CHAPTER 5

Soil Bioengineering Techniques

Soil bioengineering is an applied science that combines the use of engineering design principles with biological and ecological concepts to construct and assure the survival of living plant communities that will naturally control erosion and flooding. Horticultural principles are applied to establish the plant communities. Engineering design principles are applied to build structures that will help protect the communities as they grow to maturity and function as they would in their natural settings.

History

The use of bioengineering principles in the Forest Service dates back several decades. In the early 1900s it was called erosion control; soil bioengineering is its relatively new name. The Forest Service was using these principles in 1934, and probably earlier, when trees, brush, live fascine, brush layering, and rock were used to stop erosion.

The "Erosion Control Progress Report," by John E. Hughes, Junior Forester, Plumas National Forest, Milford Ranger District, 1934, describes in detail the 17 projects, including hours and costs, that were undertaken that year. The report states that, "Erosion control structures should be considered only as temporary expedients to hold the soil in place until vegetation can become established and stabilize a [bank] permanently."

A history of the area and the causes of the problems are described as well. The once resplendent meadows were lost to overgrazing, trampling, and meadow roads. The water tables had dropped as much as 15 ft, allowing for invasion by dryland plant species.

Hughes noted, "Some local meadow owners have carried on erosion control for as much as [20] years past. The areas where this work has been done show strikingly what can be accomplished by checking erosion and in restoring meadow vegetation through control.

"Originally the meadows in the area were well watered by meandering streams whose courses were often concealed by rank vegetation. The streams ran through frequent deep pools covered with lily pads, and in the spring water stood over practically the entire area of many of the meadows, while the water table was high, even in the summer, because the drainage channels were shallow. This abundance of water produced an excellent crop of forage or hay, and the country was prosperous."

The first road was built in the Last Chance country in the 1860's and stock patents were let. By 1934, "no such meadow exists in the Last Chance area and, instead of meandering streams with well vegetated courses, bare gullies with caving banks cut straight across practically every meadow. The result [was] that instead of water being distributed to the soil from meanders and pool[s] throughout the summer it runs off rapidly when snow melts and leaves the meadow with water tables as much as 15 feet lower than they formerly were… ."

The emphasis on ecosystem management, on improving fisheries, and on healthy watersheds has renewed interest in erosion control in the form of soil bioengineering.

Bank Stabilization

Soil bioengineering is an applied science that combines structural, biological, and ecological concepts to construct living structures (plant communities) for erosion, sediment, and flood control. Although soil bioengineering implies that this type of work is an engineering feat, it is not. It is more horticultural. It is about shepherding cuttings, rooted and transplanted stock, and seedlings through the process of harvesting, storage, nursery growing, planting, and survival. The goal is plant growth and bank stability. The application of engineering and engineering science should be reserved for calculations and design of structures, such as log revetments and cribwalls. Soil bioengineering is not a method that imposes manmade structures on the site at the expense of existing native plant materials. Intended to compliment nature, it is a collection of methods that speed up the recovery process by reestablishing native plant communities and stabilizing banks after structures (that is, log revetments and coconut logs) have decomposed. It is important to work in concert with nature.

The techniques shown in this chapter are currently in use by the Forest Service, other agencies, conservation organizations, and businesses to stabilize streambanks and lakeshores. Most of the techniques can be used on streambanks and lakeshores, and a few, as noted, are specific to lakeshores.

Careful planning and investigation by an interdisciplinary team and knowledge of the cause of the problem are imperative for success. Data should be collected and assessed prior to exploring the use of any particular stabilization technique. If one cannot "fix" what is causing and contributing to the problem, there should be no attempt to treat the unstable bank. The project will fail.

Many of the techniques can be used together. For example, a toe might be stabilized using a tree revetment, with live stakes and live posts installed on the bank behind it. In another instance, a coconut log or live fascine could be used at the toe, with a brush mattress installed above to cover the bank. Where available, rock could be used to stabilize the toe.

The Stabilization Techniques and Applications Chart that follows presents all of the techniques and uses in a matrix format. Read all the way down and across to assess the wide variety of choices. The techniques are presented in alphabetical order, with an explanation of each technique's primary use and strengths. Materials and directions for fabrication and installation follow. The presentation of the material and some of the text was borrowed with permission from the NRCS "Engineering Field Handbook," Chapter 16.

Ecological subregions shown in relation to national forests and grasslands are in appendix D. The NRCS "Field Engineering Handbook," Chapter 16, *Plants for Soil Bioengineering and Associated Systems* is in appendix D. References also include resources to research plant materials appropriate for certain areas.

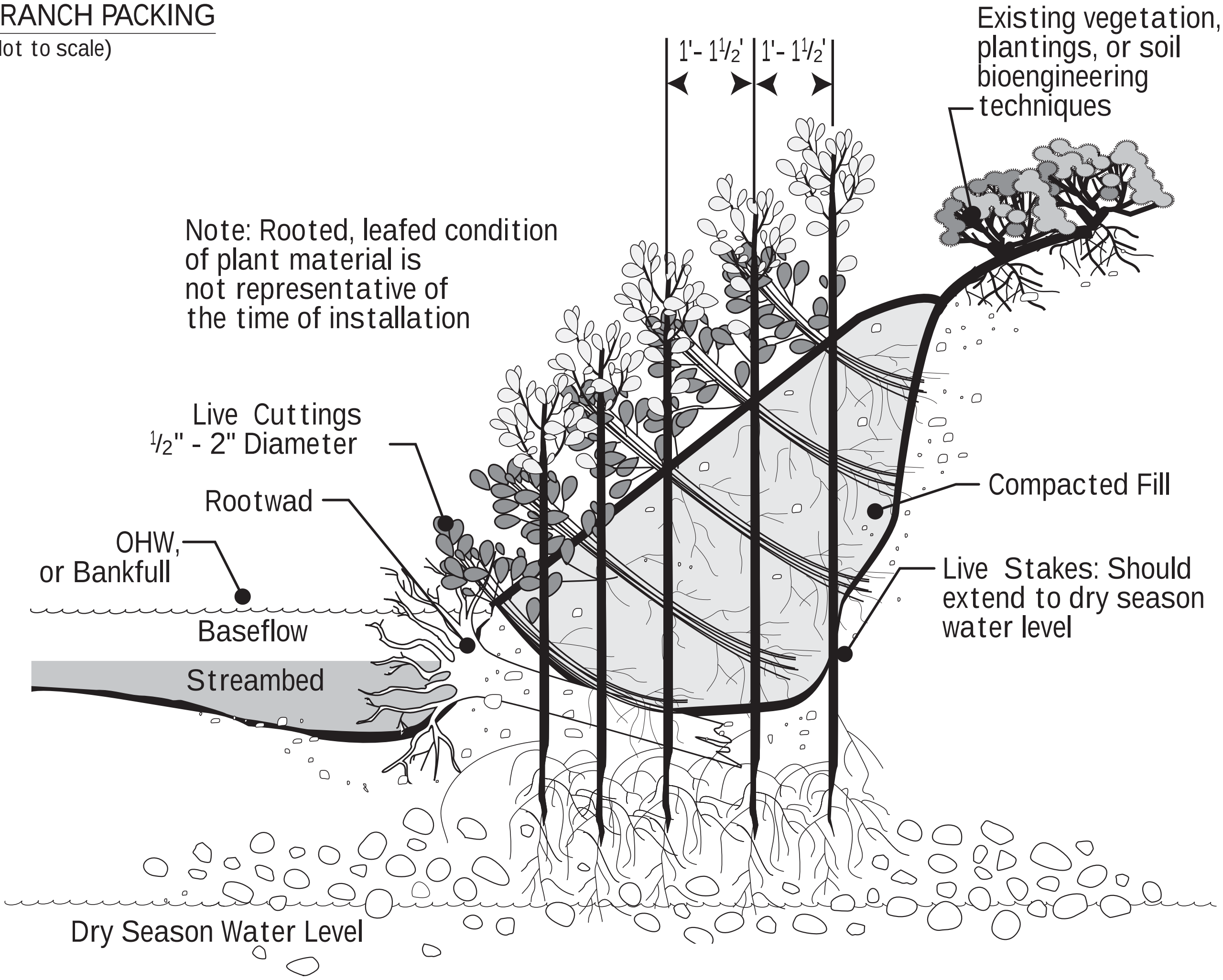
Stream Stabilization Techniques Chart

Applications \ Techniques	Branch Packing	Brush Layering	Brush Mattress	Coconut Fiber Log	Erosion Control Fabric	Hay Bale Breakwater	Joint Planting	Jute-mat Log	Live Cribwall	Live Fascine	Live Post	Live Siltation
Aides natural regeneration colonization	x	x	x	x	x	x	x	x	x	x	x	x
Appropriate above and below OHW/bankfull				x				x			x	
Branches add tensile strength to the bank	x	x									x	x
Deflects strong or high flows when placed close together											x	
Facilitates drainage on wet sites, dries excessively wet sites			x							x		
Filter barrier to prevent erosion and scouring of the bank	x	x	x	x	x	x		x		x		
Flexible, can be molded to existing contours				x	x			x				
Good on lakes where water levels fluctuate						x					x	
Helps establish sods and grasses					x	x						
Immediate protective cover for the bank			x		x				x			
Instant habitat improvement												
Little site disturbance	x			x	x	x	x	x		x		
Maintains a natural bank appearance	x	x	x	x	x			x		x	x	x
Manufactured in the field	x	x	x			x	x	x	x	x	x	x
Minimum site disturbance		x		x	x	x	x					
Maximum site disturbance during construction		x							x			
Rapid reestablishment of riparian vegetation	x	x	x				x	x	x	x	x	x
Protects banks from shallow slides	x			x			x	x	x	x	x	
Reduces a long beach wash into shorter segments										x		x
Reduces slope length	x	x		x				x		x	x	
Reduces surface erosion		x		x				x		x		
Reduces toe erosion			x	x		x		x	x	x		
Reduces wind and water velocities hitting bank						x					x	x
Retains moisture					x	x		x				
Roots stabilize banks	x	x	x				x		x	x	x	x
Survives fluctuating water levels											x	
Traps sediment	x	x	x	x	x	x	x	x	x	x		x
Useful where spaces is limited			x	x				x	x	x	x	x
Lakes and shorelines	x	x	x	x	x	x	x	x	x	x	x	x

