Cantilever and counterfort walls
- Reinforced earth and geogrid walls

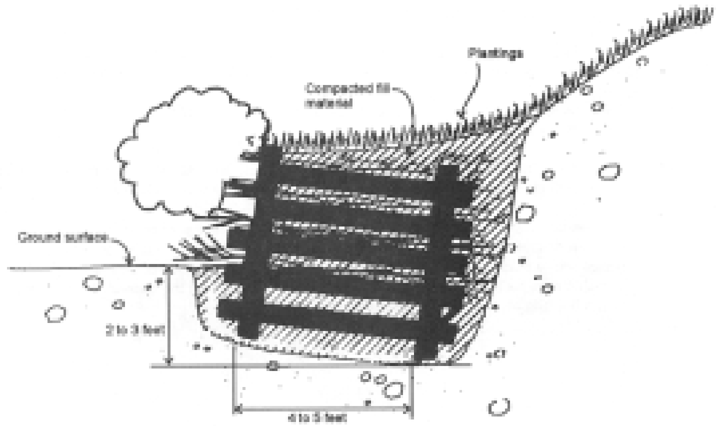
Each of these can be modified in a variety of ways to fit nearly any condition or requirement. The retaining structure should be designed by a qualified engineer.

Tiered Wall or Bench Plantings

These are alternatives to a low wall with face planting. They allows vegetation to be planted on slopes that would otherwise be too steep. Shrubs and trees planted on the benches screen the structure behind and lend a more natural appearance while their roots permeate and protect the benches.

Almost any type of retaining structure can be used in a tiered wall system. A tiered wall system provides numerous opportunities for use of vegetation on steep slopes and embankments.

Vegetated Cribwall



A cribwall is a structure formed by joining a number of cells together and filling them with soil, gravel, or rock to furnish strength and weight. A vegetated cribwall is filled with suitable backfill material and layers of live branch cuttings. The cuttings root inside the crib structure and extend into the slope. Once the live cuttings root and become established, the subsequent vegetation gradually takes over the structural functions of the wood members.

The cribwall provides immediate protection from erosion; while established vegetation provides longterm stability.

Where Practice Applies

This technique is appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and reduce its steepness.

Not designed for or intended to resist large, lateral earth stresses. Recommended only to a maximum of 6 feet in overall height, including the excavation required for a stable foundation.

Useful where space is limited and a more vertical structure is required.

Should be tilted back or battered if the system is built on a smooth, evenly sloped surface.

May also be constructed in a stair-step fashion, with each successive course of timbers set back 6 to 9 inches toward the slope face from the previously installed course.

Construction Recommendations

Live material sizes

Live branch cuttings should be ½ to 2 inches in diameter and long enough to reach the back of the wooden crib structure.

Installation

Starting at the lowest point of the slope, excavate loose material 2 to 3 feet below the ground elevation until a stable foundation is reached.

Excavate the back of the stable foundation (closest to the slope) slightly deeper than the front to add stability to the structure.

Place the first course of logs or timbers at the front and back of the excavated foundation, approximately 4 to 5 feet apart and parallel to the slope contour.

Place the next course of logs or timbers at right angles (perpendicular to the slope) on top of the previous course to overhang the front and back of the previous course by 3 to 6 inches.

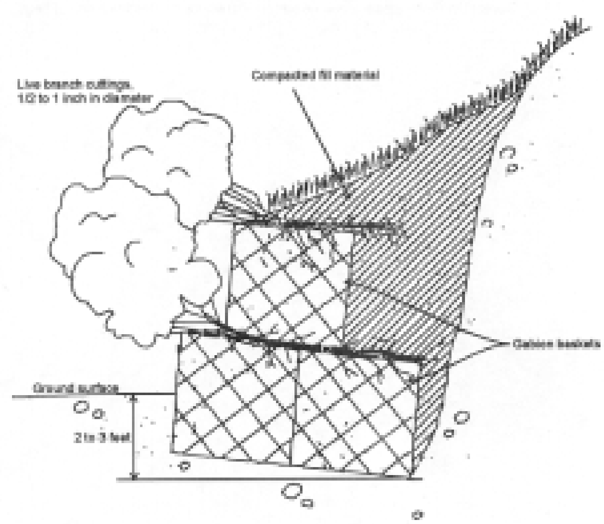
Each course of the live cribwall is placed in the same manner and nailed to the preceding course with nails or reinforcement bars.

When the cribwall structure reaches the existing ground elevation, place live branch cuttings on the backfill perpendicular to the slope; then cover the cuttings with backfill and compact.

Live branch cuttings should be placed at each course to the top of the cribwall structure with growing tips oriented toward the slope face. Follow each layer of branches with a layer of compacted soil to ensure soil contact with the live branch cuttings. Some of the basal ends of the live branch cuttings should reach to undisturbed soil at the back of the cribwall with growing tips protruding slightly beyond the front of the cribwall.

Vegetated Gabions

Empty gabions are placed in position, wired to adjoining gabions, filled with stones and then folded shut and wired at the ends and sides. Live branches are placed on each consecutive layer between the rockfilled baskets. These will take root inside the gabion baskets and in the soil behind the structures. In time the roots consolidate the structure and bind it to the slope.



Construction Recommendations

Live material sizes

Branches should range from ½ to 1 inch in diameter and must be long enough to reach beyond the back of the rock basket structure into the backfill.

Installation

Starting at the lowest point of the slope, excavate loose material 2 to 3 feet below the ground elevation until a stable foundation is reached.

Excavate the back of the stable foundation (closest to the slope) slightly deeper than the front to add stability to the structure. This will provide additional stability to the structure and ensure that the living branches root well.

Place the fabricated wire baskets in the bottom of the excavation and fill with rock.

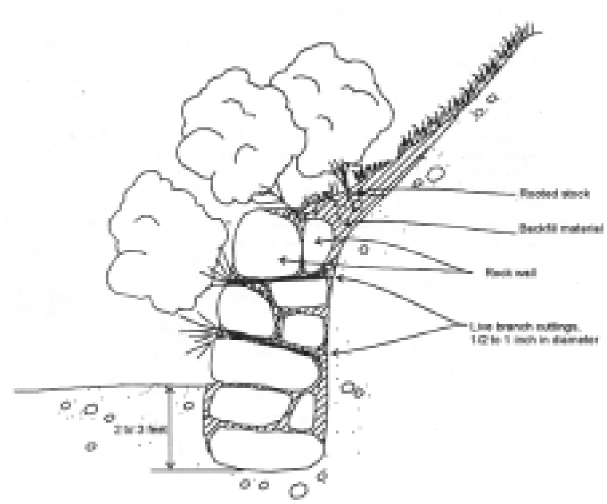
Place backfill between and behind the wire baskets.

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

Repeat the construction sequence until the structure reaches the required height.

Vegetated Rock Wall

Vegetated rock walls differ from conventional retaining structures in that they are placed against relatively undisturbed earth and are not intended to resist significant lateral earth pressures. A vegetated rock wall is a combination of rock and live branch cuttings used to stabilize and protect the toe of steep slopes.



This system is appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and reduce its steepness.

Construction Recommendations

Live material sizes

Live cuttings should have a diameter of ½ to 1-inch and be long enough to reach beyond the rock structure into the fill or undisturbed soil behind.

Inert materials

Inert materials consist of rocks and fill material for the wall construction. Rock should normally range from 8 to 24 inches in diameter. Larger boulders should be used for the base.

Installation

Starting at the lowest point of the slope, remove loose soil until a stable base is reached. This usually occurs 2 to 3 feet below ground elevation. Excavate the back of the stable foundation (closest to the slope) slightly deeper than the front to add stability to the structure.

Excavate the minimum amount from the existing slope to provide a suitable recess for the wall.

Provide a well-drained base in locations subject to deep frost penetration.

Place rocks with at least a three-point bearing on the foundation material or underlying rock course. They should also be placed so that their center of gravity is as low as possible, with their long axis slanting inward toward the slope if possible.

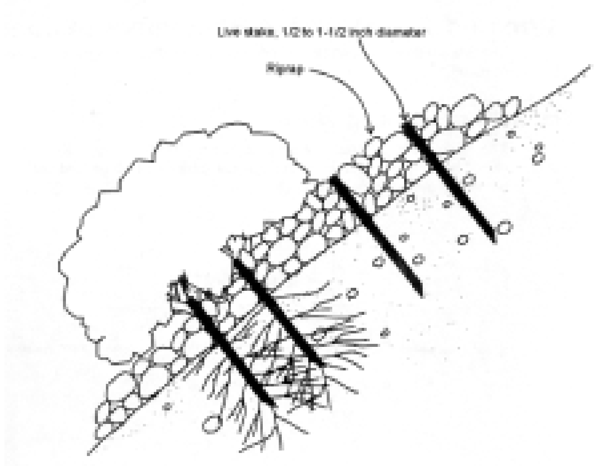
When a rock wall is constructed adjacent to an impervious surface, place a drainage system at the back of the foundation and outside toe of the wall to provide an appropriate drainage outlet.

Overall height of the rock wall, including the footing, should not exceed 5 feet.

A wall can be constructed with a sloping bench behind it to provide a base on which live branch cuttings can be placed during construction. Live branch cuttings should also be tamped or placed into the openings of the rock wall during or after construction. The butt ends of the branches should extend into the backfill or undisturbed soil behind the wall.

The live branch cuttings should be oriented perpendicular to the slope contour with growing tips protruding slightly from the finished rock wall face.

Joint Planting



Joint planting or vegetated riprap involves tamping live cuttings of rootable plant material into soil between the joints or open spaces in rocks that have previously been placed on a slope. Alternatively, the cuttings can be tamped into place at the same time that rock is being placed on the slope face.

Roots improve drainage by removing soil moisture. Over time, they create a living root mat in the soil base upon which the rock has been placed. The root systems of this mat help to bind or reinforce the soil and to prevent washout of fines between and below the rock units.

Construction Recommendations

Live material sizes

The cuttings must have side branches removed and bark intact. They should range in diameter from ½ inch to 1 ½ inches and be sufficiently long to extend into soil below the rock surface.

Installation

Tamp live branch cuttings into the openings of the rock during or after construction. The butt ends of the branches should extend into the backfill or undisturbed soil behind the riprap.

Orient the live branch cuttings perpendicular to the slope with growing tips protruding slightly from the finished face of the rock.

Slope Stabilization

Bioengineering techniques for slope stabilization involve using a combination of vegetative and mechanical measures on steep slopes, cut and fill banks, and unstable soil conditions that cannot be stabilized using ordinary vegetative techniques.

Advantages

Vegetation reduces sheet erosion on slopes and impedes sediment at the toe of the slope.

Where soils are unstable and liable to slip due to wet conditions, utilization of soil moisture by vegetation can reduce the problem.

Shrubs and trees shelter slopes against the impact of rainstorms, and the humus formed by decaying leaves further helps to impede runoff.

Mechanical measures help to stabilize soil long enough to allow vegetation to become established.

Disadvantages/Problems

The planting of non-seeded material such as live willow brush is a specialized operation and cannot be highly mechanized or installed by unskilled labor.

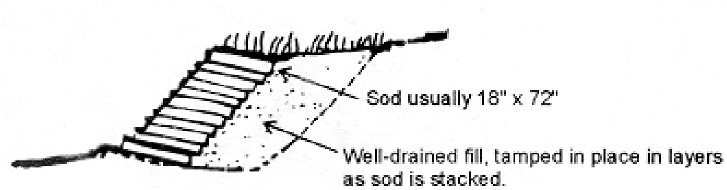
The methods described are effective but require familiarity with soils, hydrology, and other physical data to design measures that will solve the problem.

Design and Construction Recommendations

The following bioengineering methods can be used after slopes have been protected by diversion of runoff.

