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650.1600 Introduction

(A) Purpose and Scope

(1) Erosion along streambanks and shorelines can threaten agricultural assets, riparian infrastructure (such as road crossings), natural resources (such as water quality and aquatic habitat), or a combination of resource concerns.

(2) Streambank and shoreline protection consist of restoring or protecting the banks of streams, lakes, reservoirs, estuaries, or excavated channels against erosion. Measures can include a combination of vegetative plantings, soil bioengineering, channel grade stabilization, channel realignment, and flow redirective techniques, as well as structural revetments. The purpose of streambank and shoreline protection vary from protection of infrastructure to ecosystem restoration, or a combination of purposes.

(3) The focus of this chapter is soil bioengineering techniques and practices that are implemented along a streambank or a shoreline. Many practitioners consider soil bioengineering as a broad category of bank treatments that are more ecologically beneficial than traditional stabilization approaches, such as riprap revetments.

(4) Soil bioengineering is defined as the use of live and dead plant materials in combination with natural and synthetic support materials for slope stabilization, erosion reduction, and vegetative establishment.

(5) This chapter is national in scope and should be supplemented with regional and local information. Planning and design of streambanks and shoreline protection projects generally requires a team of experts, such as plant biologists, soil conservationists, geologists, geomorphologists, landscape architects, and engineers.

(6) Additional resources for planning and design of streambank and shoreline protection projects include, but are not limited to:

(i) Title 210, National Engineering Handbook, Part 654, “Stream Restoration Design”, Chapter 14, “Treatment Techniques” (210-NEH-654-14)

(ii) 210-NEH-654, Technical Supplement 14I Streambank Soil Bioengineering

(iii) Title 210, Engineering Technical Release 56 (TR-210-56) A Guide for Design and Layout of Vegetative Wave Protection for Earth Dam Embankments (4/2014)

(iv) TR-210-69, “Riprap for Slope Protection Against Wave Action” (2/1983)

(7) This chapter does not apply to erosion problems on ocean fronts, large river and lake systems, or other areas of similar scale and complexity.

(B) Categories of Protection

(1) Protection measures generally reduce the force of water against a streambank or shoreline, or by increasing the resistance of the streambank or shoreline to erosive forces, or both to form a combined system. Techniques and practices that reduce the stress on channel and shoreline boundaries can include upland stormwater retention and detention ponds and reservoirs, channel realignment, improving floodplain access, and installing redirective techniques. Techniques and practices that increase the resistance of channel and shoreline boundaries to erosive forces include installing concrete, riprap, gabions, streambank soil bioengineering measures, and vegetation.

(2) Soil bioengineering treatments are classified as either Structural Based Soil Bioengineering treatments or Plant Based Soil Bioengineering treatments. This distinction is not just based on the material used in the construction of the treatment, but also on how the resulting treated bank or shoreline will function or behave over time to meet conservation or restoration goals.

   (i) A **Structural Based Soil Bioengineering** approach is successful when it results in a fairly static bank or shoreline. These treatments are generally applied at high risk sites and areas where additional bank or shoreline movement is unacceptable. The bank or shoreline for these projects remains in a defined location over the life of the project. These treatments rely on rock, dead wood, manufactured products, or other inert materials to immediately stabilize the bank and shoreline. Supplemental plant material provides aesthetic and habitat benefits as well as increases structural strength. However, if the structural material fails, the project fails, since the bank and shoreline limits are defined by the installed inert material. These projects do not allow bank and shoreline movement, and self-healing is generally not an option. Stone toes with bank grading and riparian plantings, vegetated gabions, vegetated mechanically stabilized earth (MSE) walls, root wads, some toe wood installations, and log cribs are examples of typical structural based soil bioengineering treatments. An example of a structural based soil bioengineering project for streambank protection is shown in figure 16-1.

Figure 16-1: Vegetated wire face MSE wall. Under construction and after 2 years.

(ii) A **Plant Based Soil Bioengineering** results in a flexible, dynamically stable project and does not produce a static bank line or shoreline. A successful project is a flexible project. These treatments rely on riparian plants to provide long term strength to the bank or shoreline although the treatment may include inert material and bank or shoreline grading to promote plant establishment. A plant-based soil bioengineering treatment approach is characterized by reliance on treatments such as live clumps, fascines, vertical bundles, brush mattress, brush barbs, brush revetments, some toe wood installations, and live cuttings. The goal of using these treatments is to slow changes to the bank or shoreline to a more natural or a sustainable rate. Bank and shoreline movement after construction of the project is acceptable and expected during high flows and wave action. Bank and shoreline stability rely on plants and the self-healing process. Plant survivability defines the success of the project. An example of a plant-based soil bioengineering project is shown is figure 16-2.

Figure 16-2: Brush Mattress. Under construction and after 2 years.

(3) Soil bioengineering is a proven approach to stabilize and restore streambanks and shorelines. The plant based and structural based soil bioengineering approaches both can apply to most systems. Cost, tolerance for risk, and amount of acceptable bank movement and self-healing are factors in selecting the soil bioengineering approach. Figure 16-3 summarizes additional factors that can be used to distinguish between the structural based and plant-based soil bioengineering treatments.

Figure 16-3: Summary of Structural Based Soil Bioengineering and Plant Based Soil Bioengineering Treatments

Treatment Features	Structural Based Soil Bioengineering	Plant Based Soil Bioengineering
Bankline or Shoreline	Determined by designer and defined by placement of hard, inert material.	Approximated by designer and defined over time by natural processes.
Dynamism (Degree of bank line or shoreline movement)	Low to moderate. A successful project is relatively static. Although it will generally be more flexible than a traditional project.	Moderate to high. A successful project is as dynamic as a natural, unimpacted reach.
Material used	Inert material such as wood, rock, and manufactured products that are enhanced with plantings.	Living riparian plants. Inert materials may be used to provide temporary stabilization until plant establishment.
Ability to self-heal	Limited. Once a structural component fails, the treatment is compromised.	Significant. Plant material can be severely impacted yet recover over time.
Ecological benefits	Terrestrial and aquatic benefits provided by plants and placement of inert material.	Terrestrial and aquatic benefits provided by plants and the dynamic habitat.
Typical applications	Areas where high value infrastructure, structurers or both are adjacent to the waterway or where life could be endangered. Typically found in urban or suburban situations.	Areas where some movement of the bankline or shoreline will not endanger life or property. Often found in suburban, rural, or park situations.
Example treatments	Rip rap with live cuttings	Live cuttings and pole plantings
	Vertical bundles with a rock toe	Vertical bundles
	Brush mattress with rock toe	Fascines
	Fascines over a rock toe	Brush mattress
	Log cribs	Brush revetment
	Rootwads	Some toe wood installations
	Some toe wood installations	Bio logs
	Green gabions	Wattles
	Vegetated wireface MSE wall	Vegetated stream barb
	Vegetated geocells	Willow clump planting
	Permanent erosion control fabric	Temporary erosion control fabric

650.1601 Streambank Soil Bioengineering Protection Planning

(A) General

(1) The principal causes of streambank erosion are geologic, climatic, cultural, vegetative, and hydraulic. These causes may act independently, but normally work in an interrelated manner. Direct human activities, such as channel confinement, channel realignment, damage to or removal of vegetation, and animal management activities can be major factors in streambank erosion.