Live Stake	Log Breakwater	Plant Mat	Plant Roll	Root Wad	Rooted Stock	Snow Fence	Terraced Crib	Tree and Log Revetment	Trench Pack	Vegetated Geogrid	Notes
x	x	x	x	x	x	x	x	x	x	x	
			x	x				x			
x										x	
				x							
			x	x							
x			x	x		x	x		x	x	
			x	x						x	
	x					x					
		x	x	x		x					
		x					x			x	
	x	x				x					
		x			x						
x	x	x	x		x	x		x	x		
x	x		x				x	x	x	x	
x	x	x	x		x	x					
				x						x	
x		x	x		x				x	x	
x							x				
			x	x	x				x		
x			x				x			x	
		x								x	
x		x	x	x	x		x	x	x	x	
	x			x		x			x		
		x	x								
x		x	x		x				x	x	
		x	x	x	x	x		x	x	x	
x			x	x	x			x	x	x	
x	x	x	x	x	x	x	x	x	x	x	

Techniques and Applications

BRANCH PACKING
(Not to scale)



Branch Packing

Branch packing is used to repair small, localized slumps and holes in streambanks. It consists of alternating layers of live branches and compacted backfill. Branches trap sediment that refills the localized slump or hole, while roots spread throughout the backfill and into the surrounding earth to form a unified mass.

Applications and Effectiveness

- Repairs slumps and holes in streambanks that range from 2 to 4 ft. in height and depth and 4 ft. in width effectively and inexpensively.
- Retards runoff and reduces surface erosion and scour as plant tops begin to grow.
- Establishes a vegetated streambank rapidly.
- Enhances conditions for colonization of native vegetation.
- Provides immediate soil reinforcement.
- Serves as tensile inclusions for reinforcement once live branches are installed.

Construction Guidelines

Live material

Live branches should be from 0.5 to 2 in. in diameter, and long enough to touch the undisturbed soil of the back of the slump and extend slightly from the rebuilt streambank.

Inert material

Wooden stakes should be 5 to 8 ft. long, depending on the depth of the particular slump or hole being repaired, and made from poles that are either 3 to 4 in. in diameter or 2- by 4-ft. lumber. Live posts can be substituted.

Installation

- Dig out the bottom at or below the stream or lake bed. Place a layer of rock and/or root wad in combination on the bottom. Cover with 2 to 4 in. of soil.
- Start at the lowest point of the slump or hole, drive the poles vertically 3 to 4 ft. into the ground. Set them 1 to 1.5 ft. apart.
- Place an initial layer of living branches 4- to 6-in. thick in the bottom of the hole between the vertical stakes and perpendicular to the slope face (see illustration). Place them in a crisscross configuration with the growing tips oriented toward the slope face. The basal ends of the branches should touch the undisturbed soil at the back of the hole.
- Follow each layer of branches with a layer of compacted soil to ensure soil contact with the branches. Wet the soil.
- Install subsequent layers of branches with the basal ends lower than the growing tips of the branches.
- Conform to the existing slope. At final installation branches should protrude only slightly.
- Key in this technique to the bank or end at an existing tree or rock outcrop.
- Control or divert water if the original stream bank damage was caused by water flowing over the bank. If this is not done, it is likely that erosion will occur on either or both sides of the new branch packing installation.

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Live branches installed in crisscross configuration.

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Each layer of branches is followed by a layer of compacted soil.

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A growing branch packing system.

BRUSH LAYERING: FILL METHOD

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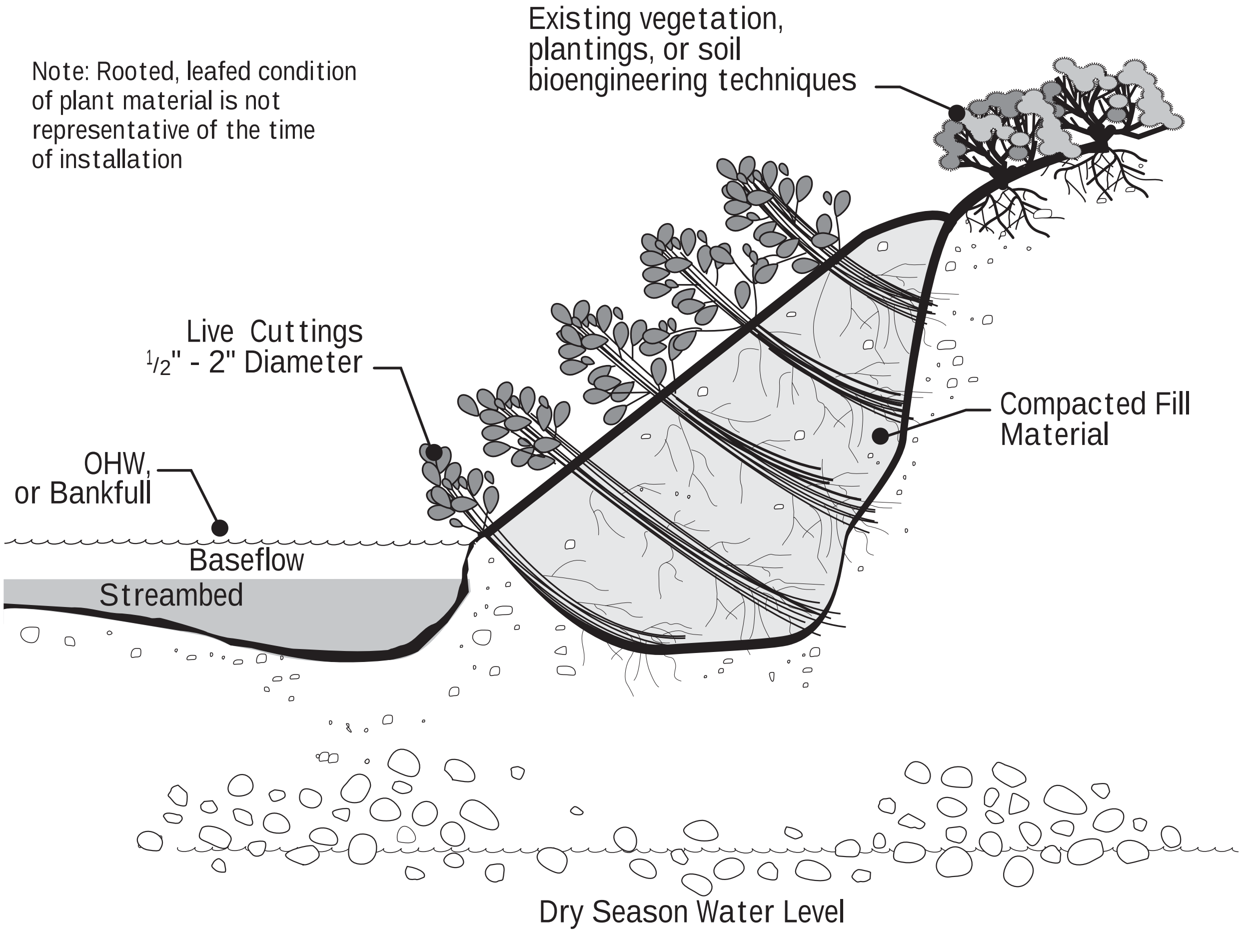


Brush Layering

Brush layering is the technique of laying cuttings on horizontal benches that follow the contour of either an existing or filled bank (slope). Branches serve as tensile inclusions or earth-reinforcing units to provide shallow stability of slopes.

The cuttings are oriented more or less perpendicular to the slope face. The portion of the brush that protrudes from the slope face assists in retarding runoff and reducing surface erosion. When used on a fill slope, this technique is similar to vegetated geogrids without the geotextile fabric.

Applications and Effectiveness

- Breaks up the slope length into a series of shorter slopes separated by rows of brush layer.
- Dries excessively wet sites.
- Works where the toe is not disturbed.
- Works on a slump and as a patch.
- Reinforces the soil with the unrooted branch stems.
- Reinforces the soil as roots develop, adding significant resistance to sliding or shear displacement.
- Traps debris on the slope.
- Aids infiltration on dry sites.
- Adjusts the site's microclimate, aiding seed germination and natural regeneration.
- May cause flow to wash soil from between layers.
- Does not work on outside bends.