Sod walls or retaining banks

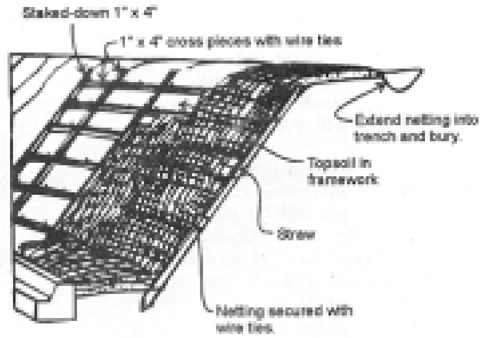
These may be used to stabilize terraces. Sod is piled by tilting it slightly toward the slope and should be backfilled with soil and compacted as they are built up. Sod walls can be as steep as 1: 8 but should not be higher than 5 feet.



SOD WALLS OR RETAINING BANKS

Timber frame stabilization

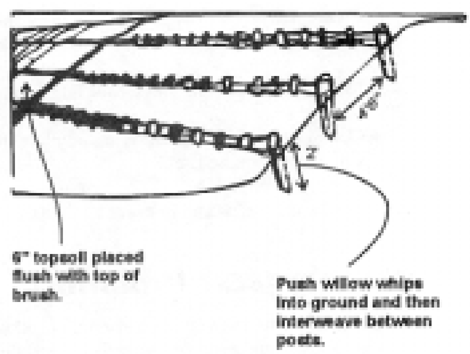
This can be effective on gradients up to 1:1. The following steps are involved in construction:



- Lay soil retarding frames of 2 x 4 in. vertical members and 1 x 4 in. horizontal members on slopes. Frames on slopes over 15 feet in length need to be anchored to slope to prevent buckling.
- Attach 14 gauge galvanized wires for anchoring wire mesh.
- Fill frames with moist topsoil and compact the soil.
- Spread straw 6 inches deep over slope.
- Cover straw with 14 gauge 4-inch mesh galvanized reinforced wire.
- Secure wire mesh at least 6 feet back of top slope.
- Plant ground cover plants through straw into topsoil.

Woven willow whips

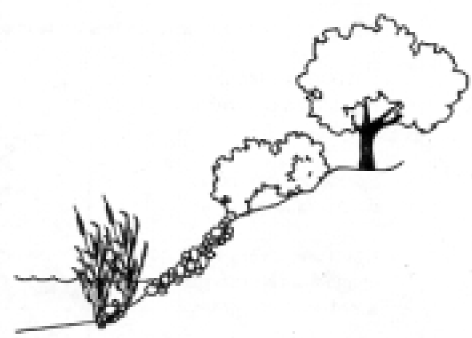
May be used to form live barriers for immediate erosion control. Construction:



- Three-foot poles are spaced at 5 foot distances and driven into the slope to a depth of 2 feet.
- Two-foot willow sticks are inserted between poles at one foot distances.
- Live willow branches 5 feet long are sunk to a depth of 1 inch and interwoven with poles and stocks.
- Spaces between the woven “fences” are filled with topsoil. Fences are generally arranged parallel to the slope or in a grid pattern diagonal to the direction of the slope.

Streambank Stabilization

Often channel reaches can be made stable by establishing vegetation where erosion potential is low and installing structural measures, or a combination of vegetative and structural measures on more vulnerable areas; such as the outside of channel bends and where the natural grade steepens.



Any work in or adjacent to a stream should be coordinated with the local Conservation Commission, and done in accordance with wetlands protection laws.

Advantages

Bioengineering techniques are generally less costly than structural practices and more compatible with natural stream characteristics.

Roots and rhizomes stabilize streambanks.

Certain reeds and bulrushes have the capability of improving water quality by absorbing certain pollutants such as heavy metals, detergents, etc.

Plants regenerate themselves and adapt to changing natural situations, thus offering a distinct economic advantage over mechanical stabilization.

Mechanical materials provide for interim and immediate stabilization until vegetation takes over.

Once established, vegetation can outlast mechanical structures and requires little maintenance while regenerating itself.

Aesthetic benefits and improved wildlife and fisheries habitat.

Disadvantages/Problems

Native plants may not be carried by regular nurseries and may need to be collected by hand, or obtained from specialty nurseries. Nurseries which carry these plants may require a long lead time for large orders.

Flow retarding aspects of vegetated waterways need to be taken into account.

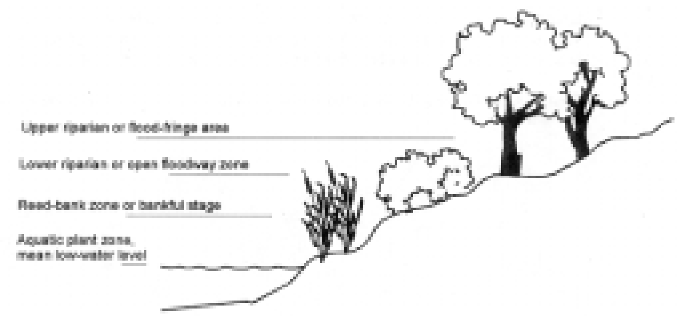
Planning Considerations

Streambanks can be divided into:

- Aquatic plant zones, at the mean low-water level;
- Reed bank zones, covered at bankfull stage;
- Lower riparian zones or open floodway zones naturally covered with willows and shrubbery plants;
- Upper riparian areas or flood fringe areas that would naturally be covered with canopy-forming trees.

Aquatic plant zones

Aquatic plants are often considered weeds and a nuisance, though they do slow down streamflow and protect the streambed.



STREAMBANK VEGETATIVE ZONES

Primary emphasis of streambank stabilization lies in the bankfull zone.

Reed bank zone

The reed bank zone forms a permeable obstacle, slowing down current waves by friction. Plant shoots, with a root clump, can be planted in pits at ½ to 1 foot depth below water, or in a reed roll.

Lower riparian zone

Lower riparian zones often have a natural growth of willow, alder, cottonwood, small maples, and various berries. These vegetative types can be reintroduced on denuded floodplains to stabilize the soil with their roots. In periods of high water, their upper branches reduce the speed of the current and thereby the erosive force of water. The most commonly used vegetative stabilizer is willow; because of its capability to develop secondary roots on cut trunks and to throw up suckers. Willows are planted either as individual cuttings bound together in various forms or wired together in fascines.

Slip banks of the lower riparian zone and tidal banks can be stabilized with grass. First the bank needs to be graded to a maximum slope of 3:1. Topsoil should be conserved for reuse; lime and fertilizer should be applied. Coarse grass and beach grass should be planted at the water's edge to trap drift sand; and bermuda grass, suitable for periodic inundation, should occupy the face of the slope, followed by tall fescue on higher ground.

In the lower riparian zone (open floodway) bank stabilization efforts should be concentrated on critical areas only. The stabilizing effect of riprap can be supplemented with willows which will bind soil through their roots and screen the bank. Banks can be paved with stone (set in sand). Willow cuttings in joints need to be long enough to extend to natural soil and should have 2 to 4 buds above surface. Willow branches in riprap should be installed simultaneously.

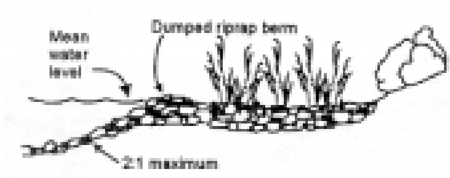
Branches should extend 1 foot into the soil below stone and 1 ½ feet above ground, pointing downstream.

Bioengineering Techniques for Streambank Stabilization

Reed Roll

A trench 1- ½ feet wide and deep is dug behind a row of stakes; wire netting is then stretched from both sides between upright planks; coarse gravel is dumped on this and covered with reed clumps until the two edges of the netting can just be held together with wire. The upper edge of the roll should not be more than two inches above water level. The planks are then removed and gaps in the ditch are backfilled.

Reed Berm



Reed berms, consisting of a combination of reeds and riprap, break wave action and erosion of banks by currents. Banks should not exceed a 2:1 slope. Riprap is placed to form a berm that extends beyond the surface at mean low-water level, separating the reed bed from the body of water.

Fascines

Packed fascine-work can be employed on cut banks. It consists of one foot layers of branches covered with young, freshly cut shoots secured by stakes. The spaces between the shoots are filled with dirt and another layer is added on top.

Brush-mesh

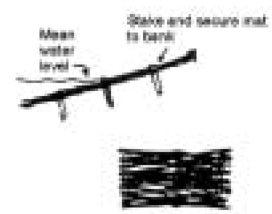
A variation is the brush-mesh technique, which is designed to stabilize breached cut banks and to encourage the deposition of sediment. It involves the following steps:

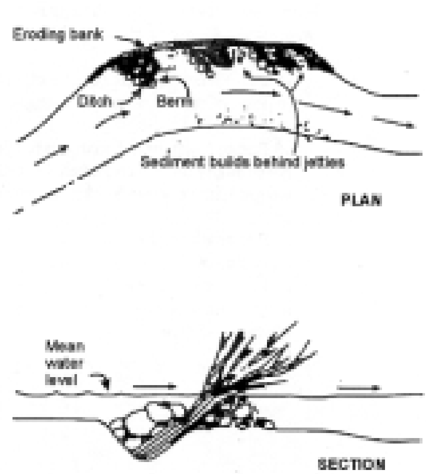
- Placement of poles at 10 foot distance.
- Placement of large branches and brush facing the stream.
- Setting cuttings of live willow branches between the brush vertically, and
- Securing vertical willows with cuttings set diagonally facing the streamflow.

Streams in urban settings may carry an increase in runoff of such great magnitude that they cannot be maintained in a natural state. Soil bioengineering methods can provide for stabilization more aesthetically and with higher effectiveness than purely mechanical techniques. This applies primarily to: the reed bank zone and the lower riparian zone. The following techniques apply to the reed bank zone:

Willow Mattress

Willow mattresses are made from 4 to 6 foot willow switches set into six inch trenches and held down by stakes that are braided or wired together. The entire mattress is lightly covered with soil.





Willow Jetty

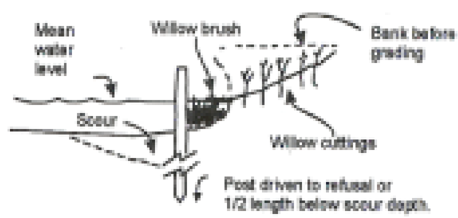
Willow jetties can be constructed at the water level to stabilize a cutbank by deflecting the current and by encouraging deposition of sediment.

- Dig ditches diagonally to direction of flow, and place fill to form berm downstream from ditch.
- Set 2-foot willow branches (4-foot may be needed) at 45 degree angle and 3-inch spacing facing downstream.
- Weigh down branches with riprap extending beyond water level.

Willow Gabions

Willow gabions can be used when a hard-edged effect is desired to deflect the eroding flow of water. Live willow branches, pointing downstream, are inserted through the wire mesh when the gabion is packed with stone and an addition of finer materials. Branches need to be long enough to extend through the gabion into the soil of the bank. They also should be placed at an angle back into the slope.

Piling revetment



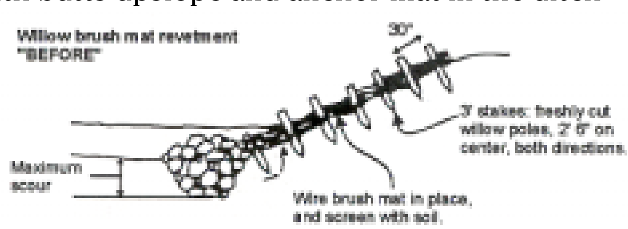
Piling revetment with wire facings is suited for the stabilization of cutbanks with deep water. It involves the following steps:

- Drive heavy timbers (8-12 inch diameter) on 6 to 8-foot centers along bank to be protected to point of refusal or one half length of pile below maximum scour.
- Fasten heavy wire fencing to the post and if the streambed is subject to scour, extend it horizontally on the streambed for a distance equal to the anticipated depth of scour and weight with concrete blocks. As scour occurs, this section will drop into place.
- Pile brush on the bank side of the fence, and plant willow saplings on bank to encourage sediment deposits.