(2) Streambank erosion is a natural process that occurs when the forces exerted by flowing water on the channel boundary exceed the resisting forces of bank materials and vegetation. Erosion occurs in many natural streams that have vegetated banks. However, land use changes or natural disturbances in the watershed can cause the frequency and magnitude of water forces to increase. Loss of streamside vegetation can reduce resisting forces and increase the erodibility of the streambank. Channel straightening can increase stream velocities and may cause streambeds and banks to erode.

(3) A stable toe is vitally important to the success of any stabilization project. In many cases, streambed or toe of bank stabilization is a necessary prerequisite to the placement of streambank protection measures.

(B) Site Assessment for Streambank Protection Measures

(1) Interdisciplinary teams are effective in planning and designing stream stabilization projects, with the project stakeholder, the owner, and each discipline providing individual knowledge, experience, and expertise. Clear communication between team members is critical when discussing streambank erosion causes and solutions and when selecting treatment approaches. Stream stabilization approaches should be selected in terms of the performance and function of the treated bank over time. This will help assure that the decision makers are truly in concurrence with the treatment selection.

(2) The first phase of the NRCS planning process involves the collection and analysis of data. A variety of site-specific data, as well as watershed area information are assessed. The list that follows in figure 16-4, although not exhaustive, includes data commonly needed for planning and design purposes. Specific information on site investigations is available in 210-NEH-654-3, “Site Assessment and Investigation”.

Figure 16-4: Data Collection for Streambank Soil Bioengineering Projects

Typical Issues	Information to Assess	How is this information used
Watershed Data	History of land use History of storms and extreme weather (floods and droughts) Prior stream modifications, Past stability problems, Previous treatments Potential future watershed changes that increase magnitude and frequency of flooding Potential riparian development Potential future changes in land use or resource management	Planners and designers should determine if the current erosion is a result of an event that frequently or rarely occurs. An analysis of stream and watershed conditions includes historical information and considers future changes most likely to occur or might be planned to occur in the future. Designers should asses if the selected approach can withstand both current and future stress.
Hydrologic/ Hydraulic Data – Low Flows	Estimate of magnitude, duration and seasonality of low flows. Estimate of velocities and depths at low flows.	Design of a low flow channel may be required as part of a channel modification. Conditions at low flows are evaluated since critical aquatic habitat is often at low flows. Evaluate the depths and velocities of low flows for fish spawning or fish passage during critical times of the year.
Hydrologic/Hydraulic Data – Frequent Storms and Channel Forming Flows	Estimate of magnitude of frequent storms, channel forming and /or bankfull flows. Estimates of channel geometry measurements and velocities at channel forming/ bankfull flows.	Estimates of channel-forming discharges are used to classify stream types, estimate channel dimensions, assess stability, and express hydraulic geometry relationships.
Hydrologic/Hydraulic Data – Large or infrequent storms	Estimate of magnitude and frequency of large storms, typically from the 10-year to 100-year recurrence interval. The recurrence interval of these design storms is selected in consideration of not only project funding authority but also with an assessment of project risk and consequence of failure.	The impacts of velocities and depths expected to occur during high storms on the adjacent channel boundary, adjacent property, and the stability of proposed project must be assessed. Evaluate the impact of flooding on the project and compliance with local floodplain regulations and regulated floodplains.
Extent of Erosion Problems	Localized Reach Scale System Scale	If bank failure problems are the result of widespread bed degradation or headcutting, determine what triggered the problem. If bank erosion problems are localized, determine the cause of erosion at each site.

Figure 16-4: Data Collection for Streambank Soil Bioengineering Projects - continued

Typical Issues	Information to Assess	How is this information used
Causes of Erosion	Damage to Banks: Recent storms, fire, over grazing, vegetation removal, drought, ice damage, etc. Scour: Headcuts or local scour over steepening bank. Reach or system scale lateral migration, incision, or both: watershed changes, lack of riparian buffer, large scale storm event, livestock access.	Determining the cause of the erosion is an important tool in selecting a sustainable treatment. If the same cause can be expected to reoccur, the designers should assure that the proposed technique can withstand it. The designer may need to address stresses outside of the channel.
Current Bank Condition	Vegetation Bank Height Bank Material Nutrients Soil Compaction Water Availability Geotechnical stability	Current bank condition determines the extent of the intervention that is necessary. The erosion on the bank may have been initiated by flowing water but could have progressed to the point where it is failing from geotechnical instability. In such a case, both fluvial and geotechnical stabilization measures may be necessary.
Channel Grade	Location and activity of head cuts and/or nick points Steepness of channel Recent cut offs History of channel straightening	Bank protection needs a stable channel bed unless the bank protection is safely and economically constructed to a depth well below the anticipated lowest depth of bed scour. Determine if channel grade stabilization measures are needed to ensure feasibility of soil bioengineering. Control can be by natural or artificial means. More information on grade assessments is found in 210-NEH-654-14.
Channel Description	Width Depth Meander Amplitude Belt Width Incision Entrenchment Debris Sediment load Bed Material	These measurements not only define the working area but can indicate the activity and stresses that a bank treatment must be able to withstand. An assessment of how energy is dissipated in a channel is important in the selection of a sustainable treatment approach. Debris and sediment can adversely impact a treatment and must be assessed. More information on sediment assessments is found in 210-NEH-654-3.

Figure 16-4: Data Collection for Streambank Soil Bioengineering Projects - continued

Typical Issues	Information to Assess	How is this information used
Channel Classifications	Assessments necessary to classify the subject reach using Rosgen and/or a Schumm type Channel Evolution Model (CEM).	Channel classification has been used as not only a valuable communication method but also a tool to select potential treatments. Further information and guidance on the use of different channel classification tools is found in 210-NEH-654-3.
Terrestrial and Aquatic Habitat Conditions	Water Quality Water Quantity Adjacent Wetland Flood Plain Access Riparian area composition and abundance Habitat and species complexity and abundance	Selection, design, and construction of streambank protection measures must consider existing and planned habitat conditions. Fully consider ecological stability and productivity and incorporate alternative protection type on a species and site-specific basis.
Social and Economic Factors	Public acceptance of soil bioengineering treatment type Installation costs Land acquisition costs Temporary construction impact Maintenance cost and maintenance capacity of stakeholders.	The natural appearance of some soil bioengineering techniques can appear un kept and periodic movement in response to storms may be concerning to stakeholders. Stakeholder acceptance and support of not only the project type but the construction disruptions as well as long term maintenance is critical to determine early in the planning process.

(C) Risk and Streambank Soil Bioengineering

(1) The goal of many streambank soil bioengineering stabilization projects is to mimic natural conditions to stabilize the bank. Natural channels in many environments can be expected to move and suffer erosion during large storms. Therefore, it should be recognized that, even with an established project, the bank will often not be static and periodic bank erosion should be expected in many stream systems. While banks addressed with plant based soil bioengineering techniques are especially prone to movement, the structural based soil bioengineering will also have some flexibility. The consequences of this flexibility, which is inherent to all streambank soil bioengineering stabilization project, should be assessed in terms of overall project goals, risk tolerance, land ownership, and maintenance plans.