Construction Guidelines

Brush layering can be installed on an existing or filled slope. On an existing slope, a bench is cut 2- to 3-ft. deep and angled slightly down into the slope. On a fill slope, brush layers are laid into the bank as it is filled.

Live material

- Branch cuttings should be 0.5 to 2 in. in diameter and long enough to reach the back of the bench and still protrude from the bank.
- Side branches should remain intact.
- Mix easy-to-root species such as willow, dogwood, and poplar.

Installation

- Begin above the ordinary high-water mark or bankfull level.
- Begin at the bottom of the slope and work up the bank.

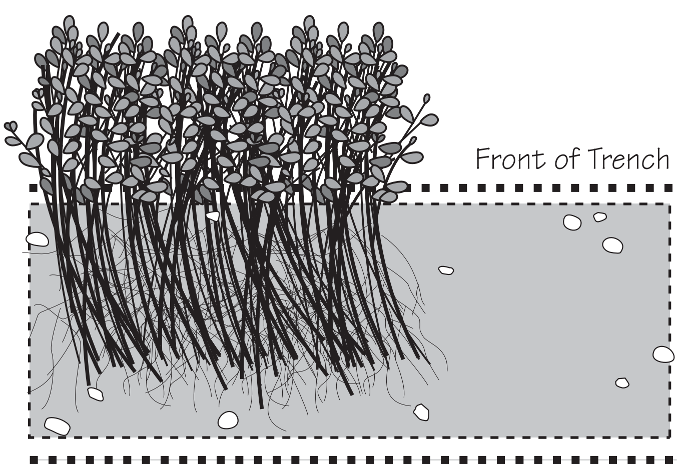
On a cut bank:

- Excavate 2- to 3-ft. wide horizontal benches on the contour.
- Slope the bench so that the outside edge is higher than the inside.
- Arrange live branch cuttings on the bench in a crisscross or overlapping configuration.
- Arrange 20 to 25 branches per yard.
- Extend 1/4 of the cutting's length beyond the slope face.
- Compact 2 to 4 in. of soil around the cuttings, then fill the remainder of the trench.
- Backfill each lower bench with the soil obtained from excavating the bench above.
- Place long straw or similar mulching material with seeding between rows on 3:1 or flatter slopes, while placing mulch or an erosion control fabric on slopes steeper than 3:1 (Gray 1996). (This is optional.)
- Control or divert water to prevent exposed soil from being washed away if the original streambank damage was caused by water flowing over the bank. Otherwise, erosion is likely to occur on the slope before vegetation can protect it.

On fill bank:

Build layers until the desired height is reached.
Install branches following instructions for the cut bank.

BRUSH LAYERING: PLAN VIEW
(Not to scale)



Brush layering with coconut logs.

Brush Layering Installation Guidelines

Brush layer rows should vary from 3 to 5 ft. apart, depending upon the location along the stream, the slope angle, and overall stability.

Slope	Slope distance between benches: Wet slopes (ft.)	Slope distance between benches: Dry slopes (ft.)	Maximum slope length (ft.)
2:1 to 2.5:1	3	3	15
2.5:1 to 3:1	3	4	15
3.5:1 to 4:1	4	5	20

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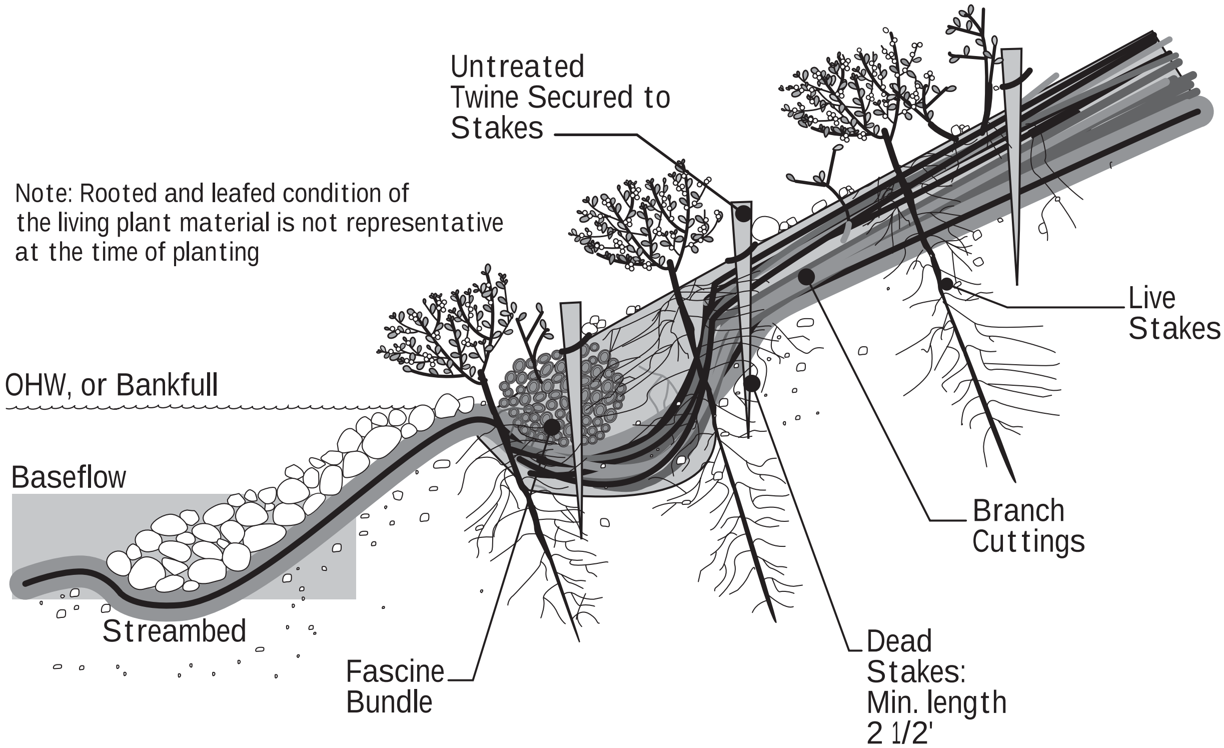
BRUSH MATTRESS

(Not to scale)



Brush Mattress

A brush mattress is a layer of dormant branches laid on and secured to a bank surface. It offers immediate bank coverage. This technique is also effective on lakeshores. Typically, it is combined with a toe stabilizing technique such as rock, root wads, live siltation, fascines, coconut fiber logs, or tree revetments. In this example, a fascine will be used with the mattress.

Applications and Effectiveness

- Works well on steep fast-flowing streams.
- Restores riparian vegetation and streamside habitat rapidly.
- Requires good soil to stem contact. It will not grow if all of its branches are exposed.
- Allows installation in combination with live stakes and rooted stock on the bank.
- Forms an immediate, protective cover over the streambank.
- Captures sediment during flood conditions.
- Enhances conditions for colonization of native vegetation.

Construction guidelines

Live materials

- Use branches that are 6- to 9-ft. long (the height of the bank to be covered), with 8 to 12 in. to be anchored at the toe, and approximately 1in. in diameter. Multiple species can be used.
- Use cuttings that are flexible enough to conform to variations in the slope face.

Inert materials

- Use jute twine for bundling the live fascines and tying down the branch mattress.
- Use dead stout stakes to secure the live fascines and brush mattress in place. Make dead stout stakes from 2.5- to 4-ft. long, untreated, 2-ft. by 4-in. sound lumber. Cut each length diagonally across the 4-in face to make two stakes. Use only new, sound lumber. Discard any stakes that shatter upon installation.

Installation

- Grade the unstable area of the streambank to its angle of repose, and decompact the slope, if necessary.
- Prepare live stakes and live fascines immediately before installation.
- Apply just above ordinary high-water mark or bankfull level.
- Excavate a trench on the contour large enough to accommodate a live fascine and the basal ends of the mattress cuttings. (Typically, a shovel deep and a shovel wide.)
- Ensure that basal (cut) ends are in soil that will retain moisture throughout the growing season.
- Install an even mix of live and dead stout stakes at a 1-ft. depth over the face of the slope using 2-ft. square spacing. Live stakes need to be installed deeply enough to reach the dry season water table (see Live Stakes).
- Place branches slightly crisscrossed in a layer 4- to 6-in. thick on the slope with basal ends located in the trench.
- Stretch twine diagonally from one dead stout stake to another by tightly wrapping twine around each stake no closer than 6 in from its top.

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Brush mattress installation.

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An installed brush mattress system.