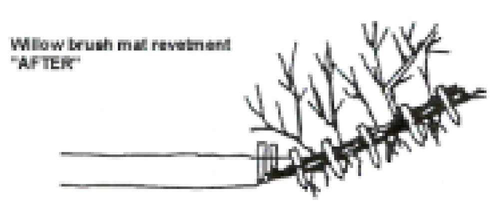
Willow Branch Mat Revetment

Willow branch mat revetment takes the following steps to install:

- Grade slope to approximately 2:1 and excavate a 3 foot ditch at the toe of slope.
- Lay live willow brush with butts upslope and anchor mat in the ditch below normal waterline by packing with large stones.



- Drive 3-foot willow stakes 2 ½ feet on center to hold down brush; connect stakes with No. 9 galvanized wire and cover brush slightly with dirt to encourage sprouting.



Maintenance

Under normal conditions, maintenance needs should be minor after the system is established. Maintenance generally consists of light pruning and removal of undesirable vegetation. Heavy pruning may be required to reduce competition for light or stimulate new growth in the project plantings.

A newly installed bioengineering project, however, will need periodic inspections until it is established. New vegetation is vulnerable to trampling, drought, grazing, nutrient deficiencies, toxins, and pests, and may require special attention at times.

In many situations, installed bioengineering systems become source sites for future harvesting operations. Selective removal of vegetation may be required to eliminate undesirable invading species. They should be cut out every 3 to 7 years.

More intensive maintenance may be needed to repair problem areas created by high intensity storms or other unusual conditions. Site washouts should be repaired immediately. Generally, reestablishment should take place for a one-year period following construction completion and consist of the following practices:

- Replacement of branches in dead unrooted sections
- Soil refilling, branchpacking, and compacting in rills and gullies
- Insect and disease control
- Weed control

Gullies, rills, or damaged sections should be repaired using of healthy, live branch cuttings; preferably installed during the dormant season. Use the branchpacking system for large breaks, and the live gully repair system for breaks up to 2 feet wide and 2 feet deep. If the dormant season has passed, consider using rooted stock.

Final Check

A final check should be made two years after the installation is completed. Healthy growing conditions (overall leaf development and rooted stems) should exist as follows:

Live stakes	70%-100% growing
Live fascines	20% - 50% growing
Live cribwall	30% - 60% growing
Brushlayers	40% - 70% growing
Branchpacking	40% - 70% growing
Live gully repair	30% - 50% growing
Vegetated rock wall	50% - 80% growing
Vegetated gabion	40% - 60% growing
Joint planting	50% - 70% growing

Growth should be continuous with no open spaces greater than 2 feet in linear systems. Spaces two feet or less will fill in without hampering the integrity of the installed living system.

References

Goldsmith, W. and Bestmann, L., An Overview of Bioengineering for Shore Protection, Proceedings of Conference XXIII, International Erosion Control Association, Reno, Nevada, February 1992.

Gray, Donald H. and Leiser, A. T., ***Biotechnical Slope Protection and Erosion Control***, Leiser Van Reinhold Inc., 1982.

U.S. Department of Agriculture, ***Natural Resources Conservation Service Engineering Field Handbook***, Chapter 18, Soil Bioengineering for Upland Slope Protection and Erosion Reduction.

Washington State Department of Ecology, ***Stormwater Management Manual for the Puget Sound Basin***, Olympia, WA, February, 1992.

Herbaceous Plants for Streambank Soil Bioengineering Applications in Massachusetts

Native Plants Suited for Planting in Saturated Soils and/or Coir Geotextile1/:

Scientific Name	Common Name	Notes
Asclepias incarnata	Swamp milkweed	Peat plugs/pots.
Acorns calamus or antericanus	Sweet Flag	Plants in peat plugs/ pots or dormant rootcuttings.
Calamagrostis canadensis	Blue Joint Reed Grass	Peat plugs/pots. Can be seeded if no standing or flowing water.
Carex spp.	Sedges	Some native species are: comosa, crinita,intumescens, lurida, stricta and vulpanoidea.Peat plugs/pots or bare-rooted OK.
Cinna arundinacea	Wood Reed Grass	Peat plugs/pots. Can be seeded if nostanding or flowing water.
Distichlis spicata	Sea Shore Saltgrass	Peat plugs/pots. Coastal areasonly.
Eupatorium perfoliatum and E. purpureum	Boneset and Joe-Pye Weed	Peat plugs/pots.

Scientific Name	Common Name	Notes
Glyceria canadensisand G. striata	Manna Grasses	Peat plugs/pots or bare-rooted plants.Can be seeded if no standing or flowing water.
Iris versicolor	Blue Flag Iris	Dormant plants.
Juncus canadensis and J. effusus	Rushes	Peat plugs/pots or bare rooted plants.
Leersia oryzoides	Rice Cut Grass	Peat plugs/puts. Can be seeded if no standing or flowing water.
Pontederia cordata	Pickerel Weed	Peat pots or bare rooted plants.
Sagittaria latifolia	Arrowhead	Plant as tuber or in peat plug/put.
Scirpus spp.	Bulrushes	Some native species are: S.acutus, S.atrovirens, S. cyperinus, S. pungens, S. validus. Peat plugs or bare root plants.
Sparganium spp.	Bur Reed	S. americanum and S. eutycarpum are native species.
Spartina alterniflora	Salt Marsh Grasses	Peat plugs/pots. Plantings within proper tidal zone is critical.
Spartina pectinata	Fresh Water Cordgrass	Peat pots/pots.
Typa latifolia and T angustifolia	Cattails	Peat pots or bare root plants.
Verbena hastata	Blue Vervain	Peat plugs/pots.

Herbaceous Plants for Streambank Soil Bioengineering Applications in Massachusetts (Continued)

Grasses Suited for Planting on Streambanks in Combination with Bioengineered Applications2/3/:

Name	Status	Application	Notes
Agrostis alba Red Top	Introduced	All bank zones	Cool Season.
Agrostis stolonifera, var. palustris Creeping/Marsh Bentgrass	Native statewide	Low to mid bank zone	Cool Season.
Ammophila breviligulata American Beachgrass	Native to coastal counties	Sandy, gravelly droughty bank	Cape cultivar is native to MA Use culms to establish
Andropogon gerardii Blue Bigstem	Native statewide	Droughty upper bank	Warm season
Andropogon virginicus Broomsedge	Native statewide except Berkshire and Franklin	Mid to upper bank zone	Warm season
Dichanthelium clandestinum Deertongue Grass	Native statewide	Mid to upper bank zone	Warm season.
Elymus canadensis Nodding Wild Rye	Native statewide	Mid to upper bank zone	Cool season.
Festuca rubra Red Fescue	Native away from coastal areas. Introduced to coast.	Mid to upper bank zone	Cool season. Shade tolerant
Lolium perenne Perennial Ryegrass	Introduced	Mid to upper bank zone	Cool season. Fast growing-short term.
Panicum virgatum Switchgrass	Native statewide	Mid to upper bank zone	Warm season.
Sorghastrum nutans Indiangrass	Native statewide	Mid to upper bank zone	Warm season
Schizachyrium scoparium Little Bluestem	Native Statewide	Upper bank zone	Warm season

Notes:

Bank Zones:

Lower is at or near the normal waterline to the upper limit of saturation due to capillary action.

Mid is the surface area above the upper limit of the lower zone to about 3 feet from the top of bank.

Upper is the surface area about 3 feet from the top of bank and extending into the riparian zone.

Seeding Periods:

Warm season grasses are seeded in spring up to June 1, or as a dormant seeding November - March.

Cool season grasses are seeded in spring up to June 1, or in late summer/early fall August 15 - October.

1/ Table prepared by R. DeVergilio, Natural Resources Conservation Service, Amherst, MA., with technical input from M. Marcus, New England Wetland Plants, Inc., Amherst MA. Technical review by C. Miller, Plant Materials Specialist, NRCS, Somerset, NJ.

2/ Table prepared by R. DeVergilio, Natural Resources Conservation Service, Amherst, MA., with technical input from C. Miller, Plant Materials Specialist, NRCS, Somerset NJ.

3/ Grasses are usually seeded upon the bank or over a particular bioengineering application, however most species listed are also commercially available as rooted plants.

4/ Beachgrass is established by vegetative means only (planting of dormant culms).

Native plant review by The Massachusetts Native Plant Advisory Committee,1/29/96

Woody Plants for Streambank Soil Bioengineering Applications in Massachusetts

Name	Native	Size, Form	Plant Material Type 1/	Rooting Ability	Notes
Alnus rugosa/serrulata Speckled/Smooth Alder	State wide	Large Shrubs	Rooted Plants only	Poor	Good for low to mid bank zone
Aronia arbutifolia Red Chokecherry	Statewide	Shrub	Rooted Plants only	Poor	Good for low to mid bank zone
Baccharis halimifolia Eastern False Willow	Coast only	Med. Shrub	Facines Cuttings Rooted Plants	Good	Good for low to mid bank zone. Resistant to salt spray
Cephalanthus occidentalis Button Bush	Statewide	Med. Shrub	Layering Cuttings Rooted Plants	Good	Good for low bank zone. Prefers at least periodic inundation.
Clethera alnifolia Sweet Pepper Bush	Statewide	Med. Shrub	Rooted plants only	Poor	Good for mid-upper bank zone. Good for salt tolerance.
Cornus amomum Silky Dogwood	Statewide	Small Shrub	All	V. Good	Good for all bank zones. Tolerates shade.
Cornus racemosa Gray Dogwood	Statewide	Med. Shrub	All	Good	Good for mid-upper bank zone. Tolerates shade and drought.
Cornus sericea Red Osier Dogwood	Western MA only 2/	Med. Shrub	All	V. Good	Good for all bank zones.
Ilex opaca American Holly	SE MA	Sm.Tree	Rooted Plant only	Poor	Good for upper bank zone. Shad and drought tolerant.
Ilex verticillata Winterberry Holly	Statewide	Med. Shrub	Rooted plant only	Poor	Mid to lower banks. Prefers seasonal flooding.
Lindera benzoin Spicebush	Statewide	Shrub	Rooted Plant only	Poor	All bank zones. Good shade tolerance.
Populus balsamifera Balsam Poplar	W. MA only 2/	Tree (see note)	All	V. Good	3/ Use cautiously on streambanks. Good for riparian zone.
Populus deltoides Eastern Cottonwood	W. MA only 2/	Tree (see note)	All	V. Good	3/ Use cautiously on streambank. Good for riparian zone.
Rhododendron viscosum	Statewide	Med. Shrub	Rooted Plant only	Poor	Good for mid- to lower bank zones

Woody Plants for Streambank Soil Bloengineering Applications in Massachusetts (Continued)

Name	Size, Native	Form	Plant Material Type 1	Rooting Ability	Notes
Rosa palustris Swamp Rose	Statewide	Sm. Shrub	Facines Rooted Plants	Good	Low-mid bank zone
Salix amygdaloides Peachleaf Willow	No-Introduced	Lg. Shrub	All	V.Good	Good for all bank zones
Salix discolor Pussy Willow	Statewide	Med. Shrub	All	V.Good	Good for all bank zones
Salix eriocephala Erect Willow	Statewide	Lg. Shrub	All, But no Brush Mattress	V.Good	Good for all bank zones.
Salix exigua Sandbar Willow	CT River Valley	Lg. Shrub	All	Good	Mid to lower bank zones
Salix nigra Black Willow	Statewide	Tree (see note)	All	V.Good	3/ Use cautiously on streambank. Good for riparian zone.
Salix Humilis Prarie Willow	Statewide	Med. Shrub	All	Good	Good for bank zones
Salix pupurea Purpleosier Willow	No- (see note)	Lg. Shrub	All	V.Good	“Streamco” Cultivar released by NRCS. All bank zones
Salix x cottetii Dwarf Willow	No - (see note)	Sm. Shrub	All	V.Good	“Bankers” cultivar released by NRCS. Low to mid-bank zones
Sambucus canadensis American Elderberry	Statewide	Sm. Shrub	Facines Cuttings	Good	Good for mid-bank zone. Use with other good rooting species only.
Spirea tomentosa Steeple Bush	Statewide	Sm. Shrub	Layering	Poor-Fair	Midto upper bank.Use with other good rooting species only.
Virburnum dentatum Southern Arrowood	South and East	Med. Shrub	Rooted Cuttings and plants	Fair	Good for mid-bank zone
Virburnum recognitum Northern Arrowood	North and West	Med. Shrub	Rooted plants	Poor	Good for all bank zones. Rooted cuttings good.
Virburnum trilobum 4/ American Cranberry Bush	Yes, but not Cape and islands	Med. Shrub	Rooted Plants	Poor	Good for all bank zones. Good shade tolerance.
Virburnum lentago Nannyberry	Yes, but not Cape and islands	Lg. Shrub	Facines, Stakes	Fair	Good for mid-bank. Tolerates shade. Use with other good rooting species only.

