BIOENGINEERED STREAMBANK STABILIZATION

Audience: The intended audience for this job aid is local, tribal, and state government representatives who do not necessarily have a technical background or experience in bioengineering. FEMA has developed this job aid to encourage planners, government officials, and others to consider bioengineering approaches to stream restoration in addition to more traditional "hard" methods.

DEFINITION

Bioengineered streambank stabilization (bioengineering) methods increase the strength and structure of the soil with a combination of biological and mechanical elements. This job aid presents the benefits of bioengineered solutions, describes commonly used measures, and identifies steps to plan and execute a successful project, including criteria to use in selecting the right approaches. It includes case studies demonstrating practical applications of bioengineering methods in riverine environments subject to bank erosion and habitat degradation.

Bioengineered solutions use a combination of biological, mechanical, and ecological concepts to control erosion and stabilize soil through the sole use of vegetation, or a combination of vegetation and construction materials. While conventional riprap may be unavoidable in some cases, bioengineering approaches provide a self-stabilizing, long term solution for many streams and banks damaged by erosion resulting from weather-related factors, construction, and wildfires. The underlying principle requires the application of an integrated watershed-based approach that uses sound engineering practices together with ecological principles to assess, design, construct, and maintain living vegetative systems. Bioengineering can be used on streambanks that require structural intervention to facilitate growth of natural vegetation. Once the root system of the vegetation is established, it provides additional stream and bank stability. Successful projects can help repair damage caused by erosion and slope failures; protect or enhance already healthy, functioning systems; and ensure long term sustainability of the impaired area.

Projects will likely involve an interdisciplinary effort between scientists, engineers, and landscape architects. Conservation Districts might be able to provide technical support or recommend suitable resources. Well-designed and documented bioengineering approaches incorporated into a project may enable regulatory review to be streamlined. However, under FEMA programs, proposed bioengineered bank stabilization projects must also mitigate potential infrastructure damage to meet eligibility requirements.

BENEFITS

TECHNICAL BENEFITS:

1. Protects against surface erosion, which can adversely affect water quality and habitats (as compared with riprap, which merely shifts the location of erosion if not installed properly)
2. Improves hydrology, stream function, and stability, allowing the stream to function more naturally
3. Protects against rock fall and wind, which can cause further erosion and impede the flow of water
4. Reduces possibility of washouts and sediment flushing that can cause water to flow outside the stream channel
5. Establishes a lasting surface on which plants can take root and grow
6. Provides a transition zone from stream to upland areas where trees can be used to increase stabilization
7. Viable in areas with access/space issues
8. Can reduce flow velocities in the stream, reducing in-stream and bank erosion to maintain water quality

ECONOMIC BENEFITS:

1. Vegetation requires little to no maintenance after establishment (which can take several years)
2. Minimal maintenance requirements can be beneficial in all areas
3. Protects existing infrastructure from damage
4. Native, local plants and seeds better adapt to local climates without becoming invasive, yielding long term savings
5. Local ownership and control of riparian management

6. Contributes to property values and recreational values that are economic drivers for many communities with integrated natural areas

ECOLOGICAL BENEFITS:

1. Creates more natural habitats for wildlife in-stream and along streambanks
2. Provides beneficial environment for native wildlife
3. Promotes conservation of species, particularly those struggling to survive
4. Reduces water pollution by capturing excess nutrients such as nitrogen and phosphorous to improve water quality
5. Controls stream temperature and humidity at the surface, improving habitats
6. Reduces runoff when plants absorb and store water and when leaves intercept falling water and return the water to the atmosphere through evaporation
7. Forms topsoil, which improves soil's ability to support plant growth
8. Attracts pollinators if appropriate plants are used

SOCIAL AND CULTURAL BENEFITS:

1. Improves landscape in riparian and overland areas
2. May protect cultural and archaeological resources (although care must be taken to ensure extents and depths of disturbance during installation do not adversely affect existing cultural and archaeological resources)
3. Creates outdoor recreational opportunities

While FEMA supports and encourages bioengineering, it has some limitations. Establishment takes several years, and most installations require some re-planting in the second year. Livestock and wildlife can be sources of detrimental grazing. In addition, plants can be uprooted in high erosional environments, caused by high flows and velocities.