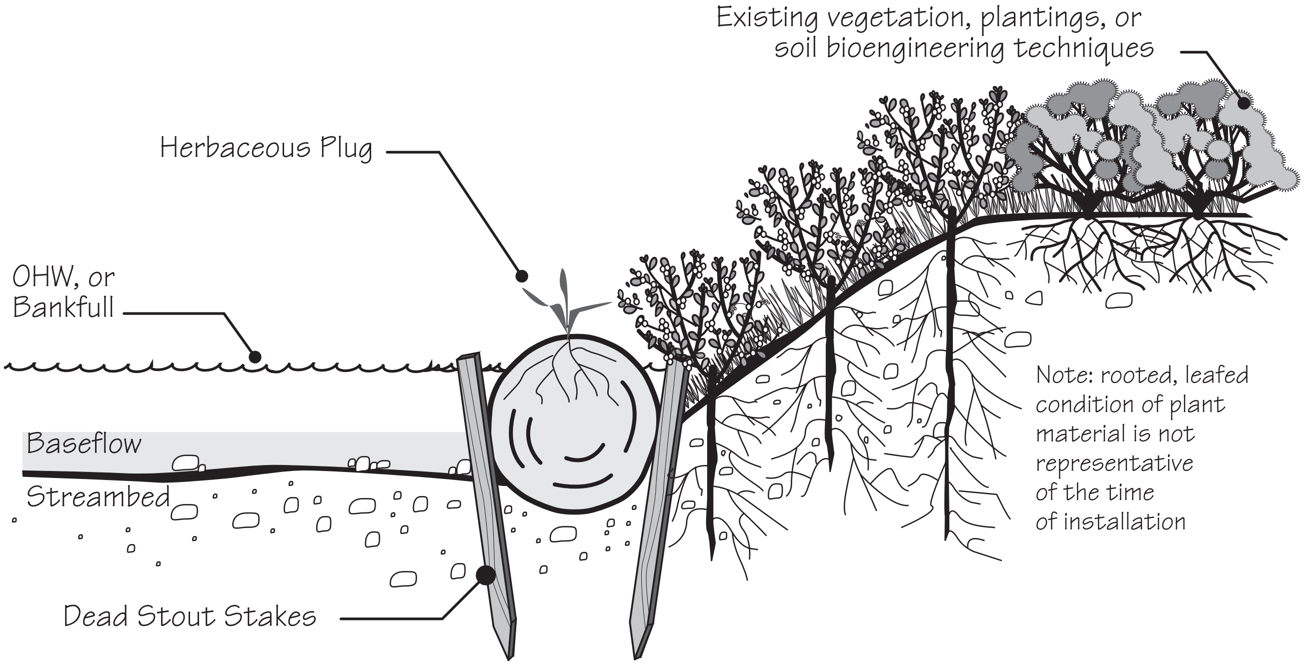
- Tamp and drive the live and dead stout stakes into the ground until branches are tightly secured to the slope. Use a dead blow hammer on the live stakes.
- Place a live fascine in the trench over the basal ends of the mattress branches.
- Drive dead stout stakes directly into the live fascine every 2 ft. along its length.
- Fill voids between branches with a layer of soil to promote rooting. Wet the surface to wash soil down in between the branches. Leave the top surface of the brush mattress and live fascine slightly exposed.
- Add a live fascine just above the mattress to help break up sheet runoff that may undermine the bank. (This is optional.)

USDA Forest Service

Brush mattress with live siltation at Kenai River, AK.

COCONUT FIBER ROLL

(Not to scale)



Coconut Fiber Roll

A coconut fiber roll (Coir™ log) is used to protect a bank's toe and to define an edge. It is a cylindrical structure composed of coconut husk fibers bound together with twine woven from coconut fiber. This product is most commonly manufactured in 12 in. diameters and lengths of 20 ft. However, purchases of prefabricated rolls can be expensive. Use stakes or duckbills to anchor it in place at the toe of the slope, generally at the ordinary high-water mark or bankfull level.

Applications and Effectiveness

- Protects slopes from shallow slides or undermining.
- Molds to existing curvature of the streambank.
- Traps sediment in and behind the roll.
- Produces a well-reinforced toe without much site disturbance.
- Lasts an estimated 6 to 10 years, according to manufacturer's claims.

Construction Guidelines

Inert materials

- Coconut logs (Coir™).
- Untreated twine.
- Cable and duckbill anchors.
- 5/16 in cable and cable clips.
- Dead stout stakes. Make dead stout stakes from 2.5- to 4-ft. long, sound, untreated 2- by 4-in. lumber. Cut each length diagonally across the 4-in. face to make two stakes. Use only sound lumber. Discard any stakes that shatter upon installation.

Installation

- Excavate a shallow trench at the toe of the slope to a depth slightly below channel grade.
- Place the coconut fiber roll in the trench.
- Drive dead stout stakes between the binding twine and coconut fiber. Stakes should be placed on both sides of the roll on 2- to 4-ft. centers depending upon anticipated velocities. Tops of stakes should not extend above the top of the fiber roll.
- Notch the outside of stakes on either side of the fiber roll and secure with 16-gauge wire in areas that experience ice or wave action. Cable with duckbill anchors may also be used in these situations.
- Backfill soil behind the fiber roll.
- Install rooted herbaceous plants in the coconut fiber if conditions permit (plants will not easily wash away).
- Install additional bioengineering techniques upslope of the fiber roll.

These three photographs show coconut fiber log placed in three different sections of Chicken Creek, La Grande RD, Wallowa-Whitman NF.


USDA Forest Service

Fence keeps cattle out. Coconut fiber log helps prevent further erosion at edge of creek.


USDA Forest Service

Coconut fiber log at bend in creek, protecting the toe of the bank. This log was placed into and across the creek to help create a pool for fish habitat.


USDA Forest Service

Coconut fiber log arresting bank toe erosion and becoming part of the bank.

COCONUT FIBER ROLL: LAKESHORE

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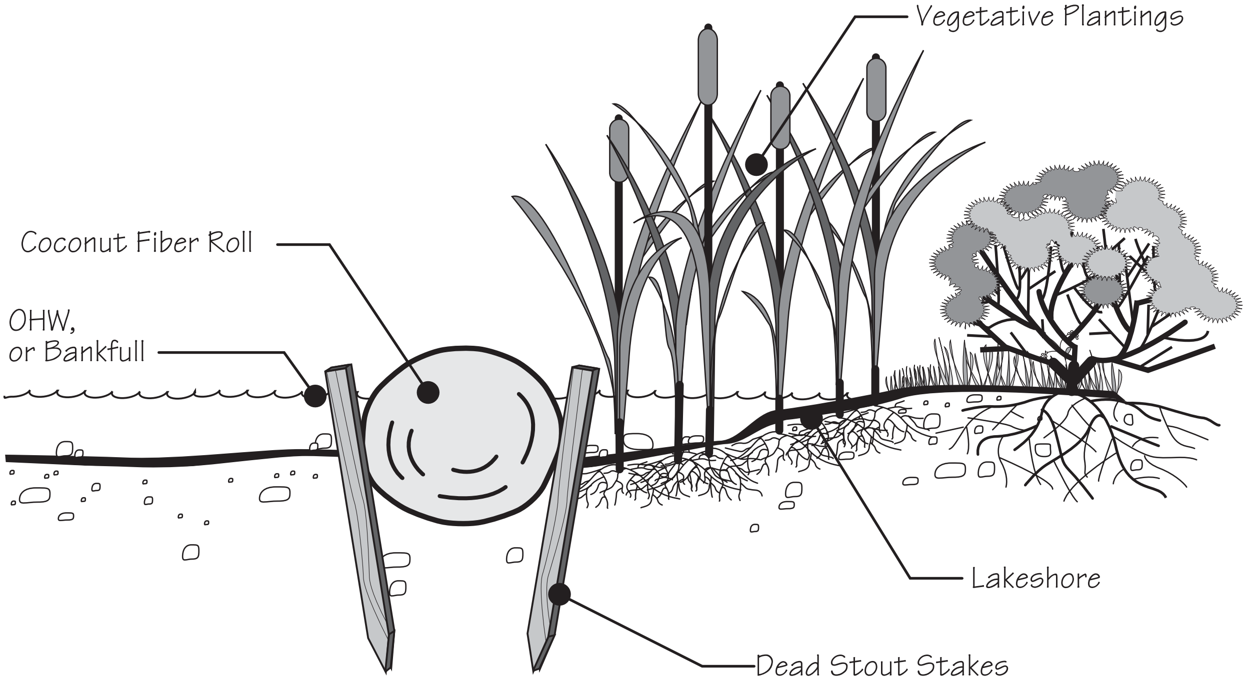


Lakeshore Construction Guidelines

A coconut fiber roll can function as a breakwater along a calm shallow lakeshore. In addition to reducing wave energy, this product can help contain substrate and encourage development of wetland communities.

Applications and Effectiveness

- Protects the shoreline and encourages new vegetation. Effective in lake areas where the water level fluctuates.
- Molds to the curvature of the shoreline.
- Lasts an estimated 6 to 10 years, according to manufacturer's claims.