Notes:
Table prepared by R. DeVergilio, Natural Resources Conservation Service, Amherst MA. Adapted from NRCS data base 'Plants For BioEngineering, Uses, H. W. Everett, 11/95'. Native plant review by the Massachusetts Native Plant Advisory Committee.
Special Note...... 'Streamco' and 'Bankers' are not native to Massachusetts. It is recommended they only be used in combination with native species.
1/ Plant Material Types: 'All' includes Dormant Fascines, Stakes, Brush Mattresses, Layering, and Cuttings as well as Rooted Cuttings and Plants.
2/ Western Mass. includes Berkshire, Franklin, Hampshire, and Hampden Counties.
3/ Tree species, such as cottonwood, poplar and black willow, are recommended for riparian area plantings and are not recommended for establishment upon the streambank itself due to potential for windthrow at maturity, and subsequent damage to the streambank.
4/ *Viburnum opulus* is similar to *V.trilobum* and is often confused with it. *V. opulus* is introduced to Massachusetts.
Streambank Zones:
Lower is at or near the normal waterline to the upper limit of saturation due to capillary action.
Mid is the surface area above the upper limit of the lower zone to about 3 feet from the top of bank.
Upper is the surface area about 3 feet from the top of bank and extending into the riparian zone.

Erosion and Sediment Control Best Management Practices for Individual Homesites and Small Parcels

Construction on small developments can cause large amounts of sediment to be transported to receiving waters. The following are some of the damaging activities and conditions that may occur during development:

Exposed and unprotected soil is often left throughout the development. When runoff occurs, sediment is transported into the nearest stormwater facility or stream, eventually clogging it.

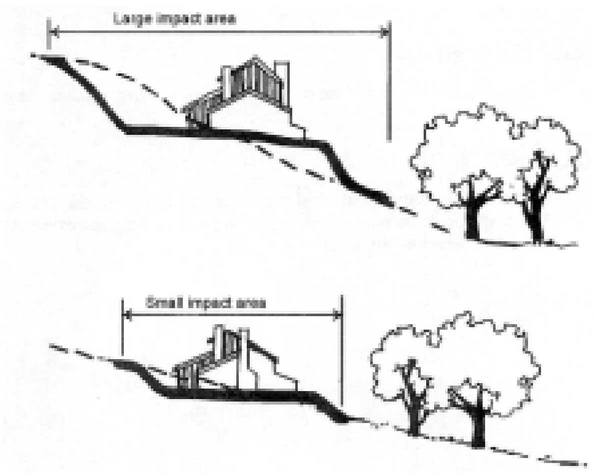
Vehicles and heavy equipment track soil from the development onto the street. Gullies formed by tire tracks become channels for runoff flow.

Vegetation bordering streams or lakes is often removed during construction. This increases the water temperature by removing shade. An increase in water temperature can contribute to algae blooms and may change the species composition of the lake or stream. Because the vegetation has been removed, there is no barrier to prevent sediment from entering the stream. This can clog spawning grounds and fish gills.

These problems may occur during work performed by subcontractors who are on-site for a very short time. Cooperation and communication between developers, builders, and subcontractors are essential to minimize erosion and damage to the environment.

Clearing and Grading

Plan and implement proper clearing and grading of the site. It is important to clear only the areas needed, thus keeping exposed areas to a minimum. Phase the clearing so that only those areas that are actively being worked are uncovered. Clearing limits should be flagged prior to the start of clearing work.



Excavated Basement Soil

Locate excavated basement soil a reasonable distance behind the curb, such as in the backyard or side yard area. This will increase the distance eroded soil must travel to reach the storm sewer system. Soil piles should be covered until the soil is either used or removed. Piles should be situated so that sediment does not run into the street or adjoining yards.

Backfilling

Backfill basement walls as soon as possible and rough grade the lot. This will eliminate large soil mounds which are highly erodible and prepares the lot for temporary cover which will further reduce erosion potential.

Removal of Excess Soil

Remove excess soil from the site as soon as possible after backfilling. This will eliminate any sediment loss from surplus fill.

Management Of Soil Banks

If a lot has a soil bank higher than the curb, a trench or berm should be installed moving the bank several feet behind the curb. This will reduce the occurrence of gully and rill erosion while providing a storage and settling area for stormwater.

Construction Road Access

Apply gravel or crushed rock to the driveway area and restrict truck traffic to this one route. Driveway paving can be installed directly over the gravel. This measure will eliminate soil from adhering to tires and stops soil from washing into the street. This measure requires periodic inspection and maintenance including washing, top-dressing with additional stone, reworking and compaction.

Soil Stabilization

Stabilize denuded areas of the site by mulching, seeding, planting, or sodding.

Street Cleaning

Provide for periodic street cleaning to remove any sediment that may have been tracked out. Sediment should be removed by shovelling or sweeping and carefully removed to a suitable disposal area where it will not be re-eroded.

References

Lobdell, Raymond, ***A Guide to Developing and Re-Developing Shoreland Property in New Hampshire***, North Country Resource Conservation and Development Area, Inc., Meredith, NH, 1994.

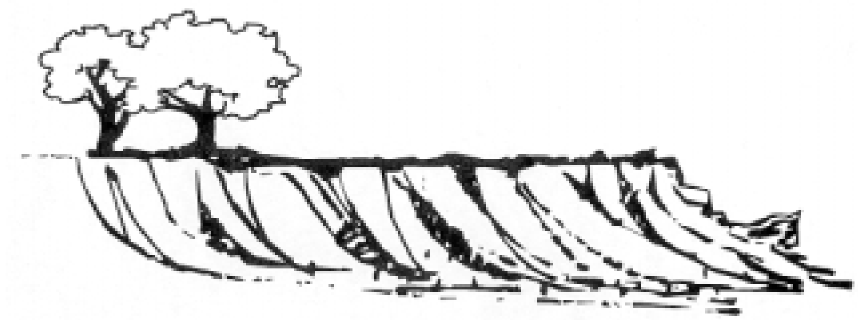
Minnesota Pollution Control Agency, Division of Water Quality, ***Protecting Water Qualily in Urban Areas, Best Management Practices for Minnesota***, MN, October, 1989.

Washington State Department of Ecology, ***Stormwater Management Manual for the Puget Sound Basin***, Olympia, WA, February, 1992.

Erosion and Sediment Control Best Management Practices for Sand and Gravel Pits

Erosion from sand and gravel pits can contribute a large amount of sediment to adjacent water courses. Sand and gravel also provides a very porous medium for transporting soluble pollutants to the underlying groundwater. Many sand and gravel operations are located within or near the recharge area of public and private wells. A major threat to groundwater exists when excavation activities take place in these areas. Exposure of the saturated zone in recharge areas can leave groundwater resources vulnerable to contamination because it decreases filtering. An added problem is that abandoned excavation pits have been used for the unregulated disposal of solid and liquid wastes and salt-laden snow.

The information in this section was adapted from *Resource Extraction, Guidelines for Sand and Gravel Pits*, in Chapter Four of the *Massachusetts Nonpoint Source Management Manual, Appendix D, Vegetating New Hampshire Sand and Gravel Pits*, in *Stormwater Management and Erosion Control for Urban and Developing Areas in New Hampshire*, and *Revegetating Sand and Gravel Pits in the Northeast States* by Dickerson, Kelsey, Godfrey, Gaffney, and Miller.



Soil erosion, aesthetics, and adverse impacts on water quality are concerns associated with the operation, maintenance, and closure of sand and gravel pits. A good vegetative cover of grasses and legumes can alleviate these concerns. Vegetative cover will retard surface runoff and prevent erosion, reducing the sedimentation of nearby streams, waterways, and waterbodies. Vegetative cover will enhance the aesthetics of sand and gravel pits while providing nesting and escape cover for wildlife.

Controlling the removal of soil in recharge areas is a commonly used technique to minimize groundwater impacts. Many municipalities statewide have adopted earth removal bylaws which limit excavation within varied distances to the water table (ranging from 4 feet to 10 feet). When regulating excavation activities, the seasonal and annual fluctuations in the water table should be considered. To insure maximum groundwater protection, local controls should be designed to incorporate more conservative groundwater table estimates.

Massachusetts law (310 CMR 22.21 (2) (b) 6) prohibits the removal of soil, loam, sand, gravel or other mineral substance within 4 feet of the historical high groundwater table elevation. The regulations do allow for removal of soil provided the same soil is replaced at a final grade greater than 4 feet above the historical high water mark within 45 days. This is intended to facilitate necessary, short term excavation/soil movement activities while insuring that sand and gravel deposits associated with favorable groundwater areas are not replaced with materials of poorer quality. Building foundations and utility work are also given exemptions under this provision.

Sand and gravel pits are difficult sites to permanently vegetate. The difficulty is due to droughty conditions, low soil organic matter, low soil fertility, and lack of topsoil. Stockpiling topsoil can greatly reduce the difficulty of establishing vegetation. Most town by-laws prohibit selling topsoil. A 4-inch cap of topsoil will usually be sufficient for establishing selected vegetation that is otherwise compatible with the site condition.

Recommendations for sand and gravel pit operation.

Information Needed For Developing A Stabilization Plan

Topography for the "original ground surface" based on no greater than five-foot contour intervals (2 foot contour levels should be provided whenever possible).

Log of soil borings taken to the depth of the proposed excavation. The number of borings taken will vary with the size and geological make-up of the site.

Topographical map showing planned final grades, drainage facilities, etc. after excavation.

Operation Standards

No excavation should be closer than 200 feet to an existing public way unless specifically permitted by authorized official. No excavation should approach neighboring lot lines closer than 50 feet. (No excavation closer than 50 feet.) Natural vegetation should be left and maintained on the undisturbed land for screening and noise reduction purposes.

All loaded vehicles should be suitably covered to prevent dust and contents from spilling and blowing from the load.

The active gravel removal operation area should not exceed a total area of three acres at any one time.

All access roads leading to public ways should be treated with stone, or other suitable material to reduce dust and mud for a distance of 200 feet back from said public way; unless there is a stabilized construction entrance/tire wash at points of vehicular ingress/egress. Any spillage on public ways should be cleaned up by the operator.

Access roads should be constructed at an angle to the public way or constructed with a curve so as to help screen the operation from public view.

Most communities limit gravel removal close to the seasonal high water table; usually a range of 2 to 10 feet above seasonal high water table. This elevation should be established from test pits or soil borings and the level related to a permanent monument on the property. This information should show on the topographic plan.