COMMONLY USED MEASURES

Bioengineering techniques are applicable to all geographies but will vary based on project goals, site and watershed characteristics, and habitat. The types of plants used will vary based on geographic region of the United States. Lists of native plants are generally available from state natural resources or conservation agencies.

Details of the applicability, installation instructions, and methods can be found in published and manufacturer-provided literature. Some commonly used bioengineering measures focusing on natural process-based river design, bank armor and protection, and slope stabilization can be classified in the following groups:

1. **Fascines/Stakes:** Cuttings placed perpendicular to the ground or in trenches to improve slope and bank stability; project owners should work with appropriate local agencies to identify which plants to use
2. **Blankets/Mats:** Protective layer of fiber, live cuttings, or synthetic material placed on slopes for erosion protection
3. **Toe Stabilization/Revetments:** Vegetated or rock structures placed parallel to a bank at its base to protect against scour and erosion
4. **Drainage-Promoting Measures:** Free-draining material placed on a slope or bank to intercept and control runoff and seepage to ensure long-term stability
5. **Structural Measures:** Large retaining structures used to stabilize banks and slopes
6. **Weirs and In-Stream Structures:** Structures that extend into the stream to direct flows away from banks to reduce erosion

Projects may use a combination of bioengineering and structural techniques. Additional information about specific stabilization measures in each classification group is included in the Appendix.

EXAMPLES

The following case studies discuss the selection and successful implementation of some of the commonly-used bioengineered measures in locations across the United States with varied site conditions and project objectives.

Figures 1 & 2. Malletts Creek, MI Bioengineered Streambank Restoration (Source: Goldsmith, Gray, and McCullah 2014)

1: Malletts Creek, Ann Arbor, Michigan: High flow velocities across fine sandy and loamy soils caused channel and bank erosion along with water quality issues. Streambank restoration measures included conventional riprap along high-velocity reaches; coir logs along other sections for erosion reduction; rock and cross vanes along tight outside bends for flow diversion; grading bank slope to 2:1 (horizontal:vertical) based on site and soil conditions and covering with biodegradable straws or coconut fiber Erosion Control Blanket (ECB); and live willow stakes inserted through ECBs for additional bank protection and vegetation reestablishment. Benefits included runoff mitigation, pollutant loading reduction, and improved aquatic habitat for fish and wildlife. The installed measures performed well during and immediately after intense rainstorms shortly after construction in March 2012. Channel degradation was arrested, and considerably less sediment was found flushed through the creek to the Huron River. Rock vanes provided superior and more diverse aquatic habitat, and sediment collected behind these vanes as intended. Quick establishment and performance of the installed streambank measures addressed initial concerns of residents living along the creek regarding loss of vegetation.

2: San Vicente Creek, Davenport, California: High intensity storms caused erosion of banks and threatened structures located on the high bank. Flood flows undermined an existing section of rock-filled gabion baskets protecting business establishments located at the lower reach. Techniques employed included vegetated riprap with willow pole planting and brush layering on a smoothly graded slope; rootwads incorporated into rock revetment for additional flow resistance on the outside bend of stream; and rock vane upstream of critically eroded bank for flow deflection from the bank and to alleviate erosive hydraulic forces. Benefits included

Figure 3. San Vicente, CA: Rootwads and Revetments (Source: Goldsmith et al. 2014)

expedited permitting by California Department of Fish and Game and National Marine Fisheries (NMFS) due to habitat enhancement and conservation measures for endangered species habitat; reestablishment of native and naturalized species of woody vegetation on the stream bank; and increased slope stability, habitat enhancements, and improved aesthetics.

Figures 4 & 5. Lower Sulfur Creek, CA Bioengineered Streambank Restoration (Source: Goldsmith et al. 2014)

3: Lower Sulfur Creek, North Redding, California: Flooding caused by mining and roadway construction resulted in stream aggradation, "upside down" channel bottom, stream choking by large cobbles, severe bank erosion, and loss of bank vegetation. Techniques employed included excavation of a new low flow channel to divert flows; bendway rock weir to split flow and fish escapement; Large Woody Debris (LWD) and rock structures anchored with live poles at impinging flow locations, rock vane to protect oak trees and direct stream flow; and Longitudinal Peaked Stone Toe Protection (LPSTP) with live siltation to provide local roughness. Benefits included habitat restoration for salmonid species, removal of obstruction for anadromous fish migration, and provision for stream cleaning up by washing fine sediments.