(2) Generally, the risk is higher with soil bioengineering treatments when compared with hard structures. Consider the risk by examining the limitations of the treatment approach, the consequences of channel movement, the expected future conditions of the site, and owner willingness to maintain site. Risk associated with stream restoration and stabilization projects is addressed in more detail in 210-NEH-654-14.

650.1602 Streambank Soil Bioengineering Design

(A) General

(1) The design of any streambank protection approach requires a variety of conventional science-based analysis and computational tools, including geotechnical, hydrologic, hydraulic, geomorphic, and landscape architecture analysis. In addition, plant expertise is critical for a successful design and project.

(2) Design tools are available from a variety of sources. Figure 16-5 summarizes analyses commonly employed by designers and associated NRCS guidance references.

Figure 16-5: Design resources for streambank soil bioengineering practices

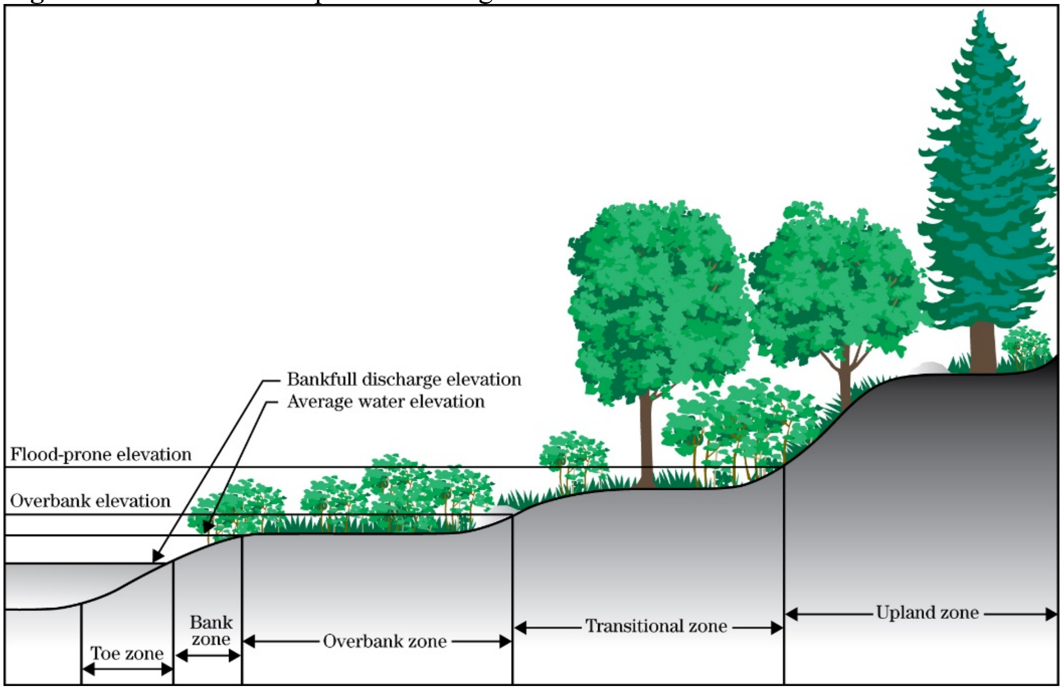
Issue	Summary of analysis	Technical Reference
Geological Analysis	A geologist may be called upon to conduct a general or a site detailed geologic subsurface investigation to support the design. The focus is on slope stability, subgrade conditions, bearing capacity, and depth to bedrock; and any geologic conditions or hazards that need to be addressed in the design, construction, or operation of the structure.	210-NEM-531, “Geology” 210-NEH-631, “Geology”
Geotechnical, Geomorphic, Hydrologic and Hydraulic Analysis	A variety of engineering tools can be used to design successful streambank soil bioengineering practices. Reach level analysis includes fluvial geomorphology, hydrology, hydraulics, and sediment transport. The level of analysis is dependent on the scale of the project and the level of acceptable risk. Project-specific site analysis is often necessary, including but not limited to potential scour, slope stability, geotextiles, rock size estimate, velocities, shear, bank stability, stable channel design.	210-NEH-633, “Soil Engineering” 210-NEH-653, “Stream Corridor Restoration” 210-NEH-654, “Stream Restoration Design”
Landscape Architecture Analysis	Landscape Architects can assist with the planning, design, construction, maintenance, preservation, and conservation of landscapes for aesthetic, interpretive, functional, economic, social, environmental, and other interrelated purposes. Landscape architecture considers the landscape resource as a composite of: Ecological Attributes: functions of the landscape in sustaining life cycle processes. Social Attributes: The use of the landscape for economic, functional, and cultural purposes. Aesthetic Attributes: The classifiable appearance of a landscape.	EM 535, “Landscape Architecture” 210-TR-65, “Procedures to Establish Priorities in Landscape Architecture”

(B) Riparian Planting Zones

(1) The success of a stream bank soil bioengineering project depends on the establishment of riparian plant species appropriate to the site location and climate. The success of the plants, in turn, depends on their location relative to the stream. The location and types of existing vegetation in and adjacent to the project area is important to note to assist in species selection and identifying planting zones. The elevation and lateral relationship of different plants to the stream are referred to as riparian planting zones. Assessing and designing streambank soil bioengineering techniques must consider the location of the plants relative to the stream and water table.

(2) An idealized depiction of riparian planting zones is illustrated in figure 16-6. Not all streams look exactly like what is shown in this figure. Some of these zones may be absent, especially in Southwest streams as well as in areas that have been significantly impacted by development.

Figure 16-6: Idealized Riparian Planting Zones



(3) Identifying riparian planting zones aids in the selecting treatments and plants. A summary of the zones is provided in figure 16-7. The zones are primarily based on vegetation but are indexed to stream flows, such as baseflow, bankfull flow, and flood flows. The estimation and analysis of these flows are discussed in detail in 210-NEH-654-5.

Figure 16-7: Riparian Planting Zones Location and Attributes

Zone	Hydrologic Position	Attributes and Treatments
Toe	Located below the average water elevation or baseflow.	Typically, this is the zone of highest stress. It is vitally important to the success of any stabilization project that the toe is stabilized. Due to long inundation, this zone will rarely have any woody vegetation in it (however some areas of the American Southwest will have woody vegetation in this zone). Often stone or some inert protection is required for this zone.
Bank	Located between the average water elevation and the bankfull discharge elevation.	While the bank zone is generally in a less erosive environment than the toe zone, it is potentially exposed to wind generated waves, wet and dry cycles, ice scour, debris deposition, predation, and freeze–thaw cycles. The bank zone is generally vegetated with early colonizing herbaceous species, flexible stemmed willows, and low shrubs.
Overbank	Located above the bankfull discharge elevation. This typically flat zone may be formed from sediment deposition. It is sporadically flooded, usually about every 2 to 5 years.	Vegetation found in the overbank zone is generally flood-tolerant and may have a high percentage of hydrophytic plants. Shrubby willow with flexible stems, dogwoods, alder, birch and others may be found in this zone. Larger willows, cottonwoods and other trees may be found in the upper end of this zone.
Transition	Between the overbank elevation and the flood-prone elevation. This zone may only be inundated every 50 years.	The transition zone is not exposed to high velocities except during high water events. Larger upland species predominate in this zone. Since it is infrequently flooded, the plants in this zone need not be especially flood-tolerant.
Upland	Above the flood-prone elevation.	Under natural conditions the upland zone is typically vegetated with upland species.