During operations, when an excavation is located closer than 200 feet from a residential area or public way and where the excavation will have a depth of more than 15 feet with a slope in excess of 1: 1, a fence at least four feet high should be erected to limit access to this area.

No area should be excavated so as to cause accumulation of free standing water. Permanent drainage should be provided as needed in accordance with good construction practices. Drainage should not lead directly into streams or ponds.

All topsoil and subsoil should be stripped from the operation area and stockpiled for use in restoring the area after the removal operation has ceased.

No excavation should be allowed closer than 100 feet from a natural stream.

Restoration Standards

Slopes should be left no steeper than 3:1; to provide stability and facilitate seeding efforts.

Avoid long slopes to help prevent erosion and to allow access for seeding, mulching, and maintenance. Control slope length by installing one terrace (10 feet wide and sloped into the cut slope) for every 40 vertical feet.

All debris, stumps, boulders, etc., should be removed from the site and disposed of in an approved location, or in the case of inorganic material, buried and covered with a minimum of two feet of soil.

Following excavation and as soon as possible thereafter, ground levels and grades should be established as shown on the completed topographical plan.

Construct diversions at tops of slopes to divert runoff water away from the slope banks to a stable outlet.

Construct rock lined chutes or equivalent to conduct concentrated flow of water to stable outlets.

Remove large stones, boulders, and other debris that will hinder the seeding process and the establishment of vegetation.

Spread a minimum depth of 4 inches of topsoil over the site, if available. Supplement as necessary with subsoil retained from. pit operations.

Retained subsoil and topsoil should be respread over the disturbed area to a minimum depth of four inches. Seed with a grass or legume mixture designed for the specific site. (Recommendations follow.)

Trees or shrubs should be planted to provide screening, natural beauty, and erosion control during the establishment period.

Upon completion of the operation, the land should be left so that natural storm drainage leaves the property within the original watercourses that existed prior to construction. The rate and volume of surface water runoff should not be increased as a result of the excavation operations.

Obtain soil samples by collecting 6 to 8 small samples (one or two handfuls each) of soil material from the upper 4 inches of the area to be seeded. Mix the small samples to obtain one composite sample.

Use part of the sample for a soil test to determine lime and fertilizer needs. Run the balance of the sample(s) through a sieve analysis to determine the percent by weight passing a No. 200 sieve. Those passing are called "fines."

If no soil tests are made, soil can be treated with three tons of lime per acre and 1,000 pounds of 10-10-10 fertilizer per acre. Basing lime and fertilizer recommendations on actual soil tests is preferable, however, and will result in much better long-term vegetative performance.

Planting Procedures

Species and Variety Selection

Select a grass/legume mix (see chart following) based on the percent weight passing a No. 200 sieve as outlined above. The standard conservation mixes available from local seed suppliers are not recommended on droughty sites. These mixes usually provide a green cover very quickly, but the plant species begin to die in two to four years on sterile and droughty sites.

Where percent by weight passing a No. 200 sieve is less than 15, select options from Mix 1.

Mix 2 is recommended if suppression of woody growth is desired and there is more than 15 percent by weight passing a No. 200 sieve.

Where percent by weight passing a No. 200 sieve is between 15 and 20, use Mix 1 or 2. Where percent by weight passing a No. 200 sieve is above 20, use Mix 1, 2, or 3.

Lime and Fertilizer Determination

Mix 1 - If soil test data is not available, lime at the rate of 1 ton/acre (50 lbs/1,000 sq ft). Fertilize with 500 lbs/acre (11 lbs/1,000 sq ft) of 10-20-20 or equivalent. Incorporate lime, fertilizer, and seed using rakes if seeding is done by hand. It is highly recommended to use a bulldozer to “track” the site after seeding. Tracking will incorporate the lime, fertilizer, and seed to promote seed germination.

Mix 2 - In lieu of a soil test, lime at the rate of 2 tons/acre (90 lbs/1,000 sq ft). Fertilize with 500 lbs/acre (11 lbs/1,000 sq ft) of 1020-20 or equivalent. The seed needs to be incorporated into the soil to ensure success and to shorten establishment time. This is most critical for the large seeded legumes in Mix 2. On the flatter slopes, use a bulldozer to “track in” the seed.

Mix 1. Warm season grasses.

Species	Varieties, listed in preferential order (select one)	Options for various Situations (1) Lbs Per Acre (PLS)		
		(2)	(3)	(4)
Switchgrass	Trailblazer, Pathfinder	6	2	6
Big Bluestem	Niagara, Kaw	4	2	4
Little Bluestem	Aldous, Camper, Blaze	2		
Deertongue Grass			— 5-10 —	
Indian Grass			— 5-10 —	

Notes:
(1) Warm season grass seed is sold and planted on the basis of pure live seeds (PLS). An adjustment is made to the bulk pounds of seed to compensate for inert material and dead seed.
(2) This combination most closely represents the naturally occurring vegetation where warm season grasses are native in the northeast.
(3) This combination has the fastest establishment and cover.
(4) This combination is the simplest and may be easier to obtain. Options 2 or 1, however, will produce better results.

Mix 2. Legumes and cool season grass.

Species	Varieties, listed in preferential order (select one)	Lbs Per Acre
Flatpea (1)	Lathco	10
Perennial pea (1)	Lancer	10
Perennial Ryegrass		10
Tall fescue	Ky-31, Rebel, Ken-Hi	10
Red Top		1

Notes:
(1) These legumes must be inoculated at time of seeding. If seeding by hand, use a sticking agent, such as cola or milk to stick inoculant to seed. If seeding with hydroseeder, use 4 times the recommended rate of inoculant.

Mulch Determination for Hydro and Hand Seeding

Mulching for Mix 1

Use weed-free mulch. Clean straw is recommended. Mulch at the maximum rate of 500-700 lbs/acre. Higher mulching rates and mulch with weed seed content will inhibit seeding success significantly. If the erosion hazard is low and the seed is incorporated, mulching is not necessary for seeding success. Do not apply mulch prior to tracking with a bulldozer.

Mulching for Mix 2

Mulch with weed-free hay or straw and mulch at the rate of 2-3 tons/acre. The higher mulching rate is recommended where seed incorporation is difficult.

Seeding Methods

Alternative 1 - Large areas and/or steep slopes

Apply lime, seed, and fertilizer with a hydroseeder and, depending on the consistency of the soil material, steepness of slope, and seed mixture used:

- Press the seed into the soil by tracking with a bulldozer, or
- Cover the seed by walking back and forth over steep loose sandy slopes, or
- Apply mulch and a tackifier to hold the mulch in place.

Alternative 2 - Flat to gently sloping areas

(2:1 slopes maximum) Apply lime, seed, and fertilizer using farm type spreaders, and track the site with a bulldozer or apply mulch according to the circumstances.

Alternative 3 - Small areas

Apply lime, seed, and fertilizer by hand and rake.

Seeding Dates

Best seeding period is between snow melts in the spring and ends May 15. Early seeding is very important, especially for Mix 1. Actual seeding date depends on weather conditions, but substantial failure can be expected if seeding is done late.

Late summer and early fall seedings are not recommended. If late season seedings are necessary, they should be done after October 20 to prevent fall germination and subsequent winterkill.

Response of Seeding

The plant species in Mixes 1 and 2 germinate and grow slowly. Complete cover may not occur for 2-4 years. A well established stand, however, will last for years.

Follow-up seeding may be needed to establish vegetation on the more difficult parts of some sites. The need to do follow-up seeding can be determined the year after the initial planting.

Maintenance

Substantial stand vigor can be achieved if the site is topdressed with fertilizer one year after planting. If topdressing Mix 1, fertilize between June 15 and July 15. The timing of this topdressing, is important. Mixes 2 should be topdressed in the early spring.

Topdress Mixes 1 with a balanced fertilizer, applying 50 lbs of nitrogen/acre. For example, apply 250 lbs of 20-20-20/acre.

Topdress Mix 2 with 500 lbs of 0-20-20/acre in April, May, or June.

If mowing is desired to suppress woody growth, mow Mix 1 about mid-July leaving a stubble height of 6-8 inches. It is not necessary to mow Mix 2. A good cover of flatpea will prevent invasion of woody species.

References

Dickerson, John A., Kelsey, T. L., Godfrey, R. G., Gaffney, F. B., Miller, C., Revegetating Sand and Gravel Pits in the Northeast States, ____.

Massachusetts Department of Environmental Protection, Office of Watershed Management, Nonpoint Source Program, Massachusetts Nonpoint Source Management Manual, Boston, Massachusetts, June, 1993.

Minnick, E. L., and H. T. Marshall, Stormwater Management and Erosion Control for Urban and Developing Areas in New Hampshire, Rockingham County Conservation District, August 1992.

A Sample Erosion and Sedimentation Control Plan

This sample plan is for instructive purposes only. The specific number of maps, practices, drawings, specifications, and calculations required depends on the size and complexity of the development. The designer should select the most practical and efficient practices to control erosion and prevent sediment from leaving the site. The plan should be organized and presented in a clear, concise manner. Sufficient design and background information should be included to facilitate review. Construction details should be precise and clear for use by an experienced general contractor.

Due to size and space limitations, the following sections of the erosion and sedimentation control plan have not been included with this sample: vicinity map, site topography map, site development plan, erosion and sedimentation control plan drawing, detail drawings and specifications for the selected practices, vegetation plan, and supporting calculations.

Sample

EROSION AND SEDIMENTATION CONTROL PLAN ABC INDUSTRIES, INC.
ANYTOWN, MASSACHUSETTS
JULY 1995

Table of Contents

Narrative

Project Description

The purpose of the project is to construct two large commercial buildings with associated paved roads and parking area. Another building will be added in the future. Approximately 6 acres will be disturbed during this construction period. The site consists of a total of 11.1 acres and is located in ANYTOWN, Massachusetts.

Site Description

The site has rolling topography with slopes generally 4 to 6 percent. Slopes steeper to 10 to 20 percent in the northwest portion of the property where a small healed-over gully serves as the principal drainageway for the site. The site is now covered with woody vegetation, predominantly white pines, 15 to 20 feet high. There is no evidence of significant erosion under present site conditions. The old drainage gully indicates severe erosion potential and receives flow from 5 acres of woods off-site. There is one large oak tree, located in the western central portion of the property, and a buffer area, fronting Terri Road, that will be protected during construction.

Adjacent Property

Land use in the vicinity is commercial/industrial. The land immediately to the west and south has been developed for industrial use. Areas to the north and east are undeveloped and heavily wooded, primarily in white pine. Hocutt Creek, the off-site outlet for runoff discharge, is presently a well stabilized, gently-flowing perennial stream. Sediment control measures will be taken to prevent damage to Hocutt Creek. Approximately 5 acres of wooded area to the east contribute runoff into the construction area.

Soils

The soil in the project area is mapped as Paxton (see Natural Resources Conservation Service, soil survey for your town) fine sandy loam in B and C slope classes. Paxton soils are considered moderately well to somewhat poorly drained with permeability rates greater than 6 inches/hour at the surface but less than 0.1 inches/hour in the subsoil. The subsurface is pale brown sandy loam, 6 inches thick. The subsoil consists of a pale brown and brownish yellow sandy clay loam ranging to light gray clay, 36 inches thick. Below 36 inches is a layer of fine sandy loam to 77 inches. The soil erodibility (K factor; see soil survey for an explanation) ranges from 0.20 at the surface to 0.37 in the subsoil.

Due to the slow permeability of the subsoil that will be exposed during grading, a surface wetness problem with high runoff is anticipated following significant rainfall events. No groundwater problem is expected. The tight clay in the subsoil will make vegetation difficult to establish. Some topsoil exists on-site and will be stockpiled for landscaping.