Figures 6 & 7. Buffalo Bayou, TX Bioengineered Streambank Restoration (Source: Goldsmith et al. 2014)

4: Buffalo Bayou, Houston, Texas: Natural flooding, controlled releases, sandy and silty soils with little cohesion, and water seepage from banks resulted in widespread erosion, bank failure, and reduced slope factor of safety. Techniques employed included vegetated mechanically stabilized earth (VMSE) buttress fill with synthetic geogrid and live fascines; chimney drains to intercept and direct seepage; live staking on edges and sides; and a bank spur to protect sewer outfall and maintain low flow thalweg (line of lowest elevation in a watercourse). Benefits included protection against scour and slope failure, adequate drainage, and prevention of saturation or excess pressure buildup within VMSE by chimney drain.

Figures 8 & 9. Charles River, MA Watertown Arsenal Bioengineered Streambank Restoration (Source: Goldsmith et al. 2014)

5: Charles River Watertown Arsenal, Watertown, Massachusetts: River park site developed by filling marshlands resulted in coal ash and burned garbage contamination, requiring remediation of all contaminants on the federally owned parcel. Techniques employed included live brush layering and coconut fiber erosion control blanket (ECB); live stakes to establish new woody vegetation; rock layer for scour prevention; and coconut fiber rolls to act as a breakwater against wave action from passing watercraft. Benefits included effectiveness on a highly sensitive and regulated segment of Charles River; stabilization and capping of residual contaminants; enhancement of habitat, water quality, recreation, and historic landscape aesthetics; and long term protection and good vegetative establishment at a reasonable cost.

PROJECT PLANNING AND EXECUTION – STEPS FOR SUCCESS

A bioengineered streambank stabilization project should include, at a minimum, these eight tasks:

Task 1 - Problem Definition/Objective Setting: The first task toward project success is clearly and correctly defining the problem, i.e., extent and cause of bank erosion/instability, and prioritizing restoration objectives as well as stakeholder needs. Reviewing and incorporating information from state, tribal, or local mitigation plans can help facilitate development of mitigation project alternatives that align with community priorities.

Task 2 - Data Collection and Analysis: FEMA encourages project teams to coordinate with Environmental and Historic Preservation (EHP), Public Assistance (PA), or Hazard Mitigation Assistance (HMA) staff to determine what data is needed to evaluate the project. The project team should collect and review watershed data, H&H data, stream characteristics, soils and geotechnical data, fluvial geomorphic data, climatic and vegetative conditions, habitat characteristics (current and desired), and water quality and pertinent environmental data (current and desired). Important design considerations include site accessibility, channel grade, watershed flows, channel velocities, stream alignment, stream type/geometry, bed material and sediment load, and debris and maintenance needs.

Task 3 - Project Scoping: Project scoping is the initial stage of project development during which the details of mitigation activities can be evaluated and developed. The information gathered during the scoping process serves as the basis for development of a more detailed technical design, cost estimate, and regulatory compliance project components.

Task 4 – Design Development: To meet all Task 1 objectives, a combination of bioengineering techniques should be considered for a site-specific bioengineering project plan using the following selection criteria (Figure 10):

- **Hydrology:** The movement and volume of the flow to and within the stream should be used to determine the best type of stabilization structure (hard/bioengineered).
- **Hydraulics:** The anticipated water surface elevations, velocities, and related forces should be used to determine the location and extent of selected measures. Sudden changes in velocity or shear stresses in areas such as abutments or

culverts may necessitate use of traditional stabilization methods; whenever possible, projects should try to establish vegetation around hardened measures to gradually transition to upland vegetated areas.

- **Fluvial Geomorphology:** Understanding which portions of the stream channel are damaged and what changes might occur to the stream channel in response to human-caused and natural disturbances helps to determine appropriate restoration approaches. Figure 10 shows some of the strategies applicable to various zones. These strategies must take into account the form and function of the stream channel and relationship to the stream and surrounding landscape.
- **Geotechnical Considerations:** The type of rock and soil that make up the stream channel and surrounding area influence what measures are appropriate. Geotechnical deficiencies should be evaluated to focus selection of measures that can increase soil shear strength using root systems.
- **Cost Effectiveness:** Like other mitigation projects, bioengineering projects must meet cost effectiveness requirements to qualify for FEMA grant funding. Cost effectiveness is evaluated by FEMA using benefit-cost analysis; cost effective projects have a benefit-cost ratio greater than 1.0. FEMA issued supplemental guidance for incorporating environmental benefits into a BCA for stream restoration projects.