Installation

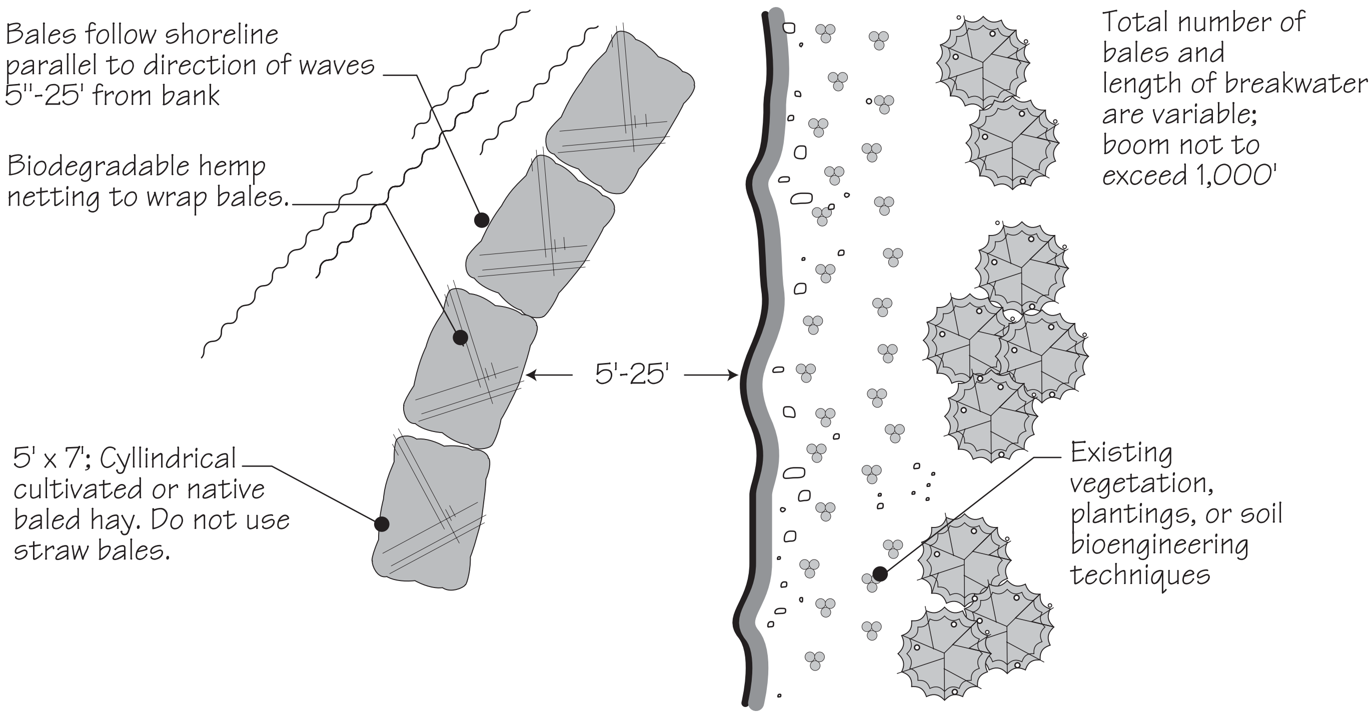
- Install the fiber roll offshore at a distance where the top of the fiber roll is exposed at low tide. In nontidal areas, the fiber roll should be placed where it will not be overtopped by wave action.
- Drive dead stout stakes between the binding twine and the coconut fiber. Stakes should be placed on 4-ft. centers and should not extend above the fiber roll.
- Secure with steel cable and duckbill anchors in areas that experience ice or wave action.
- Install rooted cuttings between the coconut fiber roll and the shoreline, if desired.
- Backfill soil behind the fiber roll if placed against the bank.
- Install rooted herbaceous plants in the coconut fiber if the roll is moist.
- Install appropriate bioengineering techniques upslope from the fiber roll.

USDA NRCS Engineering Field Handbook, Chapter 16

Coconut fiber roll forming a small breakwater.

HAY BALE BREAKWATER

(Not to scale)



Hay Bale Breakwater

Cylindrical hay bales, lined up parallel to the shore, are used in reservoirs and lakes to break wave action and to promote vegetative recovery of the shoreline. These cultivated or native hay bales weigh 1,800 lb when dry and approximately 2,500 lb when wet. They are 5-ft. in diameter and 7-ft. long. Do not use straw.

Applications and Effectiveness

Applications

- Used where the fetch is greater than 2 mi. long.
- Used parallel to shorelines to break up fetch-caused waves. Up to 1,000 ft. of shoreline can be protected with one long row of hay bales.
- Used in combination with bioengineering techniques on shore.

Effectiveness

- Breaks waves before they reach the shoreline.
- Breaks the fetch. Do not use where ice scour is a known problem.
- Lasts at least 5 years.
- Forms a natural seedbed as sediment settles between the breakwater and the shore.
- Protects archeological sites inexpensively because of minimal site disturbance.
- Provides an inexpensive method if hay is locally grown.

Construction Guidelines

Inert material

- Use cylindrical cultivated or native hay bales, 5-ft. in diameter and 7-ft. long. Do not use straw bales.
- Wrap bales with hemp netting.
- Lift the bales with a crane or use an excavator to push them into the water.

Installation

- Wrap the bales in hemp netting. This extends their useful lives.
- Lift bales into place with a crane or excavator. Be sure conditions are safe for use of specific machinery.
- Deliver by using a barge and place with a winch if desired.
- Place parallel to the shore.
- Place in water at a depth where half the bale, 2.5 ft., is below the waterline, between 5- to 25-ft. from shore.
- Place bales end to end so they touch.
- Leave the ends of the breakwater open so water can wash in and deposit sediment and silt. (See detail.)
- Decompact the soil where heavy equipment was used.
- Use two parallel rows in rough areas. The one closest to the shore becomes silted in and is the new shoreline. The other continues to act as a breakwater.
- Install soil bioengineering techniques on the shore and in the water.

U.S. Army Corps of Engineers

Placing hay bales on a barge on Lake Sharpe, SD, an Army Corps of Engineers-operated reservoir and recreation facility.

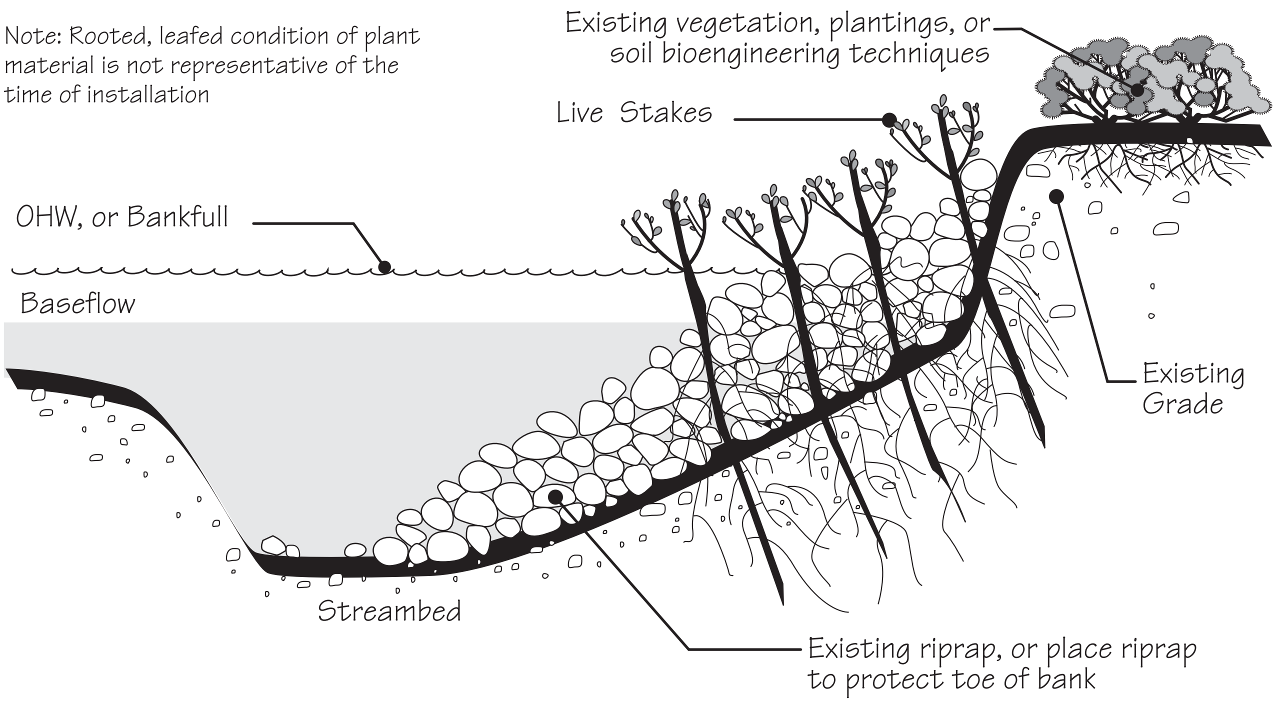
U.S. Army Corps of Engineers

Bales delivered by barge in 2.5 ft of water.

U.S. Army Corps of Engineers

Bales in place to break waves protecting the shoreline.

JOINT PLANTING
(Not to scale)



Joint Planting

Joint planting disguises riprap and may provide habitat. The plant roots help hold soil together under the rocks. It involves tamping live stakes into joints or open spaces between existing rocks or when rock is being placed on the slope face.

Applications and Effectiveness

- Useful where rock riprap is required or already in place.
- Successful 30 to 50 percent of the time. First year irrigation improves survival rates.
- Improves drainage by removing soil moisture.
- Creates, over time, a living root mat in the soil base upon which the rock has been placed. These root systems bind or reinforce the soil and prevent washout of fines between and below the rock.
- Provides immediate protection and is effective in reducing erosion on actively eroding banks.
- Dissipates some of the energy during a flood stage.

Construction Guidelines

Live material

The live stakes must have side branches removed and bark intact. They should be 1.5 in. or larger in diameter and long enough to extend well into the soil, reaching into the dry season water level.