(C) Plants for Streambank Soil Bioengineering

(1) Most streambank soil bioengineering treatments involve material that is collected from adventitiously rootable stock (plants that will easily root from a hardwood cutting). When possible, it is best to procure plants from areas that are similar in their location relative to the stream. Planting will be most successful where the soil, site, and species match a nearby stable site. If possible, harvest two or more species from different locations to increase planting success rates and provide genetic diversity.

(2) The primary woody plant species selected for soil bioengineering practices root easily from dormant, hardwood cuttings, and are fast establishing and quick growing plants with extensive fibrous roots. These plants must tolerate both inundation and drought conditions. The keystone species that meet these criteria are willows, poplars, cottonwoods, and shrub dogwoods.

(3) While it is often appropriate to include material that ranges in age up to four years, material should be harvested from plants that are at least two years old. In drier areas, one-year old stock should not be used. This younger material is often too small and does not have enough stored energy for good root establishment. Harvesting of live material should leave at least one third of the parent plant intact. The equipment should be sharp enough to make clean cuts.

(4) Woody material can be installed the same day that it is harvested but it is better to soak material before planting in cool, aerated water for a minimum of 24 hours. Optimum time for soaking is five to seven days. If it is necessary to harvest material long before installation, the cuttings should be stored dry at approximately 33 to 40 degrees F. Live hardwood cuttings can last up to four months if refrigerated. Stored material should be soaked before planting.

(5) Soil bioengineering also makes use of grasses and forbs for streambank stabilization. These plants are typically applied in a seed mix with erosion control fabric. With adequate moisture they sprout quickly and put out root systems that hold soil in place.

(6) Local expertise and guidelines should be consulted when selecting the appropriate plant material. Success can be affected by the timing of planting, age of the material used, handling and storage, and placement in the proper riparian planting zone on the streambank. Further information on recommended planting species and handling is found in technical supplement 14I of 210-NEH-654.

(D) Example Streambank Soil Bioengineering Techniques

(1) Many types of streambank soil bioengineering treatments are used to address eroding stream banks. Figure 16-8 includes a summary of some of the most popular soil bioengineering techniques. A more complete list of streambank soil bioengineering techniques, as well as construction guidelines is provided in 210-NEH-654-14. Treatments are often modified to account for site specific conditions and material availability.

Figure 16-8: Selected Streambank Soil Bioengineering Practices

Practice	Riparian Planting Zone	Category	Description
Live Stakes/ Live Poles Figure 16-9	Bank	Plant Based	Cuttings of live woody plant material inserted into the ground. Typically, live stakes are 18-36” long, whereas live poles are greater than three feet long. These live cuttings provide some limited immediate reinforcement of soil layers if they extend beyond a failure plane. The cuttings are intended to root and provide reinforcing and subsurface protection, as well as providing roughness to the streambank and some control of internal seepage.
Live Stakes and Riprap Figure 16-10	Bank	Structural Based	Live stakes or poles are frequently used in conjunction with a rock toe along streams and with erosion control fabric. Also called joint planting or vegetated riprap, this practice involves tamping live stakes into joints or open spaces in rocks that have been previously placed on a slope. Alternatively, the stakes can be tamped into place while the rock is being placed on the slope face. The cuttings need to extent through the rock to the bank soil so the cuttings will penetrate any geotextile or filter that is under the rock. The appropriateness of this must be examined closely.
Brush Mattress Figure 16-11	Bank	Plant Based	A layer of live branches placed on a slope. Wood stakes and wire (or string) is used to anchor the material. The branches provide immediate protection against surface erosion. The live cuttings eventually root and provide permanent reinforcement.
Live Fascine Figure 16-12	Toe	Plant Based	A fascine consists of live branch cuttings bound together into rope-like or sausage-like bundles. Typically, fascines are placed along the contour, though occasionally they are placed on a pitch to promote controlled drainage or used for toe protection on streambanks. The structure provides immediate protection against surface erosion. The structures can change overland flow by breaking up long slopes. The live cuttings eventually root and provide permanent reinforcement.
Live Cribwall Figure 16-13	Toe	Structural Based	A hollow, boxlike structure of interlocking logs or timbers. The structure is filled with rock, soil and live cuttings. The cuttings eventually grow and take over some of the structural functions of the logs. The maximum height is typically less than 6 feet for untreated timber. Treated timber can be used to construct larger structures. It is important to note that the structure may not be able to resist large lateral earth pressures and it may provide a false sense of security. If used adjacent to a stream, the impact of the structure being washed downstream must be considered should it fail. It is critical that the toe be set securely below the estimated maximum scour.

Figure 16-8: Selected Streambank Soil Bioengineering Practices - continued

Practice	Riparian Planting Zone	Category	Description
Brush Revetment Figure 16-14	Toe	Plant Based	This treatment is sometimes referred to as Christmas tree revetments or juniper revetment. Brush and tree revetments are nonsprouting shrubs or trees installed along the toe of the streambank. The revetment material does not need to sprout, and most species used will not. The purpose of a revetment material is to slow stream velocity adjacent to an eroding bank and to promote sediment deposition at the toe of the bank. Proper anchoring of the revetment into the bank and/or bed is essential. It is important to note that the brush and tree revetment material will deteriorate, and it is recommended that live willows or other quickly sprouting species be planted behind the revetment to provide permanent cover.
Wattles Figure 16-15	Overbank/ Transition	Plant Based	Treatments such as wattles are intended to promote sediment deposition and protect the bed from erosion. They can be used to hold or guide an established channel planform. Wattles are typically used in multiple rows along flood plains and areas adjacent to banks. Wattle fences are rows of live stakes or poles about which live brush is woven in a basket like fashion and buried in a trench. The live cuttings eventually root and provide a permanent structure.
Grasses, legumes, forbs and turf	Bank to Upland	Plant Based	These plants are typically applied in a seed mix under erosion control fabric. With adequate moisture they sprout quickly and put out root systems that hold soil in place.
Vertical Bundles Figure 16-16	Bank	Plant Based	Vertical bundles are long bundles of live branch cuttings bound together into rope or sausage-like bundles. The bundles are placed and staked along a stream bank in trenches that are perpendicular to the water surface. The structure provides immediate protection through increased roughness. The live cuttings eventually root and provide permanent reinforcement.
Toe Wood Figure 16-17	Toe to Overbank	Plant / Structural Based	This treatment consists of excavating or filling in the lower bank with a bankfull bench. The bench consists of layers of inert logs, branches, brush, root and soil as fill and planted with live cuttings. Often, large rock is used to anchor toe wood into position and for added toe stability. The structure provides immediate protection by shielding the soils, deflects flow near bank, and provides roughness to reduce velocities in the near-bank zone. If the live cuttings can replace the function of the inert wood, then this is plant-based soil bioengineering technique. If the toe wood is necessary to maintain stability, then this is a structural based technique.

Figure 16-8: Selected Streambank Soil Bioengineering Practices - continued

Practice	Riparian Planting Zone	Category	Description
Rootwad Revetment Figure 16-18	Toe to bank	Structural Based	Rootwad revetments consists of hardwood trees with an intact root fan, logs, large rock, and often cable and earth anchors. Rootwads are often installed over a stone toe, footer logs, or by themselves and in conjunction with bank shaping and planting. Rootwads are positioned in an overlapping manner and angled so that the root fan fits snugly into the bank at the upstream side and angle away from the bank on the downstream side. The trimmed trunk (or bole) is embedded into the bank pointing downstream. The structure provides immediate protection by shielding the soils, deflects flow near bank, and provides roughness to reduce velocities in the near-bank zone.