Planned Erosion and Sedimentation Control Practices

Sediment Basin

A sediment basin will be constructed in the northwest corner of the property. All water from disturbed areas, about 6 acres, will be directed to the basin before leaving the site. (NOTE: The undisturbed areas to the east and north could have been diverted, but this was not proposed because it would have required clearing to the property line to build the diversion and the required outlet structure.)

Construction Entrance

A temporary gravel construction entrance will be installed near the north-west corner of the property. During wet weather it may be necessary to wash vehicle tires at this location. The entrance will be graded so that runoff water will be directed to an inlet protection structure and away from the steep fill area to the north.

Block and Gravel Inlet Protection

A temporary block and gravel inlet protection device will be installed at the drop inlet located on the south side of the construction entrance. Runoff from the device will be directed into the sediment basin. (NOTE: The presence of this device reduces the sediment load on the sediment basin and provides sediment protection for the pipe. In addition, sediment removal at this point is more convenient than from the basin.)

Temporary Diversions

Temporary diversions will be constructed above the 3:1 cut slopes south of Buildings A and B to prevent surface runoff from eroding these banks. (NOTE: Sediment-free water may be diverted away from the project sediment basin.) A temporary diversion will be constructed near the middle of the disturbed area to break up this long, potentially erosive slope should the grading operation be temporarily discontinued. A temporary diversion will be constructed along the top edge of the fill slope at the end of each day during the filling operation to protect the fill slope. This temporary diversion will outlet to the existing undisturbed channel near the north edge of the construction site and/or to the temporary inlet protection device at the construction entrance as the fill elevation increases.

Level Spreader

A level spreader will serve as the outlet for the diversion east of Building A and south of Building B. The area below the spreader is relatively smooth and heavily vegetated with a slope of approximately 4 percent.

Tree Preservation and Protection

A minimum 2 foot high protective fence will be erected around the large oak tree at the dripline to prevent damage during construction. Sediment fence materials may be used for this purpose.

Land Grading

Heavy grading will be required on approximately 6 acres. The flatter slope after grading will reduce the overall erosion potential of the site. The buildings will be located on the higher cut areas, and the access road and open landscaped areas will be located on fill areas.

All cut slopes will be 3:1 or flatter to avoid instability due to wetness, provide fill material, give an open area around the buildings, and allow vegetated slopes to be mowed. Cut slopes will be fine graded immediately after rough grading; the surface will be disked and vegetated according to the Vegetation Plan.

Fill slopes will be 2:1 with fill depths as much as 12 to 15 feet. Fill will be placed in layers not to exceed 9 inches in depth and compacted.

The fill slope in the north portion of the property is the most vulnerable area to erosion on the site. Temporary diversions will be maintained at the top of this fill slope at all times, and the filling operation will be graded to prevent overflow to the north. Filling will be done as a continuous operation until final grade is reached.

The paved road located on the fill will be sloped to the south and will function as a permanent diversion. The area adjacent to the roads and parking area will be graded to conduct runoff to the road culverts. Runoff water from the buildings will be guttered to the vegetated channels. The finished slope face to the north will not be back-bladed. The top 2 to 6 inches will be left in a loose and roughened condition. Plantings will be protected with mulch, as specified in the Vegetation Plan.

A minimum 15 foot undisturbed buffer will be maintained around the perimeter of the disturbed area. (NOTE: This will reduce water and wind erosion, help contain sediment, reduce dust, and reduce final landscaping costs.)

Temporary Sediment Trap

A small sediment trap will be constructed at the intersection of the existing road ditch and channel number 3 to protect the road ditch. Approximately 2 acres of disturbed area will drain into this trap.

Sediment Fence

A sediment fence will be constructed around the topsoil stockpile and along the channel berm adjacent to the deep cut area, as necessary to prevent sediment from entering the channels.

Sod Drop Inlet Protection

Permanent sod drop inlet protection will replace the temporary block and gravel structure when the contributing drainage area has been permanently seeded and mulched.

Grassed Waterway

Grassed waterways with temporary straw-net liners will be constructed around Buildings A and B to collect and convey site water to the project's sediment basin.

Should the disturbed areas adjoining the channels not be stabilized at the time the channels are vegetated, a sediment fence will be installed adjacent to the channel to prevent channel siltation.

Riprap-Lined Waterways

A riprap channel will be constructed in the old gully along the north side of the property starting in the northwest corner after all other construction is complete. This channel will replace the old gully as the principal outlet from the site.

Construction Road Stabilization

As soon as final grade is reached on the entrance road, the subgrade will be sloped to drain to the south and stabilized with a 6 inch course of ¾ inch stone. The parking area and its entrance road will also be stabilized with ¾ inch stone to prevent erosion and dust during the construction of the buildings and prior to paving.

Outlet Stabilization

A riprap apron will be located at the outlet of the three culverts to prevent scour.

Surface Roughening

The 3:1 cut slopes will be lightly roughened by disking just prior to vegetating, and the surface 4 to 6 inches of the 2:1 fill slopes will be left in a loose condition and grooved on the contour.

Surface stabilization

Surface stabilization will be accomplished with vegetation and mulch as specified in the Vegetation Plan. One large oak tree southwest of Building A and a buffer area between the parking lot and Terri Road will be preserved. Roadway and parking lot base courses will be installed as soon as finished grade is reached.

Dust control

Dust control is not expected to be a problem due to the small area of exposure, the undisturbed perimeter of trees around the site, and the relatively short time of exposure (not to exceed 9 months). Should excessive dust be generated, it will be controlled by sprinkling.

Construction Schedule

1. Obtain plan approval and other applicable permits.
2. Flag the work limits and mark the oak tree and buffer area for protection.
3. Hold a pre-construction conference at least one week prior to starting construction.
4. Install the sediment basin as the first construction activity.
5. Install the storm drain with the block and gravel inlet protection at the construction entrance/exit.
6. Install the temporary gravel construction entrance/exit.
7. Construct the temporary diversions above the proposed building sites. Install the level spreader and sediment trap and vegetate disturbed areas.
8. Complete site clearing except for the old gully in the northwest portion of the site. This area will be cleared during the last construction phase for the installation of the riprap channel.
9. Clear the waste disposal area in the northeast corner of the property, only as needed.
10. Rough grade site, stockpile topsoil, construct channels, install culverts and outlet protection, and install sediment fence as needed. Maintain diversions along the top of the fill slope daily.
11. Finish the slopes around the buildings as soon as rough grading is complete. Leave the surface slightly roughened and vegetate and mulch as soon as possible.
12. Complete the final grading for roads and parking and stabilize with gravel.
13. Complete the final grading for the buildings.
14. Complete the final grading of grounds, topsoil critical areas, and permanently vegetate, landscape, and mulch.
15. Install the riprap outlet channel and extend riprap to pipe outlet under entrance road.
16. After the site is stabilized, remove all temporary measures and install permanent vegetation on the disturbed areas.
17. Estimated time before final stabilization is 9 months.

Maintenance Plan

1. All erosion and sediment control practices will be checked for stability and operation following every runoff-producing rainfall but in no case less than once every week. Any needed repairs will be made immediately to maintain all practices as designed.
2. The sediment basin will be cleaned out when the level of sediment reaches 2 feet below the top of the riser. Gravel will be cleaned or replaced when the sediment pool no longer drains properly.
3. Sediment will be removed from the sediment trap and block and gravel inlet protection device when storage capacity has been approximately 50 percent filled. Gravel will be cleaned or replaced when the sediment pool no longer drains properly.
4. Sediment will be removed from behind the sediment fence when it becomes about ½ foot deep at the fence. The sediment fence will be repaired as necessary to maintain a barrier.
5. All seeded areas will be fertilized, reseeded as necessary, and mulched according to specifications in the Vegetation Plan to maintain a vigorous, dense vegetative cover.

Note: The appropriate official from Anytown, Massachusetts should conduct regular (weekly or bi-weekly) inspections of the site and control measures to ensure proper functioning. Orders should be issued if any conservation practice is observed to be malfunctioning or incorrectly built.

References

Massachusetts Department of Environmental Protection, Office of Watershed Management, Nonpoint Source Program, ***Massachusetts Nonpoint Source Management***, Boston, Massachusetts, June, 1993.

Glossary

Access road: A temporary or permanent road over which timber is transported from a loading site to a public road. Also known as a haul road.

Acre-foot: An engineering term used to denote a volume 1 acre in area and 1 foot in depth.

Adsorption: The adhesion of one substance to the surface of another.

Aggrade: The alteration of a channel caused by the deposition of sediment.

Aggregate: The stone or rock gravel needed for an infiltration practice, such as an infiltration trench or dry well.

Alignment: The horizontal route or direction of an access road.

Alluvial: Pertaining to material that is transported and deposited by running water.

Allochthonous: Derived from outside a system, such as leaves of terrestrial plants that fall into a stream.

Angle of repose: The maximum slope or angle at which a material, such as soil or loose rock, remains stable. Angle between the horizontal and the maximum slope that a soil assumes through natural processes.

Anti-seep Collar: A device constructed around a pipe or other conduit placed through a dam, dike, or levee for the purpose of reducing seepage losses and piping failures.

Anti-vortex Device: A facility placed at the entrance to a pipe conduit structure such as a drop inlet spillway or hood inlet spillway to prevent air from entering the structure when the pipe is flowing full.

Apron: A floor or lining to protect a surface from erosion, for example, the pavement below chutes, spillways, or at the toes of dams. Erosion protection placed below the streambed in an area of high flow velocity, such as downstream from a culvert.

Aquifer: A geologic formation or structure that transmits water in sufficient quantity to supply the needs for a water development; usually saturated sands, gravel, fractures, and cavernous and vesicular rock (Soil Conservation Society of America, 1982).

Autochthonous: Derived from within a system, such as organic matter in a stream resulting from photosynthesis by aquatic plants.

Backfill: The operation of filling an excavation after it has once been made.

Backwater: The water retarded upstream of a dam or backed up into a tributary by a flood in the main stream.

Bankfull event (also bankfull discharge): A flow condition in which streamflow completely fills the steam channel up to the top of the bank. In undisturbed watersheds, the discharge condition occurs on average every 1.5 to 2 years and controls the shape and form of natural channels. (Schueler, 1987)

Barrel: The concrete or corrugated metal pipe of a principal spillway that passes runoff from the riser through the embankment, and finally discharges to the ponds outfall.

Base Flow: The stream discharge from groundwater runoff.

Bedding: (1) The process of laying a drain or other conduit in its trench and tamping earth around the conduit to form its bed. The manner of bedding may be specified to conform to the earth load and conduit strength. (2) A site preparation technique whereby a small ridge of surface soil is formed to provide an elevated planting or seed bed. It is used primarily in wet areas to improve drainage and aeration for seeding.

Bedload: The sediment that moves by sliding, rolling, or bounding on or very near the streambed; sediment moved mainly by tractive or gravitational forces or both but at velocities less than the surrounding flow.

Bedrock: The more or less solid rock in place either on or beneath the surface of the earth. It may be soft or hard and have a smooth or irregular surface.

Berm: (1) A horizontal strip or shelf built into an embankment or cut, to break the continuity of a long slope, usually for the purpose of reducing erosion, improving stability, or to increase the thickness or width of an embankment. (2) A low earth fill constructed in the path of flowing water to divert its direction, or constructed to act as a counterweight beside the road fill to reduce the risk of foundation failure (buttress).

Best Management Practice (BMP): A structural, nonstructural, or managerial technique recognized to be the most effective and practical means to prevent and reduce nonpoint source pollutants. Should be compatible with the productive use of the resource to which applied and should be cost effective.

Blind Drain: A type of drain consisting of an excavated trench refilled with previous materials, such as coarse sand, gravel or crushed stones, through whose voids water percolates and flows toward an outlet. Often referred to as a French drain because of its initial development and widespread use in France.