Installation

- Tamp live stakes into the openings between the rocks during or after placement of riprap. The basal (cut) ends of the cuttings must extend into the backfill or undisturbed soil behind the riprap.
- Prepare a hole through the riprap using a steel rod or waterjet stinger (Hoag, et al. 2001).
- Allow growing tips to protrude slightly above the rock.
- Place the stakes in a random configuration.

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An installed joint planting system.

USDA Forest Service

Three-year-old joint planting in Vermont. Can you spot the person on the shore?

Jute-mat Log

Make your own coconut fiber log. This log can reinforce a streambank without much site disturbance. Each log is 1 to 2 ft. in diameter and made out of coconut fiber mat or jute, straw, and lengths of branch cuttings. Logs are placed along the banks to provide armoring. They can vary in length from a few feet up to 100 ft.

Applications and Effectiveness

Applications

- Make in the field to meet on-site needs.
- Apply at ordinary high-water mark or bankfull level.
- Stack to cover more bank; on smaller streams a single strand may suffice.
- String together along the banks, overlapping the logs and molding them to the existing curvature of the streambank.
- Plant with rooted stock, sedges, and so on between the log and the bank.

Effectiveness

- Armors bank toe effectively while plants take root.
- Protects slopes from shallow slides or undermining while trapping sediment that encourages plant growth within and behind the log.
- Retains moisture in log, which aids vegetative growth.
- Provides an inexpensive method.

Construction Guidelines

Live materials

- Collect straight branch cuttings, 0.5 to 1 in. in diameter and 4- to 7-ft. long, from deciduous species, such as willow, dogwood, and cottonwood, which easily root from cuttings.
- Use live stakes.

USDA Forest Service

Constructing log using jute mat and hay with cuttings. Republic RD, Colville NF.

USDA Forest Service

Constructing log using jute mat and straw with willow and red osier dogwood cuttings. Republic RD, Colville NF.

USDA Forest Service

Note that the far end of this jute mat log is secured by rock, and the near end by a log. North Fork of O'Brien Creek, Republic RD, Colville NF.

Inert materials

- Straw.
- Untreated twine to tie the logs as they are made.
- Cable and duckbill anchors.
- 5/16 in. cable and cable clips.
- Coconut/jute-mat to make the log is sold by the square foot in rolls 8-ft. wide by up to 1,000-ft. long. The 3/8- to 1/2-in. mesh has been used successfully (that is the opening between strands).
- Use dead stout stakes to secure the log. Make dead stout logs from 2.5- to 4-ft. long, sound, untreated, 2- by 4-in. lumber. Cut each length diagonally across the 4-in. face to make two stakes. Use only new, sound lumber. Discard any stakes that shatter upon installation.

Installation

- Cut the mat to the length required for each segment plus 2 ft. It will be 8 ft. wide.
- Lay the mat flat and cover with a layer of straw, leaving 1 ft. of mat at each end (along the 8-ft. edge) uncovered.
- Place the cuttings lengthwise along one long edge, three to four stems together.
- Fold the empty edges inward, along the 8-ft. border, over onto the straw.
- Roll up the mat starting at the edge opposite the cuttings.
- Tie the rolls in several places to secure their shape. Use loose coconut strands from the matting as ties or twine.
- Place the log in position on the streambank at average water height with the cuttings against the bank.
- Start at the downstream end of the section, place the first log and overlap the next one by 18 in. Overlap the next log so that it is on the stream side of the original log. One long log section (70- to 100-ft.) is stronger than several shorter logs.
- Secure the log with cable spaced every 2 to 2.5 ft. Wrap the cable around the log and secure it by driving a duckbill into the bank. Be sure the anchor is in firm soil.
- Drive live stakes through the log to help anchor it and to add more plant material.
- Use dead stout stakes, if desired, to anchor the log in placid settings.
- Key in upstream and downstream ends.

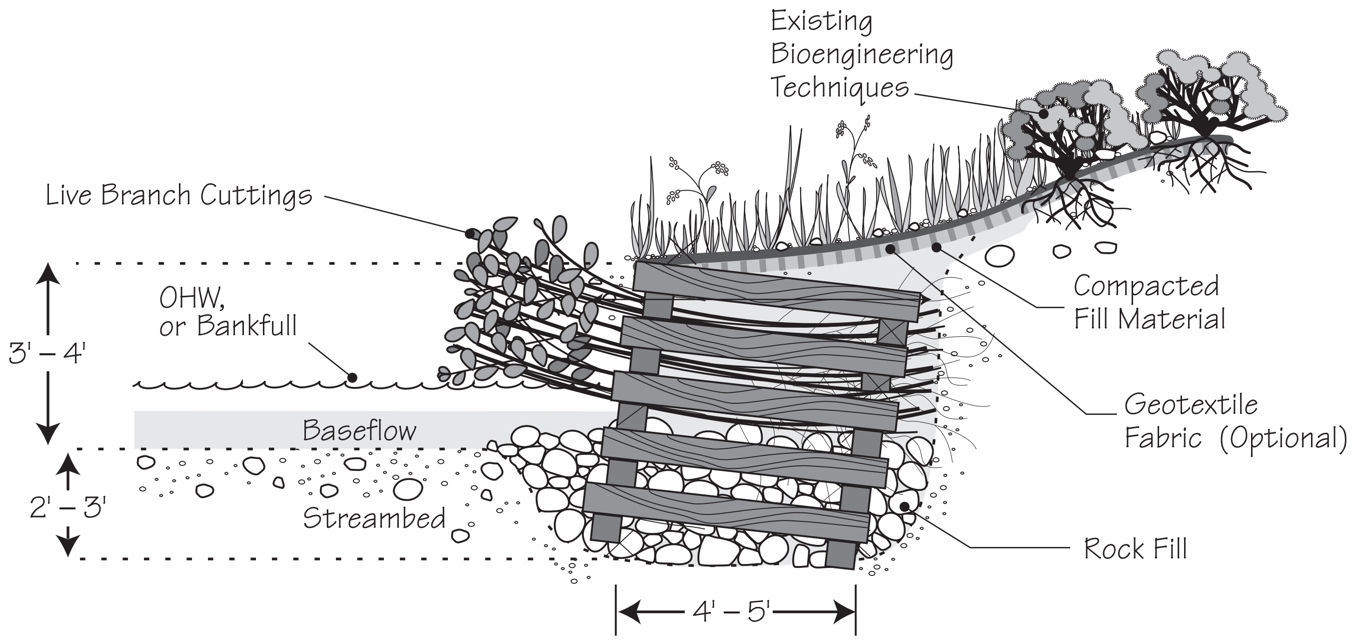
USDA Forest Service

Logs in place. North Fork of O'Brien Creek, Republic RD, Colville NF.

USDA Forest Service

Logs stacked to form toe and lower bank. North Fork of O'Brien Creek, Republic RD, Colville NF.

LIVE CRIBWALL
(Not to scale)



Live Cribwall

A live cribwall is used to rebuild a bank in a nearly vertical setting. It consists of a boxlike interlocking arrangement of untreated log or timber members. The structure is filled with rock at the bottom and soil beginning at the ordinary high-water mark or bankfull level. Layers of live branch cuttings root inside the crib structure and extend into the slope. Once the live cuttings root and become established, vegetation gradually takes over the structural functions of the wood members.

Applications and Effectiveness

Applications

- Appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and to reduce its steepness.
- Appropriate above and below the water level where stable streambeds exist.
- Useful where space is limited and requires a more vertical structure.
- Useful in maintaining a natural streambank appearance.
- Useful for effective bank erosion control on fast flowing streams.
- Tilt back.

Effectiveness

- Complex and expensive.
- Effective on outside bends of streams where strong currents are present.
- Effective in locations where an eroding bank may eventually form a split channel.
- Excellent habitat provider.
- Provides immediate protection from erosion and long-term stability.

Construction Guidelines

Live materials

Live branch cuttings should be 0.5 to 2.5 in. in diameter and long enough to reach the back of the wooden crib structure.

Inert materials

- Logs or untreated timbers should range from 4 to 6 in. in diameter. Lengths will vary with the size of the crib structure.
- Large nails or reinforcement bars are required to secure the logs or timbers together.
- Fill rock should be 6 in. in diameter.

Installation

- Excavate, starting at the base of the streambank to be treated, 2- to 3-ft. below the existing streambed until a stable foundation 5- to 6-ft. wide is reached.
- Excavate the back of the stable foundation closest to the slope 6- to 12-in. lower than the front to add stability to the structure.
- Place the first course of logs or timbers at the front and back of the excavated foundation, approximately 4- to 5-ft. 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 in. Each course of the live cribwall is placed in the same manner and secured to the preceding course with nails or reinforcement bars.
- Place rock fill in the openings in the bottom of the crib structure until it reaches the approximate existing elevation of the streambed. In some cases, it is necessary to place rocks in front of the structure for added toe support, especially in outside stream meanders. An alternative to a rock toe may be a log revetment.
- Place the first layer of cuttings on top of the rock material at the base flow water level. Change the rock fill to soil fill at this point. Ensure that the basal ends of some of the cuttings contact undisturbed soil at the back of the cribwall.
- Place live branch cuttings at each course to the top of the cribwall structure with buds oriented toward the stream. Place the basal ends of the live branch cuttings so that they reach undisturbed soil at the back of the cribwall with growing tips protruding slightly beyond the front. Cover the cuttings with backfill (soil) and compact. Wet each soil layer.
- Use an engineering analysis to determine appropriate dimensions for the system. The live cribwall structure, including the section below the streambed, should not exceed 7 ft. in ht.
- Do not exceed 20 ft. in length for any single constructed unit.