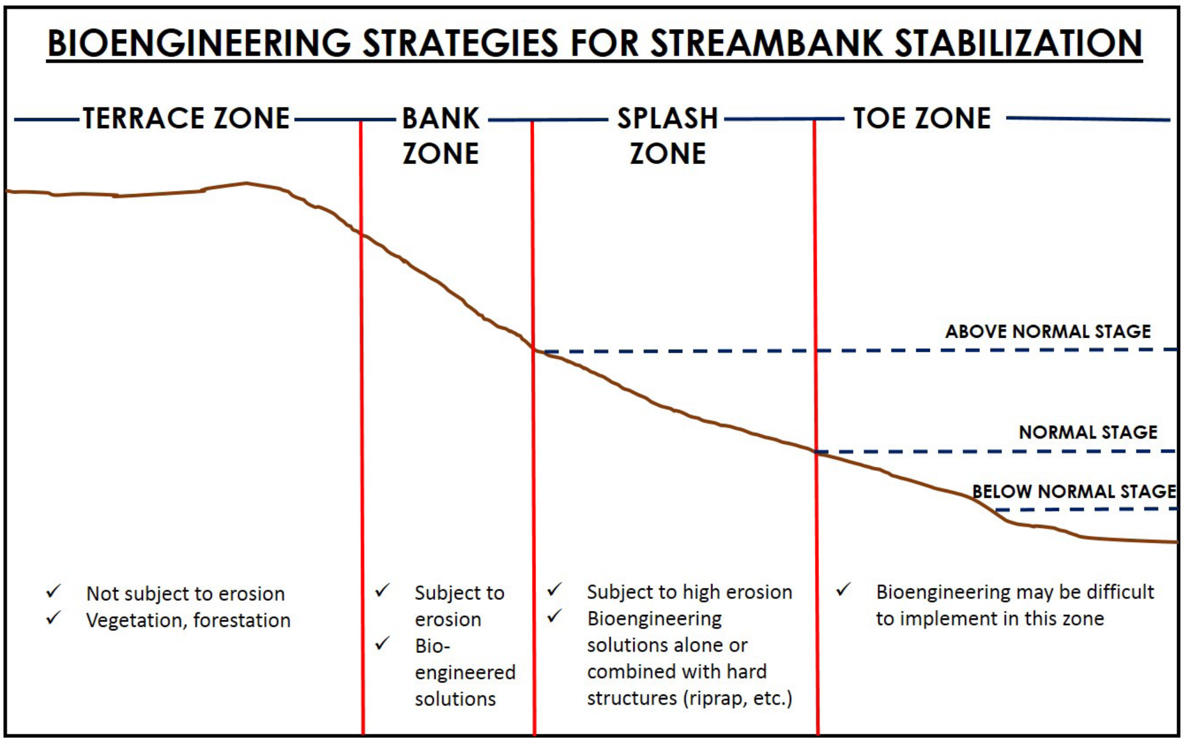

Figure 10. Bioengineering strategies for streambank stabilization (FEMA 2017)

Task 5 – Permitting and Regulations: It is important to address and comply with all federal, state, and local regulations and obtain necessary permits subsequent to the completion of conceptual design. Depending on the location, impacts, measures selected, and material employed, various permits, environmental reviews, or certifications may be required before construction. In general, permits are required from federal, state, and local levels. Starting discussions with permitting agencies early in the project development process – even in the conceptual stages – and keeping documentation will be required by FEMA for award and likely will save time and effort at the project closeout. Examples of pertinent regulations at the various levels are included at the end of this job aid.

Task 6 – Project Implementation: Project implementation includes site preparation, construction, planting, monitoring, and aftercare. For the bioengineering design to be successful, implementation must be closely supervised throughout by someone familiar with implementation of bioengineering projects. Continuity of the interdisciplinary team involved in the design is highly recommended, and consulting with someone who has implemented other bioengineering projects will help ensure the success of the project. The optimum time to install bioengineered measures is usually during seasons when stream flows are typically low and dormant cuttings have the highest success rate. Scheduling the sequence of work is critical to project success. Scheduling considerations include endangered species' nesting seasons.