Bordering Vegetated Wetlands: Freshwater wetlands which border on creeks, rivers, streams, ponds, and lakes. The types of freshwater wetlands are wet meadows, marshes, swamps, and bogs. They are areas where the topography is low and flat, and where the soils are annually saturated.

Borrow Area: A source of earth fill materials used in the construction of embankments or other earth fill structures.

Borrow pit: An excavation site outside the limits of construction that provides necessary material, such as fill material for embankments. Bottomlands: A term often used to define lowlands adjacent to streams (flood plains in rural areas).

Broad-based dip: A surface drainage structure specifically designed to drain water from an access road while vehicles maintain normal travel speeds.

Brush barrier: A sediment control structure created of slash materials piled at the toe slope of a road or at the outlets of culverts, turnouts, dips, and water bars.

Buffer area: A designated area around a stream or waterbody of sufficient width to minimize entrance of sediment and pollutants into the waterbody.

Cantilever Outlet: A discharge pipe extending beyond its support.

Catch Basin: An underground basin combined with a storm sewer inlet to trap solids.

Channel Erosion: The widening, deepening, and headward cutting of small channels and waterways, due to erosion caused by flowing water.

Channel: An open cut in the earth's surface, either natural or artificial, that conveys water.

Check dam: A small dam constructed in a gully to decrease the flow velocity, minimize channel scour, and promote deposition of sediment.

Chemigation: The addition of one or more chemicals to the irrigation water.

Chemigated water: Water to which fertilizers or pesticides have been added.

Chopping: A mechanical treatment whereby vegetation is concentrated near the ground and incorporated into the soil to facilitate burning or seedling establishment.

Chute: A device constructed to convey water on steep grades, lined with erosion resistant materials.

Composting: A controlled process of degrading organic matter by microorganisms.

Conduit: A closed facility used for the conveyance of water.

Constructed wetlands: Those wetlands that are intentionally created on sites that are not wetlands for the primary purpose of wastewater or urban runoff treatment and are managed as such.

Contour: An imaginary line on the surface of the earth connecting points of the same elevation. A line drawn on a map connecting points of the same elevation.

Conveyance system: The drainage facilities, both natural and human-made, which collect, contain, and provide for the flow of surface water and urban runoff from the highest points on the land down to a receiving water. The natural elements of the conveyance system include swales and small drainage courses, streams, rivers, lakes, and wetlands. The human-made elements of the conveyance system include gutters, ditches, pipes, channels, and most retention/detention facilities (Washington Department of Ecology, 1992).

Cover crop: A close-growing crop grown primarily for the purpose of protecting and improving soil between periods of regular crop production or between trees and vines in orchards and vineyards (Soil Conservation Society of America, 1982).

Cradle: A device, usually concrete, used to support a pipe conduit.

Crop residue: The portion of a plant or crop left in the field after harvest.

Crop rotation: The growing of different crops in recurring succession on the same land.

Crown: A convex road surface that allows runoff to drain to either side of the road prism.

Cubic foot per second: Rate of fluid flow at which 1 cubic foot of fluid passes a measuring point in 1 second. Abbreviated: cfs. Synonym: Second-foot; CUSEC.

Culvert: A metal, wooden, plastic, or concrete conduit through which surface water can flow under or across roads.

Culvert, Box: Generally a rectangular or square concrete structure for carrying large amounts of water under a roadway.

Cut-and-Fill: Process of earth moving by excavating part of an area and using the excavated material for adjacent embankments of fill areas.

Cutoff Trench: A long, narrow excavation constructed along the centerline of a dam, dike, levee, or embankment and filled with relatively impervious material intended to reduce seepage of water through porous strata.

Dam: A barrier to confine or raise water for storage or diversion, to create a hydraulic head, to prevent gully erosion, or for retention of soil, rock, or other debris.

Defoliant: A herbicide that removes leaves from trees and growing plants.

Denitrification: The anaerobic biological reduction of nitrate nitrogen to nitrogen gas.

Deposition: The accumulation of material dropped because of a slackening movement of the material-water or wind (Soil Conservation Society of America, 1982).

Desiccant: A chemical agent used to remove moisture from a material or object (Soil Conservation, of America, 1982).

Design Storm: A rainfall event of specific frequency and duration (e.g., a storm with a 2-year frequency and 24-hour duration) that is used to calculate runoff volume and peak discharge rate.

Detention: The temporary storage of storm runoff; used to control the peak discharge rates, and which provides settling of pollutants.

Detention Storage: The storage of storm runoff water for controlled release during or immediately following the design storm.

Detention Time: The amount of time that runoff water actually is stored. Theoretical detention time for a runoff event is the average time runoff of water resides in the basin over a period of release.

Dike: A temporary berm or ridge of compacted soil that channels water to a desired location. An embankment to confine or control water, especially one built along the banks of a river to prevent overflow of lowlands; a levee.

Disking (harrowing): A mechanical method of scarifying the soil to reduce competing vegetation and to prepare a site to be seeded or planted.

Diversion: A channel with a supporting ridge on the lower side constructed across or at the bottom of a slope for the purpose of intercepting surface runoff.

Drain: Usually a pipe, ditch, or channel for collecting and conveying water.

Drainage: A general term applied to the removal of surface or subsurface water from a given area either by gravity or by pumping.

Drainage area: The contributing area to a single drainage basin, expressed in acres, square miles, or other unit of area.

Drainage structure: Any device or land form constructed to intercept and/or aid surface water drainage.

Dry Well: An excavated pit backfilled with aggregate or a constructed chamber placed in an excavation and backfilled with aggregate around the chamber. Provides temporary runoff storage and allows stored runoff to infiltrate into the soil.

Duff: The accumulation of needles, leaves, and decaying matter on the forest floor.

Effluent: Solid, liquid, or gaseous wastes that enter the environment as a by-product of man-oriented processes (Soil Conservation Society of America, 1982).

Emergency or Earth Spillway: A depression in the embankment of a pond or basin that is used to pass peak discharges greater than the maximum design storm controlled by the pipe spillway of the pond.

Empirical: Originating in or relying or based on factual information, observation, or direct sense experience.

Ephemeral stream: A channel that carries water only during and immediately following rainstorms.

Equivalent Opening Size (EOS): Pertains to geotextile fabric filter. It is the Equivalent Opening Size of the fabric as it relates to the US Standard Sieve Designation used in Soil Mechanics Laboratories.

Erosion: Wearing away of land by running water, waves, wind, ice, abrasion, and transportation.

Fallow: Allowing cropland to lie idle, either tilled or untilled, during the whole or greater portion of the growing season (Soil Conservation Society of America, 1982).

Field capacity: The soil-water content after the force of gravity has drained or removed all the water it can, usually 1 to 3 days after rainfall.

Fill slope: The surface formed where earth is deposited to build a road or trail.

Filter Fabric: Textile of relatively small mesh or pore size that is used to (1) allow water to pass through while keeping sediment out (permeable), or (2) prevent both runoff and sediment from passing through (impermeable).

Filter fence: A temporary barrier used to intercept sediment-laden runoff from small areas.

Flood: Water from a river, stream, watercourse, ocean, lake, or other body of standing water that temporarily overflows or inundates adjacent lands and which may affect other lands and activities through stage elevation, backwater and/or increased ground water level.

Flood Control: The elimination or reduction of flood losses by the construction of flood storage reservoirs, channel improvements, dikes and levees, by-pass channels, or other engineering works.

Flood Frequency: See "Recurrence Interval."

Flood Plain: For a given flood event, that area of land adjoining a continuous watercourse which has been covered temporarily by flood water.

Flood Storage: Storage of water during floods to reduce downstream peak flows.

Flood Storage Area: Flood storage area is that portion of the impoundment area that may serve as a temporary storage area for flood waters.

Flume: An open conduit on a prepared grade, trestle, or bridge for the purpose of carrying water across creeks, gullies, ravines, or other obstructions; also used in reference to calibrated devices used to measure the flow of water in open conduits (Soil Conservation Society of America, 1982).

Forb: A broad-leaf herbaceous plant that is not a grass, sedge, or rush.

Ford: Submerged stream crossing where tread is reinforced to bear intended traffic.

Freeboard: The vertical distance from the top of an embankment to the highest water elevation expected for the largest design storm stored. The space is required as a safety margin in a pond or basin.

Geotextile: A product used as a soil reinforcement agent and as a filter medium. It is made of synthetic fibers manufactured in a woven or loose nonwoven manner to form a blanket-like product.

Grade: (1) The inclination or slope of a channel, conduit, etc., or natural ground surface, usually expressed in terms of the percentage of number of units of vertical rise (or fall) per unit of horizontal distance. (2) To finish the soil surface, a roadbed, top of embankment, bottom of excavation, etc.

Grade Stabilization Structure: A permanent structure used to drop water from a higher elevation to a lower elevation without causing erosion.

Grassed Waterway or Outlet: A natural or constructed channel shaped or graded and established with suitable vegetation as needed for the safe disposal of runoff water.

Headwater: (1) The upper reaches of a stream near its source; (2) the region where ground waters emerge to form a surface stream; or (3) the water upstream from a structure.

Heavy metals: Metallic elements with high atomic weights, e.g., mercury, chromium, cadmium, arsenic, and lead. They can damage living things at low concentrations and tend to accumulate in the food chain.

Herbaceous: A vascular plant that does not develop woody tissue (Soil Conservation Society of America, 1982).

Herbicide: A chemical substance designed to kill or inhibit the growth of plants, especially weeds (Soil Conservation Society of America, 1982).

High water mark: See Ordinary high water mark.

Highly erodible soils: Any soil with an erodibility class (K factor) greater than or equal to .43 in any layer.

Holding pond: A reservoir, pit, or pond, usually made of earth, used to retain polluted runoff water for disposal on land (Soil Conservation Society of America, 1982).

Hybrid: A plant resulting from a cross between parents of different species, subspecies, or cultivar (Soil Conservation Society of America, 1982).

Hydraulic gradient: A profile of the piezometric level of the water, representing the sum of the depth of flow and the pressure. In open channel flow it is the water surface.

Hydric soil: A soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions in the upper part.

Hydrograph: A graph showing variation in the water depth or discharge in a strewn or channel versus time.

Hydrology: The science that deals with the processes governing the depletion and replenishment of the water resources of the land areas of the earth.

Hydrophyte: A plant that grows in water or in wet or saturated soils (Soil Conservation Society of America, 1982).

Impervious: A term applied to a material through which water cannot pass, or through which water passes with great difficulty.

Impervious Area: Impermeable surfaces, such as pavement or rooftops, which prevent the infiltration of water into the soil.

Inert: A substance that does not react with other substances under ordinary conditions.

Infiltration: The penetration of water through the ground surface into subsurface soil.

Infiltration Trench: An excavated trench, usually 2 to 10 feet deep that is backfilled with a coarse graded stone aggregate. It provides temporary storage of runoff and permits infiltration into the surrounding soil.

Insecticide: A pesticide compound specifically used to kill or control the growth of insects.

Interflow: The portion of rainfall that infiltrates into the soil and moves laterally through the upper soil horizons until intercepted by a stream channel or until it returns to the surface in, for example, a wetland, spring, or seep.

Intermittent stream: A watercourse that flows in a well-defined channel only in direct response to a precipitation event. It is dry for a large part of the year.

Invert: The floor, bottom, or lowest portion of the internal cross section of a conduit.

Lateral: Secondary or side channel, ditch, or conduit (Soil Conservation Society of America, 1982).

Leachate: Liquids that have percolated through a soil and that contain substances in solution or suspension (Soil Conservation Society of America, 1982).

Leaching: The removal from the soil in solution of the more soluble materials by percolating waters (Soil Conservation Society of America, 1982).

Legume: A member of a large family that includes many valuable food and forage species, such as peas, beans, peanuts, clovers, alfalfas, sweet clovers, lespedezas, vetches, and kudzu (Soil Conservation Society of America, 1982).