Figure 16-9: Live Stakes growing on stream bank one season after installation.

Figure 16-10: Live Pole being installed through riprap with a stinger (left) and after 3 years.

Figure 16-11: Brush Mattress immediately after installation (left) and after 9 years.

Figure 16-12: Live Fascine during Installation (left) and after Establishment

Figure 16-13: Live Cribwall during Installation (left) and after 10 years

Figure 16-14: Brush Revetment during Installation (left) and after 2 years

Figure 16-15: Wattle during Installation (left) and after 2 years

Figure 16-16: Vertical Bundles with Brush Revetment during Installation (left) and after 2 years

Figure 16-17: Toe Wood with Bank Grading during Installation (left) and after 2 years (right).

(Photo courtesy of Trout Unlimited, Virginia Chapter)

Figure 16-18: Rootwad Revetment with Bank Grading before Installation (top left), immediately after Installation (top right), after two years (bottom left), and after five year (bottom right)

(Photos courtesy of Melanie Carter, PE, PhD Virginia Tech)

(E) Limiting Velocity and Shear Stress

(1) The effects of the water current on the stability of any streambank protection treatment should be considered. This evaluation should include the full range of flow conditions that can be expected during the design life of the project.

(2) Allowable velocity and allowable shear stress are two common approaches used to express treatment tolerances. Recommendations are provided in figure 16-19. The appropriateness of a particular treatment under consideration is evaluated by comparing the permissible velocity and/or shear stress of the technique with the expected velocity and/or shear stress that the channel may experience during a selected large, design flow. As seen in figure 16-19, recommendations for limiting velocity and shear stress of treatments widely vary. The selected design criteria must be balanced with judgement and experience. The recommendations must be scrutinized and modified according to site-specific conditions such as duration of flow, soils, temperature, debris and ice load in the stream, plant species, as well as channel shape, slope and planform. More information on the calculation of shear and velocity for design flows is described in 210-NEH-654-5 and 210-NEH-654-6.

(3) Some techniques such as rootwads, brush revetments, vegetated stream barbs, and some toe wood installations rely on earth anchors or ballast stone to hold the inert wood material to the bed or bank. The design of these is based primarily on expected channel velocity and depth during infrequent, design flows. More information on the design of anchors is available in technical supplement 14E of 210-NEH-654.

(4) Structural based techniques that include a rock toe require that both the stability of rock as well as the stability of the vegetative element be assessed. The vegetative component can be assessed with the recommendations in figure 16-19. The stability of the rock should be assessed with conventional rock sizing criterion as described in technical supplement 14C of 210-NEH-654.

Figure 16-19: Design Criteria for Various Streambank Soil Bioengineering Practices

Practice	**Permissible Shear Stress (lb./ft^2)**	**Permissible Velocity (ft/s)**	**Special concerns that can affect limits**
Live Stakes/Live Poles	Initial: 0.5 to 2 Established: 2 to 5+	Initial: 1 to 2.5 Established: 3 to 10	Length of pole Soil conditions
Live Stakes and Riprap	Initial: 3+ Established: 6 to 8+	Initial: 5 to 10+ Established: 12+	Length of pole Soil conditions Stability of rock
Brush Mattress	Initial: 0.4 to 4.2 Established: 2.8 to 8+	Initial:3 to 4 Established: 10+	Anchoring Soil conditions
Live Fascine	Initial: 1.2 to 3.1 Established: 1.4 to 3+	Initial: 5 to 8 Established: 8 to 10+	Anchoring Soil conditions
Live Cribwall	Initial: 2 to 4+ Established: 5 to 6+	Initial: 3 to 6 Established: 10 to 12+	Nature of fill Anchoring Log type Scour
Grass Turf	Established: 3.2	Established: 3 to 8	Vegetation type Soil conditions
Wattle	Initial: 0.2 to 2 Established: 1 to 5+	Initial: 1 to 2.5 Established: 3 to 10	Vegetation type Soil conditions
Vertical Bundles	Initial: 1.2 to 3 Established: 1.4 to 3+	Initial: 5 to 8 Established: 6 to 10+	Bank stability Anchoring Soil conditions

650.1603 Shoreline Soil Bioengineering Protection Planning

(A) General

(1) Shoreline erosion results primarily from erosive forces of waves that are generally perpendicular to the shoreline. As a wave moves toward shore, it begins to drag on the bottom, dissipating energy. This eventually causes it to break or collapse. The resulting turbulence stirs up material from the shore bottom or erodes it from shorelines, banks and bluffs.

(2) The key difference between streambank and shoreline erosion is the cause of erosion. Streambank erosion is primarily, but not exclusively, initiated by moving stream flows while shoreline erosion is primarily initiated by wave action. However, fluctuating tides, freezing and thawing, recreational use, floating ice, and surface runoff from adjacent uplands may also contribute to or cause shorelines to erode and must be taken into account by designers.

(3) Systems for shoreline protection can be living or nonliving. Protection can consist of vegetation, soil bioengineering, structures, or a combination of these. This document focuses on soil bioengineering protection. The shoreline soil bioengineering approach is generally to apply vegetation along a constructed or natural wave protection berm.

(4) Shoreline soil bioengineering (also referred to as vegetated shoreline stabilization) is considered a "soft" approach. This approach is often less expensive to install and maintain than hard armor (inert) protection. Unlike inert material, damaged vegetation often reestablishes itself. Vegetation provides important terrestrial and aquatic habitat benefits and improves water quality through nutrient cycling.

(B) Site Assessment for Shoreline Protection

(1) Vegetation has long been used to stabilize shorelines of lakes, reservoirs and ponds. However, it is not applicable in all situations. Select shoreline stabilization approaches in terms of the performance and function of the treated bank overtime.

(2) Interdisciplinary teams are effective at planning and designing shoreline stabilization projects, with the project stakeholder, the owner, and each discipline providing individual knowledge, experience, and expertise. Clear communication between team members is critical when discussing shoreline erosion causes and solutions and selecting treatment approaches. This will help assure that the decision makers are truly in concurrence with the treatment selection.

(3) The first phase of the NRCS planning process involves the collection and analysis of data. A variety of site-specific information should be assessed. The list that follows in figure 16-20 includes data commonly needed for planning and design of shoreline stabilization projects. The list is neither inclusive nor exhaustive. Additional discussions are included in TR-210-56.