Task 7 – Project Completion: Upon project completion, the project owner should document that the project was completed in accordance with the scope of work, and that all regulatory compliance grant conditions were implemented and documented.

Task 8 – Post-construction Monitoring: As with any constructed project, bioengineering project plans should include maintenance and monitoring. Maintenance activities may be needed more frequently during the first few years after installation while plants are establishing, but will likely be minimal after they become established. Overall need for these activities depends on site conditions including climate and probability of animal disturbance.

RELEVANT REGULATIONS

FEDERAL REGULATIONS

National Environmental Policy Act (NEPA): The President's Council on Environmental Quality (CEQ) oversees implementation of the National Environmental Policy Act (NEPA). NEPA is the basic national charter for protection of the environment including physical, biological, social, and cultural resources. This law establishes policy, sets goals, and provides the means to review data and information to assess environmental impacts of proposed actions and consider reasonable alternatives to those actions. The NEPA regulations apply to all federally funded or authorized projects.

Clean Water Act (CWA): Section 404 of the federal Clean Water Act (CWA) was written to protect and restore the quality of United States surface waters. To attain this goal, filling, grading, mechanized land clearing, ditching, other excavation activity, and piling installation in waters of the United States require a Section 404 permit prior to starting construction. Under the Nationwide Permits Program (NWP), the United States Army Corps of Engineers can issue general permits to authorize activities with minimal individual and cumulative adverse environmental effects. A project may need multiple NWPs.

The CWA also created the National Pollution Discharge Elimination System (NPDES) permit program to address water pollution by regulating point sources that discharge pollutants to waters of the United States. The NPDES permit program authorizes state governments to perform many permitting, administrative, and enforcement aspects of the program.

The Total Maximum Discharge Load (TMDL) for a stream is the greatest amount of a given pollutant that a water body can receive without violating water quality standards and designated uses. In accordance with Section 303(d) of the CWA, waters to be regulated within a state and the corresponding TMDLs for each are identified by the state in which the water body is located. States are also required to develop and submit to the U.S. EPA a prioritized list of these impaired waters, known as the 303(d) list.

Rivers and Harbors Act of 1899 ("Navigable Waters") Section 10: Section 10 of the Rivers and Harbors Act of 1899 requires that regulated activities conducted below the Ordinary High Water (OHW) elevation of navigable waters of the United States be approved/permitted by the U.S. Army Corps of Engineers. Regulated activities include the placement/removal of structures, work involving dredging, disposal of dredged material, filling, excavation, or any other disturbance of soils/sediments or modification of a navigable waterway.

Endangered Species Act (ESA): The purpose of the ESA is to protect and recover imperiled species and the ecosystems upon which they depend. Under Section 7 of the Endangered Species Act, federal agencies such as FEMA must consult with the U.S. Fish and Wildlife Service on any projects that might affect a federally-listed threatened or endangered plant or animal species on the project site prior to undertaking the project. Other permits could be required as well.

National Historic Preservation Act (NHPA): Section 106 of the National Historic Preservation Act of 1966 (NHPA) requires federal agencies to take into account the effects of their undertakings on historic properties and afford the Advisory Council on Historic Preservation a reasonable opportunity to comment. The regulations also place major emphasis on consultation with Indian tribes and Native Hawaiian organizations, in keeping with the 1992 amendments to NHPA. Based on this regulation, if a project impacts historic properties, coordination with the State Historic Preservation Officer is necessary.

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Executive Orders: Some Executive Orders, such as **11988 - Floodplain Management** and **11990 - Protection of Wetlands** apply to federally-funded projects that affect land use and development in the floodplain. FEMA requires agencies to complete an eight-step decision making process to comply with the regulations.

STATE AND LOCAL REGULATIONS:

Water Quality Certification: Projects involving work within a stream may require a 401 Water Quality Certification from the state environmental protection agency. Projects with the potential to affect public drinking supplies through dewatering or other construction activities must contact the state environmental agency to identify regulatory requirements that may apply.