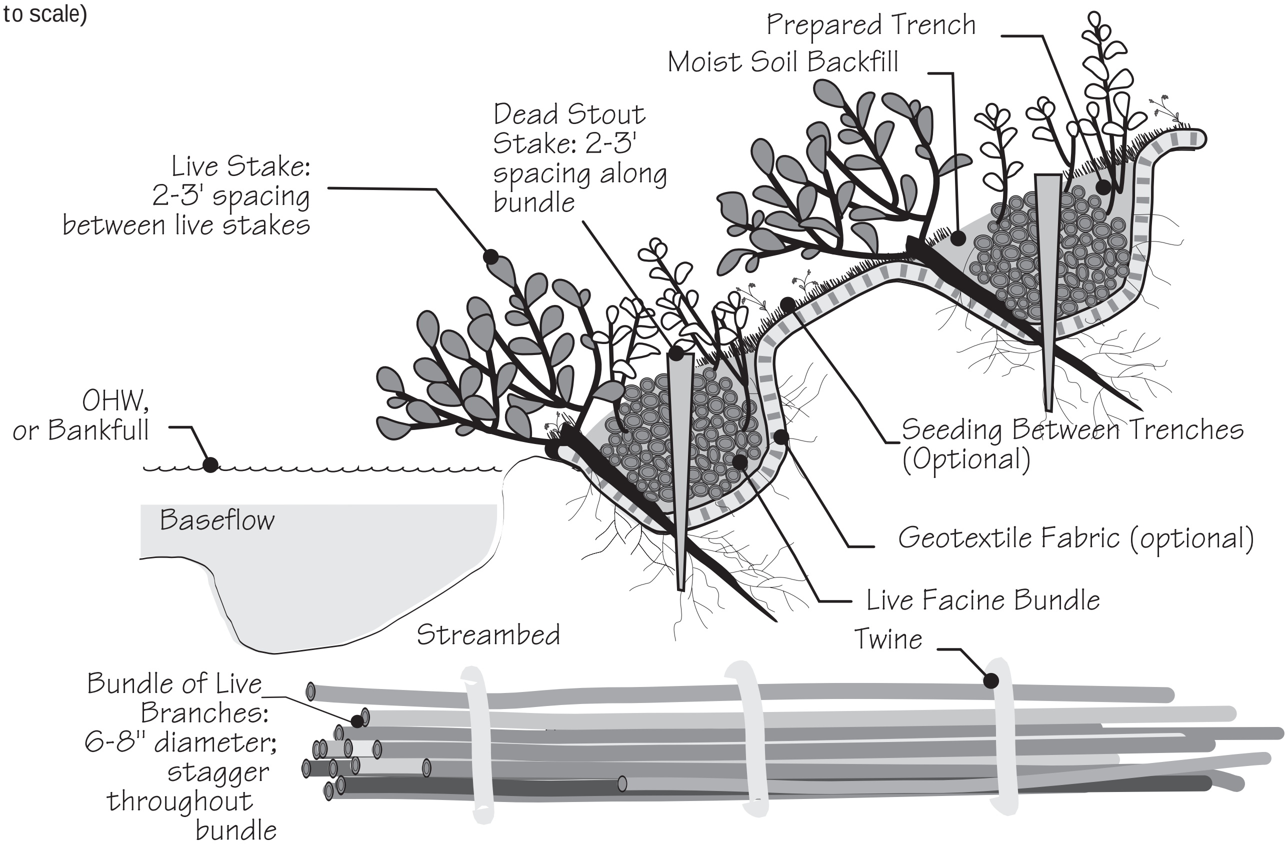
USDA; NRCS Engineering Field Handbook, Chapter 16

Live cribwall installation. Note live cuttings at bottom of photo and the next layer of frame on top of them.

USDA; NRCS Engineering Field Handbook, Chapter 16

Established live cribwall; light-colored foliage at toe of bank.

LIVE FASCINE
(Not to scale)



Live Fascine/Wattle

A live fascine helps control surface erosion and roots from the sprouted fascine help stabilize the bank. A fascine is a long bundle of branch cuttings bound together in a cylindrical structure. It should be placed in a shallow contour trench on a dry slope and at an angle on a wet slope to reduce erosion and shallow sliding.

Applications and Effectiveness

Applications

- Apply above ordinary high-water mark or bankfull level except on very small drainage area sites.
- Use between the high- and low-water marks on the bank in arid climates.

Effectiveness

- Traps and holds soil on a streambank, reducing the slope length to a series of shorter slopes by creating small dam-like structures.
- Protects slopes from shallow slides (1- to 2-ft. depth).
- Requires soil moisture or regular precipitation during the growing season to grow.
- Causes minimal site disturbance when properly installed.
- Offers immediate protection from surface erosion.
- Enhances conditions for colonization of native vegetation by creating surface stabilization and a microclimate conducive to plant growth.
- Serves to facilitate drainage when installed at an angle.

USDA Forest Service

Reddish-brown willow stems in foreground are from fascines. Mad River, VT.

Construction Guidelines

Live materials

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

Live material sizes and preparation

- Tie cuttings, 0.5 to 1.5 in. in diameter, together to form live fascine bundles that vary in length from 5 to 10 ft. or longer, depending on site conditions and handling limitations.
- Stagger the cuttings in the bundles so that tops are evenly distributed throughout the length of the uniformly sized live fascine. The completed bundles should be 6- to 8-in. in diameter.
- Ensure that live stakes are at least 2.5-ft. long.

Live Fascine Spacing

	Soils		
Slope steepness	**Fill (ft.)**	**Erosive (ft.)**	**Non-erosive (ft.)**
3:1 or flatter	3 – 5	5 – 7	3 – 5*[1]
Steeper than 3:1 (up to 1:1)	3*[1]	3 – 5	*[2]

*[1] Not recommended alone.
*[2] Not a recommended system.

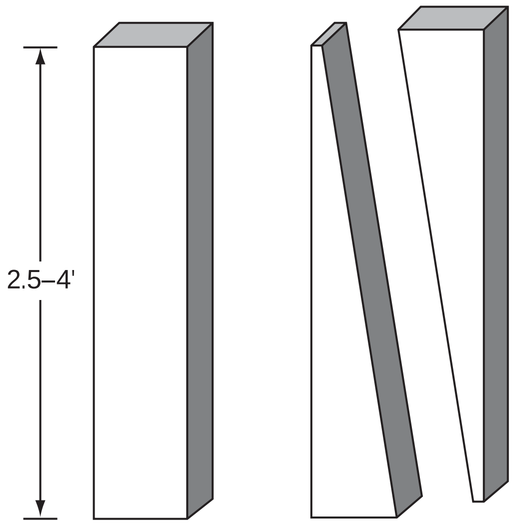
Inert materials

- Use untreated twine for bundling fascines.
- Use dead stout stakes. Make dead stout stakes from 2.5- to 4-ft. long, sound, untreated, 2- by 4-in. lumber. Cut each length diagonally across the 4-in. face to make two stakes. Use only sound lumber. Discard any stakes that shatter upon installation.

Installation

- Prepare the live fascine bundle and live stakes immediately before installation. If possible, have a fascine-tying team, a digging team, and a fascine-laying team. Team members can do double duty; everyone must know his role ahead of time.
- Jam the ends together, for longer fascines, before placing them into the trench.
- Begin at the base of the slope, marking contours before digging.
- Excavate a trench on the contour approximately 10-in. wide and 10-in. deep.
- Excavate trenches up the slope at 3- to 5-ft. intervals. Where possible, place one or two rows over the top of the slope to break up sheet runoff.