Figure 16-20: Data Collection for Shoreline Soil Bioengineering Projects

Typical Issues	Information to Assess	What is this information is used for
Fluctuating pool level	Tidal tables Records of lake levels Lake operation records Observed high and normal water lines along the shore. Observed wrack line in tidal areas Records of maximum drawdown during drought of irrigation reservoirs	If the pool elevation fluctuates considerably, the vegetation may not be able to survive without extensive supplemental irrigation or the vegetation could be drowned by prolonged flooding. This is often a concern for irrigation and industrial dams. Extended wave protection berms or inert protection may be necessary if the pool fluctuates significantly.
Adjacent Shoreline and Structures	Location and condition of structures as well as the shoreline itself.	Structures that might influence adjacent shoreline or other structures must be examined carefully. End sections need to be adequately anchored to existing measures or terminated in stable areas.
Existing Vegetation	Location and condition of adjacent vegetation.	The installation of erosion control structures can have a detrimental effect upon existing adjacent vegetation unless steps are taken to avoid unnecessary site disturbance. Existing vegetation should be saved as an integral part of the erosion control system being installed. Consideration must be given to the possible effects that erosion control measures can have on adjacent areas, especially estuarine wetlands.
Ice and Debris	O&M records Drift lines	Wind generated waves can also cause damage to embankments by driving debris and ice into the shore. A structural approach may be necessary if the embankment is in an area where it must resist ice and debris.
Boat Wake	Records of use Observation of boats in different seasons and days Harbor records	Damaging waves can be caused by boat wake. If wake from large craft is a significant issue at the site, inert protection is likely necessary.
Heavy Recreational Use	Records of use Evidence of trails Trash left by users	Heavy recreational use can damage the protective vegetation. Foot trails and paths can cause runoff to concentrate and cause erosion. Measures can be taken to protect the vegetation when this is a concern. Heavy bushes and fencing can be used to restrict access. Defined hard fishing access can also be provided in targeted areas.

Figure 16-20: Data Collection for Shoreline Soil Bioengineering Projects - continued

Typical Issues	Information to Assess	What is this information is used for
Littoral Transport	Evidence of littoral drift and transport. Source of sediment (bank or offshore) Direction of littoral transport Quantity of littoral transport	The material being moved parallel to the shoreline in the littoral zone, under the influence of waves and currents, can be an integral part of many designs. This information is used to locate several types of structures with respect to adjacent properties.

(C) Risk and Shoreline Soil Bioengineering

(1) The goal of many shoreline soil bioengineering stabilization projects is to mimic natural conditions to produce a more stable shoreline. In many environments, natural shorelines move and suffer erosion during large storms. So even with an established shoreline stabilization project, stakeholders should expect bank movement and periodic bank erosion. The consequences of this dynamic stability approach include the need for periodic maintenance and is inherent to shoreline soil bioengineering stabilization projects.

(2) Generally, the risk is higher with shoreline soil bioengineering treatments compared to hard structures mostly due to plant survivability. Consider the risk by examining the limitations of the treatment approach, the expected future conditions of the site, and owner willingness to maintain site.

650.1604 Shoreline Soil Bioengineering Design

(A) General

(1) Wind-generated waves transport a great deal of energy. Shorelines degrade due to the erosive action of wind generated waves, especially in combination with vegetation loss. Waves dislodge material on the shore or embankment, and the soil is ‘washed’ away. This is the primary mechanism that causes shoreline erosion.

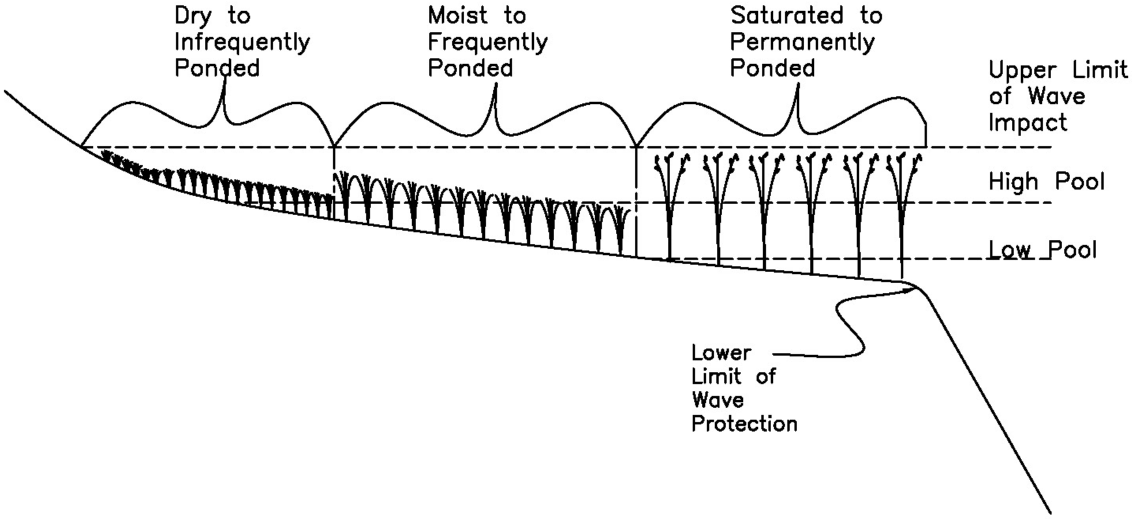
(2) A less evident shoreline erosion mechanism is wave-induced damage along the toe of constructed embankments and natural slopes. Scour along the toe effectively steepens the bank and can result in geotechnical slope stability problems (gravity triggered) because the effective resistant forces are reduced. The steepening of the bank can go beyond what is geotechnically stable and therefore results in bank failure.

(B) Planting Zones for Wave Protection

(1) The success of vegetated shoreline protection depends on the establishment of plant species appropriate to the site location and climate. The location of riparian and aquatic plants relative to the water is a critical factor for successful plant establishment. Plants used for wave protection should be from the same hydrologic regime as their native environment.

(2) To assist with locating planting zones, this document defines three areas along edge of a shoreline in terms of the expected plant communities and hydrologic regime. This *hydrologic planting zone* (or berm) is analogous to the riparian planting zones described earlier in this document but applied to shoreline environments. An idealized representation of these zones is illustrated in figure 16-21. The zones are primarily based on vegetation but are indexed to water level. There is often not a sharp demarcation between each of the zones. The zones are described in more detail in TR-210-56, including the calculation of the upper and lower limits of wave impacts.

Figure 16-21: Hydrologic Planting Zones along Shorelines and Embankments



(C) Plants for Shoreline Soil Bioengineering

(1) Identifying the hydrologic planting zones shown in figure 16-21 aids in treatment and plant species selection. A summary of the vegetation characteristics of the zones is provided in figure 16-22. Existing vegetation in stable areas of the shoreline may also be used to set the boundaries of the hydrologic planting zones.