Scenic and Historic Preservation Permits: Permits or approvals may be required from state and local historic preservation offices for projects that require earthmoving and/or demolition of a structure if the projects are in or near state wild, scenic, or recreational areas; archaeological sites; or historic structures.

Tidal Wetland and Coastal Zone Permits: Special permit requirements may apply in tidal waters and ocean shorelines in some states. Permits are required for projects including engineering activity that affects dune fields, beaches or shoreline lands.

Endangered Species Regulations: Wildlife, natural resources, and fisheries departments should be consulted to insure compliance with state threatened or endangered species regulations.

Water Rights: Each state regulates water rights within its jurisdiction. If a project diverts water or causes changes to a water course, approval or granting of water rights by the state may be required.

Floodplain Management Permits: Floodplain management permits or construction permits may be required by the local floodplain administrator for projects occurring within federally identified special hazard areas (the 100-year floodplain).

Surface Water, Stream Course, or Wetland Ordinances: Many city or county planning departments have local ordinances pertaining to creeks and wetlands. Depending on the nature of the project, several permits may be required.

Local Water Resources Permits: Local or regional irrigation and water districts are empowered to protect water resources in their jurisdiction; permits may be required for certain projects.

Other: Various agencies, utilities, and authorities should be consulted depending on specific activities and local requirements.

REFERENCES

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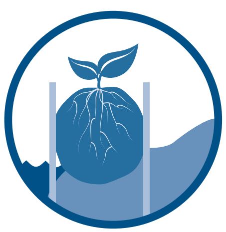
APPENDIX

Table 1a. Streambank stabilization measures summary

	Stabilization Measure	Description
Fascines/Stakes		
	Live Fascines	Long branch cuttings bundled and placed in a shallow trench to stabilize streambanks and slopes
	Pole Stakes	Cuttings from native species are embedded perpendicular to the ground in rows
	Post Plantings	Large diameter cuttings from cottonwood or willow are planted perpendicular to the ground surface, often among riprap
Blankets/Mats		
	Erosion Control Blanket (ECB)	Flexible fiber mats placed over a geosynthetic netting down a slope
	Live Brush Mattress	Thick blanket of live brushy willow cuttings and soils
	Turf Reinforcement Mat (TRM)	Rolled mat of non-degradable synthetic material that provides a matrix to reinforce the root system of vegetation for erosion protection
	Vegetated Gabion Mattress	Shallow rectangular containers 20" to 60" deep made of welded wire mesh and filled with rock and substrate to support vegetation
Toe Stabilization/Revetments		
	Coconut Fiber Rolls	Manufactured, elongated cylindrical structures that are placed at the bottom of streambanks to help prevent scour and erosion in streams with low to moderate velocities (~2.5-7 feet/second)
	Stone Filled Trenches	Rock-filled trenches placed at the base of a stream bank capable of supporting substrate for vegetation
	Vegetated Riprap	A layer of stone and/or boulder armoring that is vegetated, optimally during construction, using pole planting, brush layering, live-staking techniques
	Rootwad Revetment	Structures constructed from interlocking tree materials, primarily intended to resist erosive flows and are usually used on the outer bends of streams
	Live Siltation/Tree Revetment	A revegetation technique in which cut trees are anchored along the stream bank to secure the toe of the stream bank, trap sediments, and create fish rearing habitat
	Trench Fill Revetment	Constructed by excavating a trench along the top of the bank, placing stone riprap in the trench, and filling the trench with native soil capable of supporting vegetation
	Longitudinal Peak Stone Toe Protection (LPSTP)	A row of well-graded stones is placed parallel to the bank along its toe. The top of the stone is 1/3 to 1/2 the bank height, and the cross-section of the row is triangular. Live poles can be staked among the stones in lower velocity situations.