Levee: See Dike.

Level Spreader: An outlet constructed at zero percent grade across the slope that allows concentrated runoff to be discharged as sheet flow at a non-erosive velocity onto natural or man-made areas that have existing vegetation capable of preventing erosion.

Micronutrient: A chemical element necessary in only extremely small amounts (less than 1 part per million) for the growth of plants (Soil Conservation Society of America, 1982).

Mineral soil: Organic-free soil that contains rock less than 2 inches in maximum dimension.
Mulch: A natural or artificial layer of plant residue or other materials covering the land surface that conserves moisture, holds soil in place, aids in establishing plant cover, and minimizes temperature fluctuations.

Mulching: Providing any loose covering, such as grass, straw, bark, or wood fibers, for exposed soils to help control erosion and protect exposed soil.

Nonpoint source: Any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act. Nonpoint source pollution generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage, or hydrologic modification.

Nutrients: Elements, or compounds, essential as raw materials for organism growth and development, such as carbon, nitrogen, phosphorus, etc. (Soil Conservation Society of America, 1982).

Ordinary high water mark: An elevation that marks the boundary of a lake, marsh, or streambed. It is the highest level at which the water has remained long enough to leave its mark on the landscape. Typically, it is the point where the natural vegetation changes from predominantly aquatic to predominantly terrestrial. The line on the shore established by the fluctuations of water and indicated by physical characteristics such as a clear, natural line impressed on the bank; shelving; changes in the character of soil destruction on terrestrial vegetation, or the presence of litter and debris; or other appropriate means that consider the characteristics of the surrounding area.

Organic debris: Particles of vegetation or other biological material that can degrade water quality by decreasing dissolved oxygen and by releasing organic solutes during leaching.

Organophosphate: Pesticide chemical that contains phosphorus, used to control insects. Organophosphates are shortlived, but some can be toxic when first applied.

Outlet Protection: A rock lined apron or other acceptable energy dissipating material placed at the outlet of a pipe or paved channel and a stable downstream receiving channel.
Outslope: To shape the road surface to cause drainage to flow toward the outside shoulder.

Paved flume: A permanent lined channel constructed on a relatively steep slope. Its purpose is to conduct concentrated runoff down the slope without causing an erosion problem either on the slope or at the outlet.

Peak discharge: The maximum instantaneous rate of now during a storm, usually in reference to a specific design storm event.

Peak rate of runoff: The maximum rate of runoff during a given runoff event.

Pervious: A term applied to a material through which water passes relatively freely.

Percolation: The downward movement of water through the soil (Soil Conservation Society of America, 1982).

Perennial plant: A plant that has a life span of 3 or more years (Soil Conservation Society of America, 1982).

Perennial stream: A watercourse that flows throughout a majority of the year in a well-defined channel.

Permanent storage: The portion of a pond or infiltration BMP which is below the elevation of the lowest outlet of the structure.

Permanent wilting point: The soil water content at which healthy plants can no longer extract water from the soil at a rate fast enough to recover from wilting. The permanent wilting point is considered the lower limit of plant-available water.

Permeability: The quality of a soil horizon that enables water or air to move through it; may be limited by the presence of one nearly impermeable horizon even though the others are permeable (Soil Conservation Society of America, 1982).

Pesticide: Any chemical agent used for control of plant or animal pests. Pesticides include insecticides, herbicides, fungicides, nematocides, and rodenticides.

Pioneer roads: Temporary access ways used to facilitate construction equipment access when building permanent roads.

Plant-available water: The amount of water held in the soil that is available to plants; the difference between field capacity and the permanent wilting point.

Point source: Any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged.

Pollutant: Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water (Section 502(6) of The Clean Water Act as amended by the Water Quality Act of 1987, Pub. L. 100-4).

Postdevelopment peak runoff: Maximum instantaneous rate of flow during a storm, after development is complete.

Precipitation: Any moisture that falls from the atmosphere, including snow, sleet, rain, and hail.

Principal or Pipe Spillway: A pipe structure normally consisting of a vertical conduit (riser) and a horizontal outlet conduit (barrel). It is used to control the water level and the discharge from a pond or basin.

Rainfall data: The average depth, in inches, of rainfall occurring over a watershed or subwatershed for a given frequency and duration storm event.

Reach: Any length of river or channel. Usually used to refer to sections which are uniform with respect to discharge, depth, area or slope, or sections between gaging stations.

Recurrence interval: The average interval of time within which a given event will be equalled or exceeded once. For an annual series the probability in any one year is the inverse of the recurrence interval. Thus a flood having a recurrence interval of 100 years (100-year frequency storm) has a 1 percent probability of being equalled or exceeded in any one year.

Release rate: The rate of discharge in volume per unit time from a detention facility.

Residue: See crop residue.

Retarding basin: A basin storage designed and operated to reduce the flood flows of a stream through temporary storage.

Retention: The holding of runoff in a basin without release except by means of evaporation, infiltration, or emergency bypass.

Retention storage: The storage of storm runoff water for release after the end of the design storm at a time and in amounts that can be conveniently handled by, the drainage system.

Return flow: That portion of the water diverted from a stream that finds its way back to the stream channel either as surface or underground flow (Soil Conservation Society of America, 1982).

Right-of-way: The cleared area along the road alignment that contains the roadbed, ditches, road slopes, and back slopes.

Riprap: A combination of graded stone, cobbles, and boulders used to protect streambanks, bridge abutments, or other erodible sites from runoff or wave action.

Riser: A vertical pipe connected to a barrel, extending from the bottom of a pond that is used to control the discharge rate for a specific design storm.

Root zone: The part of the soil that is, or can be, penetrated by plant roots (Soil Conservation Society of America, 1982).

Runoff: That part of precipitation or snow melt that runs off the land into streams or other surface water.

Runoff Curve Number: A factor in the NRCS/SCS Hydrologic Soil Cover Complex runoff determination method. Relates mass rainfall to mass runoff. It is based on soil characteristics, cover type and land treatment.

Salinity: The concentration of dissolved solids or salt in water (Soil Conservation Society of America, 1982).

Scour: Soil erosion when it occurs underwater, as in the case of a streambed.

Seed bed: The soil prepared by natural or artificial means to promote the germination of seeds and the growth of seedlings.

Sediment: The product of erosion processes, the solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice.

Sediment Basin: A basin constructed to collect and store sediment or other waterborne debris.

Sedimentation: The process or act of depositing sediment (Soil Conservation Society of America, 1982).

Seepage: Water escaping through or emerging from the ground along an extensive line or surface as contrasted with a spring, where the water emerges from a localized spot (Soil Conservation Society of America, 1982).

Settleable solids: Solids in a liquid that can be removed by stilling a liquid. Settling times of one hour or more are generally used.

Sheetflow: Water, usually storm runoff, flowing in a thin layer over the ground surface.

Silt fence: A temporary barrier used to intercept sediment-laden runoff from small areas.

Sinkhole: A depression in the earth's surface caused by dissolving of underlying limestone, salt, or gypsum; drainage is through underground channels; may be enlarged by collapse of a cavern roof (Soil Conservation Society of America, 1982).

Slope: Amount of deviation of a surface from the horizontal, measured as a numerical ratio, as a percent, or in degrees. Expressed as a ratio, the first number is the horizontal distance (run) and the second number is the vertical distance (rise), as 2:1. A 2:1 slope is a 50 per cent slope. Expressed in degrees, the slope is the angle from the horizontal plane, with a 90 degree slope being vertical (maximum) and a 45 degree slope being a 1:1 slope.

Sludge: The material resulting from chemical treatment of water, coagulation, or sedimentation (Soil Conservation Society of America, 1982).

Soil profile: A vertical section of the soil from the surface through all its horizons, including C horizons (Soil Conservation Society of America, 1982).

Soil survey: A general term for the systematic examination of soils in the field and in laboratories; their description and classification; the mapping of kinds of soil; the interpretation of soils according to their adaptability for various crops, grasses, and trees; their behavior under use or treatment for plant production or for other purposes; and their productivity under different management systems (Soil Conservation, Society of America, 1982).

Storm Sewer: A closed conduit for conducting storm water that has been collected by inlets or by other means.

Storm Runoff: The water from precipitation running off from the surface of a drainage area during and immediately following a period of rain.

Straw or Hay Bale Barrier: A temporary obstruction of straw or hay installed across or at the toe of a slope. It intercepts and detains small amounts of sediment from unprotected areas of limited extent and reduce runoff velocity down the slope.

Subsurface Drain: A conduit such as tile, pipe or plastic tubing, installed beneath the ground surface that collects and/or conveys excess water emanating from the soil.

Surface detention: The storm runoff detained on the surface of the ground at or near where the rainfall occurred, and which will either run off slowly or infiltrate into the soil.

Surface infiltration: That rainfall which percolates into the ground surface and which therefore does not contribute directly to the storm runoff flow.

Surface water: All water whose surface is exposed to the atmosphere.

Suspended sediment: The very fine soil particles that remain in suspension in water for a considerable period of time.

Swale: A natural depression or wide shallow ditch used to temporarily store, route, or filter runoff.

Temporary sediment trap: A small temporary ponding area that is formed by excavation or constructing an earthen embankment across a drainageway to reduce flow velocities thus allowing soil particles to fall out of suspension before discharging into the downstream waters.

Temporary Grade Stabilization Structure: A temporary barrier of rock, timber or straw or hay bales constructed across a swale or drainage ditch to reduce flow velocity.

Tillage: The operation of implements through the soil to prepare seedbeds and rootbeds, control weeds and brush, aerate the soil, and cause faster breakdown of organic matter and minerals to release plant foods (Soil Conservation Society of America, 1982).

Tilth: The physical condition of the soil as related to its ease of tillage, its fitness as a seedbed, and its impedance to seedling emergence and root penetration (Soil Conservation Society of America, 1982).

Time of Concentration: The time required for surface runoff from the most hydraulically remote part of a drainage basin to reach the basin outlet or the point under consideration.

Time of Flow: The time required for water to flow in a storm drain from the point where it enters to any given point or location beyond the inlet.

Topography: The relative positions and elevations of the natural or man-made features of an area that describe the configuration of its surface (Soil Conservation Society of America, 1982).

Trash rack: A barrier constructed to catch debris and exclude it from entering a downstream conduit.

Trench: An excavation made for installing pipes, masonry walls, and other purposes. A trench is distinguished from a ditch in that the opening is temporary and is eventually backfilled.

Turbidity: A cloudy condition in water due to suspended silt or organic matter.

Turnout: A drainage ditch that drains water away from roads and road ditches.

Vegetated buffer: Strips of vegetation separating a waterbody from a land use with potential to act as a nonpoint pollution source; vegetated buffers (or simply buffers) are variable in width and can range in function from a vegetated filter strip to a wetland or riparian area.

Vegetated filter strip: An area of vegetation for runoff to flow through when it leaves a disturbed site before it enters into a designed drainage system.

Vegetated swale: A natural or constructed broad channel with dense vegetation designed to treat runoff and dispose of it safely into the natural drainage system. Swales are designed to remove pollutants from stormwater runoff, increase infiltration and reduce the erosion potential at the discharge point.

Water bar: A diversion ditch and/or hump installed across a trail or road to divert runoff from the surface before the flow gains enough volume and velocity to cause soil movement and erosion, and deposit the runoff into a dispersion area.

Watercourse: A definite channel with bed and banks within which concentrated water flows continuously, frequently or infrequently.

Water table: The upper surface of the ground water or that level below which the soil is saturated with water; locus of points in soil water at which the hydraulic pressure is equal to atmospheric pressure (Soil Conservation Society of America, 1982).

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Weir: Device for measuring or regulating the flow of water.

Wetlands: Areas that are inundated or saturated by surface or ground water at a frequency and duration to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions; wetlands generally include swamps, marshes, bogs, and similar areas.

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