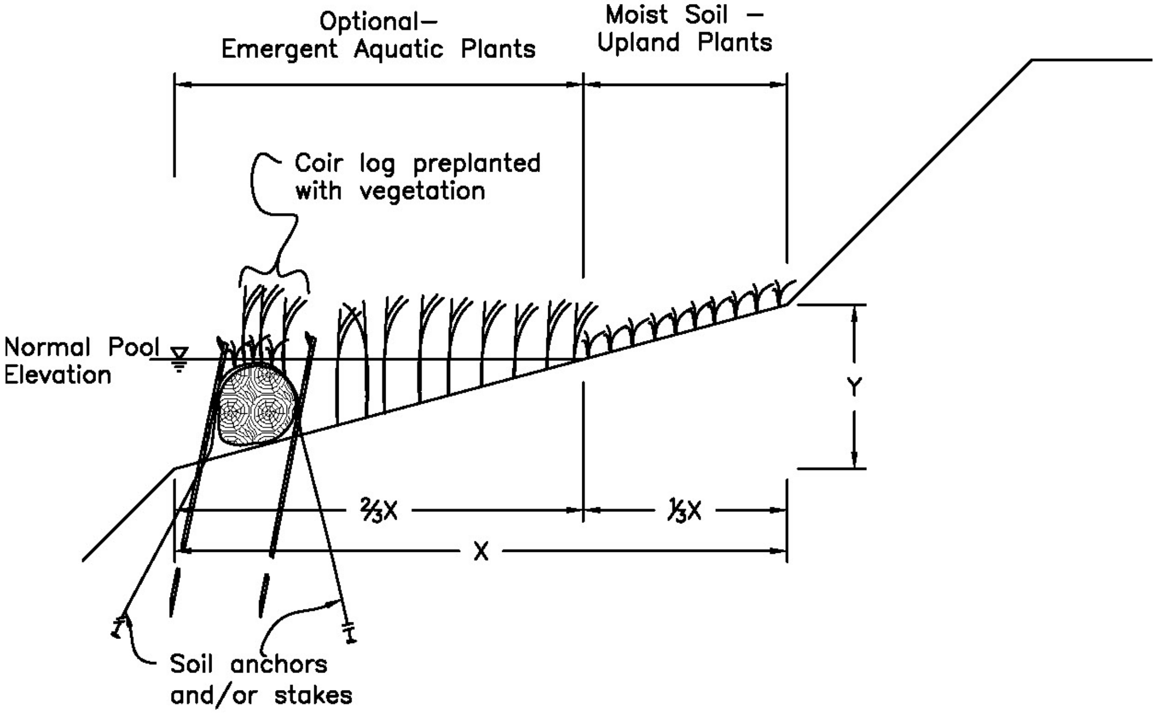
Figure 16-22: Hydrologic Planting Zones Location and Attributes

Zone	Hydrologic Position	Vegetation Attributes
Saturated to Permanently Ponded	The lower limit of wave protection is dependent on the plant species type. A practical lower limit for most emergent plant communities is a depth of 3 feet. The upper boundary is set to no higher than the pool level 80% chance annual runoff probability. If pool level analysis is made using the Soil-Plant-Air-Water (SPAW) model, the upper boundary can be set at 1 foot above the 80% probability of continuous inundation during the growing season.	Hydrophytic vegetation is adapted to grow in semi-permanent inundation conditions. These plants provide wind velocity reduction in shallow offshore areas, as well as wave energy reduction in the near shore area. Example: Inland Saltgrass
Moist to Frequently Ponded	The upper boundary can be set at the pool level with a 50% chance annual exceedance probability (2-year return period). If a hydrologic water budgeting model (such as the SPAW Model) is used, the boundary should be set at the 50% chance, 15-day duration for periods during the growing season.	Hydrophytes that thrive in the saturated to semi-permanently inundated zone are often referred to as “wet prairie” or “moist soil” plants, and can survive short to long periods of dry conditions. Example: Maiden cane
Dry to Infrequently Ponded	The upper boundary of this zone can be set at the 10% chance annual exceedance probability (10-year return period) pool level	Upland plants with a known tolerance for short-term, infrequent flooding. Example: Prairie cordgrass

(2) Plant selection is based on species suitability for the hydrologic regime on the shoreline. It is important to recognize that the hydrologic conditions change in a continuum from wet to dry across a slope. Permanently ponded conditions exist at the lower end. Plants suitable for this zone are referred to as “emergent aquatic vegetation” and the zone is referred to as “saturated to permanently ponded.” At the highest “dry to infrequently ponded” zone, where ponding is infrequent and of short duration, only upland vegetation is suitable. In between these zones, various combinations of ponding duration and frequency exist in a zone broadly shown in figure 16-21 as “moist to frequently ponded.”

(3) There is uncertainty in estimating the water levels and hydrologic planting zones. The idealized representation in figure 16-21 and described in figure 16-22 are tools to address this uncertainty. For example; it is acceptable to establish a plant community for two or even a single planting zone where water level fluctuations are small. A sketch of one such example is shown in figure 16-23. But where the hydrologic regime changes significantly from high to low elevations, it is desirable to establish multiple plant communities.

Figure 16-23: Example of vegetated coir log and planting



(D) Example Shoreline Soil Bioengineering Techniques

(1) Many types of streambank soil bioengineering treatments are adapted to address shoreline erosion. Figure 16-24 summarizes some of the soil bioengineering systems that are best suited to reducing erosion along shorelines. These treatments are commonly modified to account for site specific conditions and material availability.

Figure 16-24: Selected Streambank Soil Bioengineering Practices

Practice	Description
Vegetative Plantings	If some vegetation exists on the shoreline, the shoreline problem may be solved with more vegetation. Determine if the vegetation disappeared because of a single, infrequent storm, or if plants are being shaded out by developing overstory trees and shrubs. In either case, revegetation is a viable alternative. Consult local technical guides and plant material specialists for appropriate plant species and planting specifications.
Vegetative Plantings and Wave Berm	One of the most commonly applied techniques to provide wave protection on NRCS dams is with the use of a sloped and vegetated wave berm. The extent and slope of the vegetation reinforced berm absorbed the wave energy before the wave can impact the dam. This approach has also been successfully applied to shorelines. 210-TR-56 provides additional guidance for dimensions of wave berm and plantings.
Live Stakes	Live stakes offer no stability until they root into the shoreline area, but over time they provide excellent soil reinforcement. To reduce failure until root establishment occurs, installations may be enhanced with a layer of long straw mulch covered with jute mesh or, in more critical areas, a natural geotextile fabric.
Live Fascines	The live fascines previously described in this chapter work best in shoreline applications where the ground between them is also protected. Live fascines can be incorporated into vegetated wave berms.
Coir Fiber Roll Figure 16-25	Coir fiber rolls are cylindrical structures composed of natural fibers bound together with twine woven from coconut. This material is most manufactured in 12-inch diameters and lengths of 20 feet. The fiber rolls function as breakwaters along shorelines. In addition to reducing wave energy, this product can help contain substrate and encourage development of wetland communities. This approach is often used with a vegetated wave berm.
Brush Mattress	Brush mattresses for shorelines perform a similar function as those for streambanks. Therefore, effectiveness guidelines are similar to those given earlier in this chapter, with the following additions. May be effective in lake areas that have fluctuating water levels since they are able to protect the shoreline and continue to grow. Able to filter incoming water because they also establish a dense, healthy shoreline vegetation.
Live Siltation Figure 16-26	Live siltation branches that have been installed in the trenches serve as tensile inclusions or reinforcing units. Live siltation construction is similar to brush layering except that the orientation of the branches is more vertical. Ideally live siltation systems are approximately perpendicular to the prevailing winds. The part of the brush that protrudes from the ground assists in retarding runoff and surface erosion from wave action and wind.
Reed Clump Figure 16-27	Reed clump installations consist of root divisions wrapped in natural geotextile fabric, placed in trenches, and staked down. The resulting root mat reinforces soil particles and extracts excess moisture through transpiration. Reed clump systems are typically installed at the water's edge or on shelves in the littoral zone. They can also be incorporated into vegetated wave berms with fascines or coir fiber rolls.