BIOENGINEERED STREAMBANK STABILIZATION

Table 2a. Function and efficiency of streambank stabilization measures

Stabilization Measure	Slope Angle	In-Stream?	Function			Material		
			Erosion Control	Drainage	Flow Control	Natural Vegetation	Geo-Textile	Stone/ Rock
Fascines/Stakes								
Live Fascines	Low to High	No	X		X	X		X
Pole Stakes	Low to Moderate	No	X		X	X		X
Post Plantings	Low to Moderate	No	X		X	X		X
Blankets/Mats								
Erosion Control Blanket	Low	No	X			X	X	
Live Brush Mattress	Low to Moderate	No	X			X		
Turf Reinforcement Mat (TRM)	Low to Moderate	No	X				X	
Vegetated Gabion Mattress	Moderate to High	No	X					X
Toe Stabilization/Revetments								
Coconut Fiber Rolls	Low to Moderate	Yes	X				X	
Stone Fill Trenches	Low to Moderate	Yes	X		X			X
Vegetated Riprap	Moderate	No	X		X	X		
Rootwad Revetment	Low to Moderate	Yes	X		X	X		
Live Siltation/Tree Revetment	Moderate to High	No	X			X		
Trench Fill Revetment	Low to Moderate	No	X					X
Longitudinal Peak Stone Toe Protection (LPSTP)	Low to High	No	X					X

BIOENGINEERED STREAMBANK STABILIZATION

Table 1b. Streambank stabilization measures summary

Stabilization Measure		Description
Drainage Measures		
	Chimney Drain	A subsurface drainage course placed between a natural slope and an earthen buttress fill or other retaining structure
	Slope Drain	A drainage system used to collect and transport storm runoff down the face of a slope
	Trench Drain	A drainage trench excavated parallel to and just behind the crest of a stream bank
Structural Measures (Including Walls)		
	Geocellular Containment System (GCS)	Flexible, 3-D, high density polyethylene (HDPE), honeycomb-shaped earth-retaining structures; can be expanded/ backfilled with a variety of materials to mechanically stabilize surfaces
	Live Cribwalls	A gravity retaining structure consisting of a hollow, box-like interlocking arrangement of structural beams filled with soil and live cuttings
	Vegetated Articulated Concrete Blocks (VACB)	An articulated concrete block system consists of durable concrete blocks that are placed together to form a matrix overlay or armor layer while allowing vegetation to grow throughout the system
	Vegetated Gabion Basket	Rectangular containers fabricated from a heavily galvanized steel wire or triple twisted hexagonal mesh. Vegetation is incorporated into rock gabions by placing live branches on each consecutive layer between the rock filled baskets.
	Vegetated Mechanically Stabilized Earth	Live cut branches interspersed between lifts of soil wrapped in natural fabric
	Large Woody Debris	Structures are made from felled trees (can include rootwads) to deflect erosive flows and promote sedi-ment deposit at the base of eroding banks
Weirs and In-Stream Structures		
	Bendway Weir	Discontinuous, redirective structures usually constructed of rock, designed to capture and then safely direct the flow through a meander bend; incorproating naturally occurring vegetation enhances aquatic & ter-restrial ecosystems
	Diversion Dike	A low berm (or ditch/berm combination) constructed along the crest/top of a streambank
	Engineered Log Jam	Structures made from felled trees may be used to deflect erosive flows and promote sediment deposition at the base of eroding banks
	Rock/Cross Vane	Structures angled into the flow in order to reduce local bank erosion by redirecting flow from the near bank to the center of the channel; vegetation planted on nearby streambanks provides long-term stability

BIOENGINEERED STREAMBANK STABILIZATION

Table 2b. Function and efficiency of streambank stabilization measures

Stabilization Measure	Slope Angle	In-Stream?	Function			Material		
			Erosion Control	Drainage	Flow Control	Natural Vegetation	Geo-Textile	Stone/ Rock
Drainage Measures								
Chimney Drain	Moderate to High	No		X				X
Slope Drain	Moderate to High	No		X			X	X
Trench Drain	Moderate to High	No		X			X	X
Structural/Walls								
Geocellular Containment System (GCS)	Low to High	No	X					X
Live Cribwalls	Low to Moderate	No	X			X		X
Vegetated Articulated Concrete Blocks (VACB)	Moderate to High	No	X			X	X	
Vegetated Gabion Basket	Moderate to High	No	X			X		X
Vegetated Mechanically Stabilized Earth	Moderate to High	No	X			X	X	
Large Woody Debris	Low to Moderate	Yes	X		X	X		
Weirs and In-Stream Structures								
Bendway Weir	Low	Yes			X			
Diversion Dike	Low to Moderate	Yes	X		X			X
Engineered Log Jam	Low	Yes			X	X		
Rock/Cross Vane	Low	Yes			X			X