Figure 16-25: Coir Fiber Roll

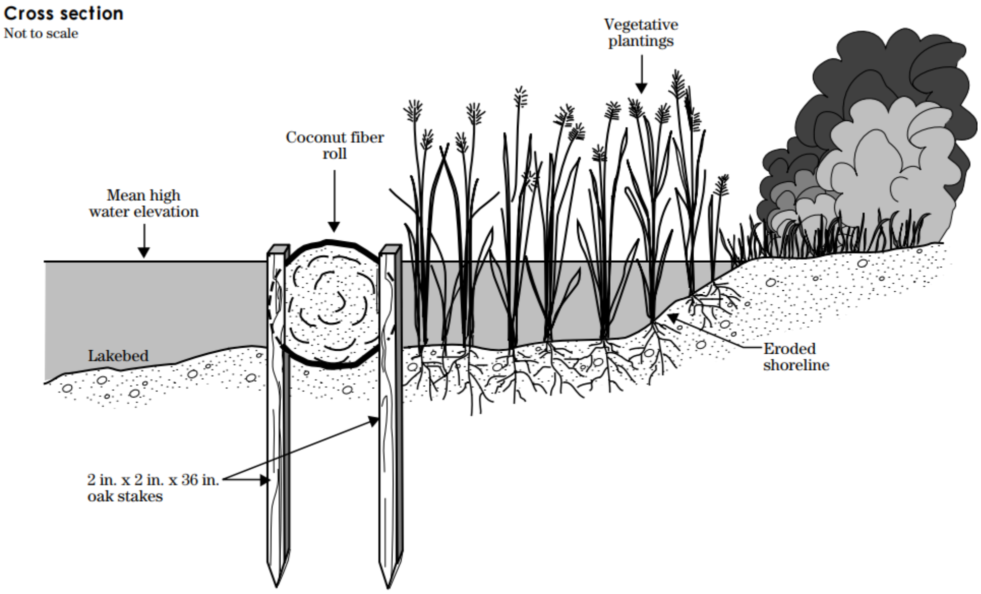


Figure 16-26: Live Siltation

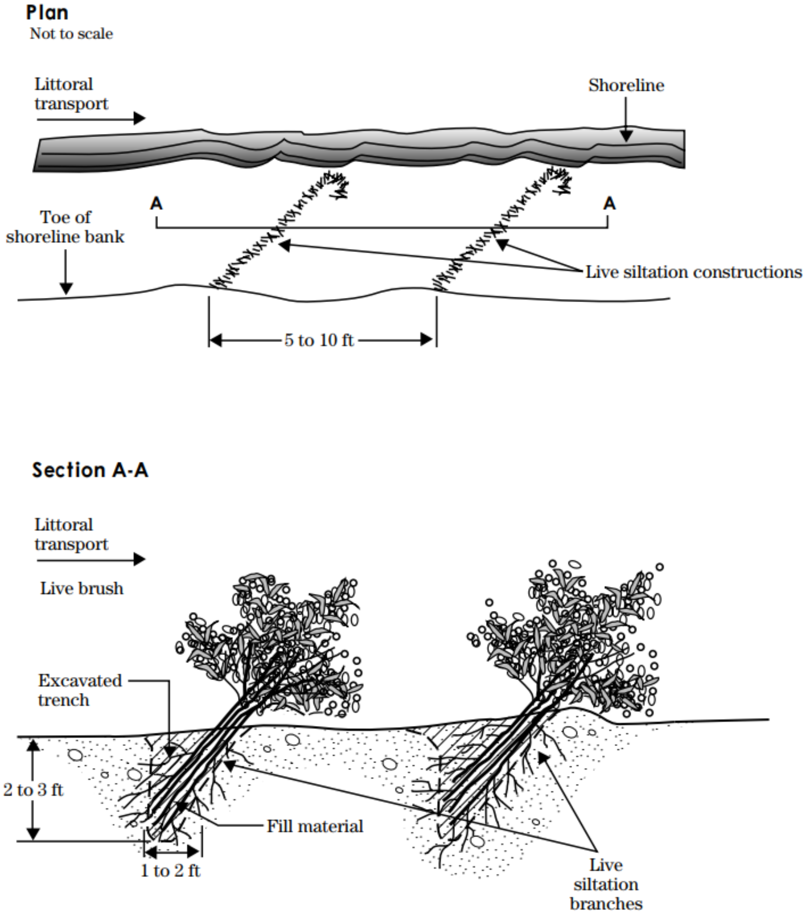
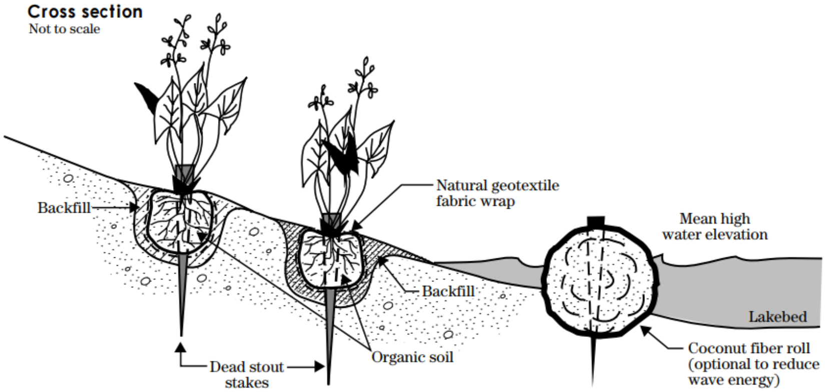


Figure 16-27: Reed Clump



(E) Wave Action and Shoreline Soil Bioengineering Techniques

(1) Consider the effects of waves on shoreline protection treatments and their ability to tolerate a full range of conditions that are expected during the design life of the project. The mechanics of wind generated waves and erosive forces caused by these waves are very complex. 210-TR-56 provides a simplified analytical design procedure for the assessment of wave attack. This document also provides guidance on the shape and dimensions of a wave berm design. Many of the techniques described in figure 16-24 are applied to sloping shorelines and wave berms that can be designed using 210-TR-56.

(2) Design guidance is available for streambank soil bioengineering practices, including 210-NEH-654-14. Some of this guidance is applicable to soil bioengineering on shorelines. However, most of these limiting criteria for streambank soil bioengineering are expressed in velocity or shear exerted by flowing fluvial systems. Little guidance is available for a designer to calculate the required treatment for wave energy. Designers who adapt streambank soil bioengineering techniques to shoreline conditions must rely on judgment and local examples of successful approaches.

(3) Designers of shoreline soil bioengineering techniques can and should reference criteria in 210-TR-69 for rock stabilization techniques and 210-TR-56 for vegetated slope wave protection techniques.

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650.1605 Acknowledgments

A. Cover: A plant-based streambank soil bioengineering installation. Photo taken 1.5 years after installation

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C. In 2020, **Jon Fripp**, Stream Mechanics Civil Engineer, NRCS-NDCSMC, Fort Worth, TX and **Kelly Ramsey**, Hydraulic Engineer, NRCS-VA, Richmond Virginia under the guidance of **Jo Johnson**, National Geologist, NRCS-NHQ, Washington, DC prepared this chapter with additional technical guidance and updates, as well as revisions, in accordance with the NRCS directives system. Excellent source material and technical review of this chapter has been provided by **Jerry Bernard**, National Geologist (retired), NRCS-NHQ, Washington, DC.