DEAD STOUT STAKE
(Not to scale)

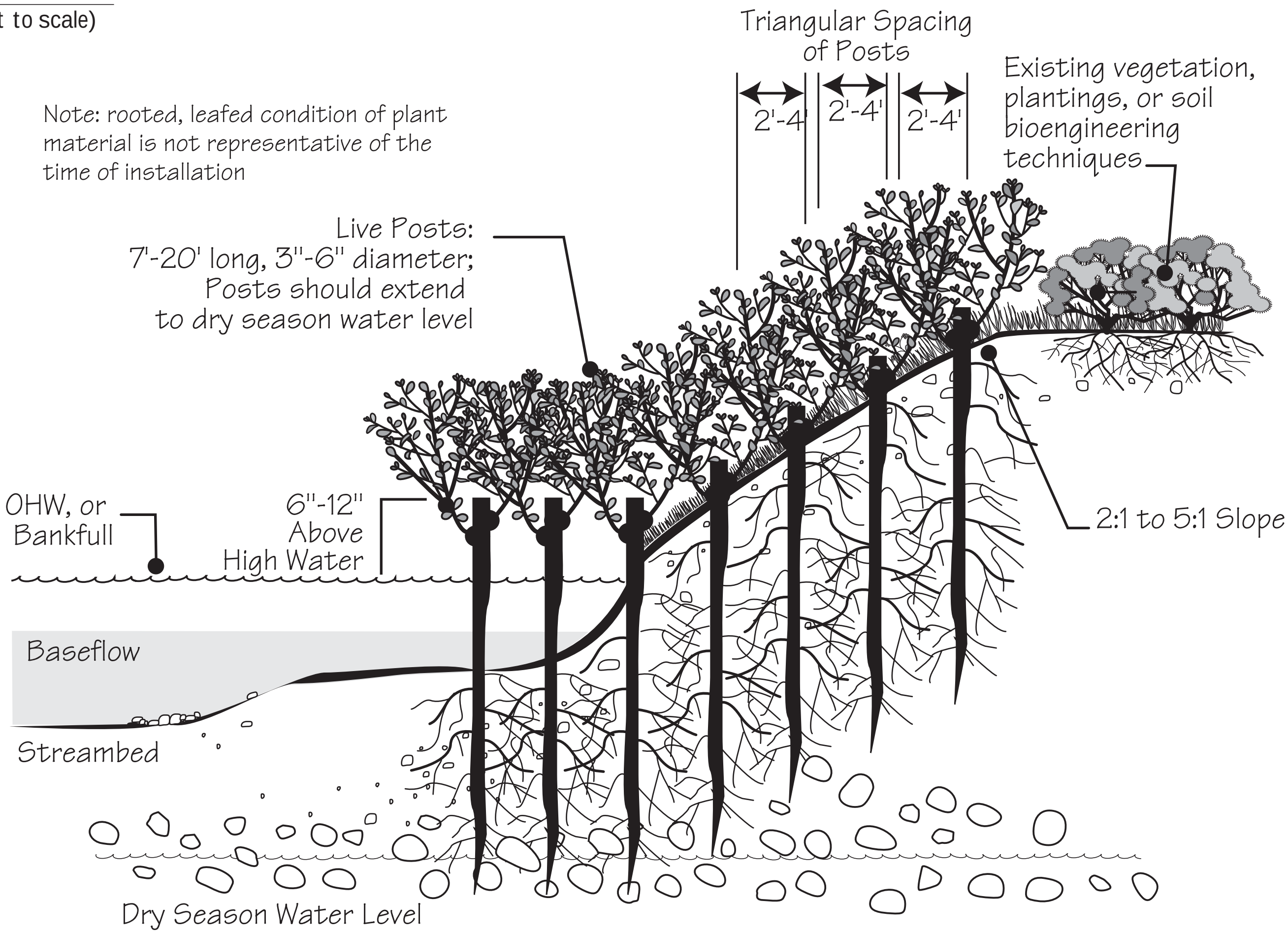


- Place the live fascine into the trench.
- Dig the next trench as the fascine is placed in the one below and use the excavated soil to partially cover the fascine.
- Place moist soil along the sides and top of the fascines. The top of the fascines should be slightly visible when the installation is completed.
- Place long straw and annual grasses or install erosion control fabric between the rows if the soil is loose. Secure the fabric.
- Drive dead stout stakes directly through the live fascine. Extra stakes should be used at fascine overlaps. Leave the top of the dead stout stakes flush with the installed fascine.
- Install live stakes on the down slope side of the fascine. Tamp the live stakes below and against the fascine between the previously installed dead stout stakes, leaving 3 in. to protrude above the top of the ground.

A fascine that fails to sprout will slow the raveling of a bank and catch sediment. This sediment rebuilds the bank and forms a natural seedbed. Sometimes a “sacrificial” fascine is installed in the water, knowing that it won’t grow, but that it will lessen erosion and promote bank stability.

LIVE POSTS

(Not to scale)



Live Post

Live posts form a permeable revetment. They reduce stream velocities and cause sediment deposition in the treated area. The roots help to stabilize a bank. Dormant posts are made of large cuttings installed in streambanks in square or triangular patterns. Unsuccessfully rooted posts at spacings of about 4 ft. can also provide some benefits by deflecting higher stream flows and trapping sediment.

Applications and Effectiveness

Applications

- Well-suited to smaller nongravel streams. If high flows and ice are a problem, they can be cut low to the ground.
- Used in combination with other soil bioengineering techniques.
- Installed by a variety of methods including water jetting or mechanized stringers (Hoag, et al. 2001) to form planting holes or by driving the posts directly with machine-mounted rams. Place a metal cap atop the post when it is necessary to pound it into the ground.

Effectiveness

- Quickly reestablishes riparian vegetation.
- Enhances conditions for colonization of native species.
- Repairs itself. For example, posts damaged by beavers often develop multiple stems.

Construction Guidelines

Live materials

Live posts 7- to 20-ft. long and 3 to 5 in. in diameter. Avoid over-harvesting from one plant or area to maintain healthy, attractive stock. Select a plant species appropriate to the site conditions that will root readily. Willows and poplars have demonstrated high success rates.

Installation

- Taper the basal end of the post for easier insertion into the ground.
- Trim off all side branches and the apical bud (top).
- Dip the apical end into a mixture of equal parts water and latex white paint. This will mark which end goes up and will help retain moisture in the post after installation.
- Install posts into the eroding bank at or just above the normal waterline. Make sure posts are installed with buds pointing up.
- Insert one-half to two-thirds of the length of the post below the ground line. Several inches of the post should be set into the dry season water level.
- Extend posts 6 to 12 in above estimated water height if the area is prone to seasonal standing water (30 days or longer).
- Avoid excessive damage to the bark of the posts.
- Place two or more rows of posts spaced 2- to 4-ft. apart using square or triangular spacing.
- Add compost to each hole before the post is installed.
- Apply on slopes of 1:1 or less.
- Supplement the installation with other bioengineering techniques.

USDA Forest Service

Second-year growth on silver cottonwood live post visible in foreground and background. Lewiston, ID.

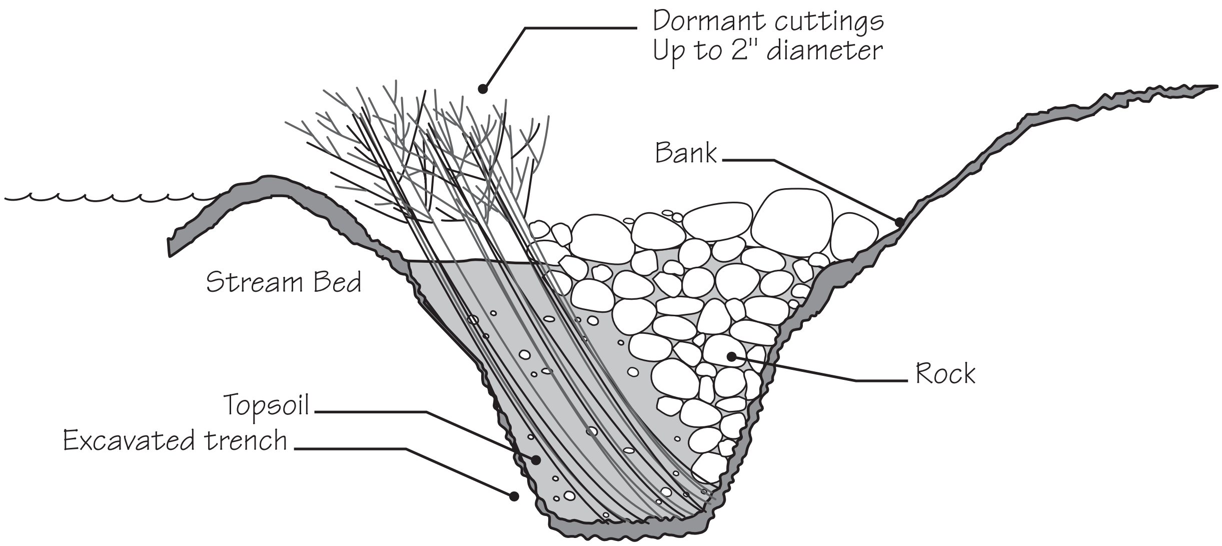
USDA Forest Service

Live post.

USDA Forest Service

Live posts ring this outside bend on the Mad River, VT.

LIVE SILTATION
(Not to scale)



Live Siltation

Live siltation is used to armor and revegetate the toe of a bank. It can be used on streams and lakeshores to combat wind and wave erosion. Plant live siltation perpendicular to the wind and waves.

Dead and live branch cuttings are used to provide immediate and long-term stability, cover, and fish habitat. Live siltation is similar to trench packing with the addition of rock and requires a v-shaped trench. Cuttings are laid against the streamside edge of the trench. A layer of soil is packed around the cuttings. A layer of gravel, small rock, and soil fill the trench to hold the cuttings in place.

Applications and Effectiveness

- Stabilizes the toe and provides good fish habitat after applying at the ordinary high-water mark or bankfull level.
- Follows the contour of the bank.
- Traps sediment first in bare branches, then in leafed out branches.
- Provides a good barrier for rooted stock and other techniques used on the bank.
- Reduces velocities of wind and water.
- Reinforces the soil as deep, strong roots develop and adds resistance to sliding and shear displacement.
- Enhances conditions for colonization of native vegetation by creating surface stabilization and a microclimate conducive to plant growth.
- Install in multiple rows if desired.

Construction Guidelines

Live materials

- Collect live deciduous material known for its good rooting structure, 1 to 2 in. in diameter and a minimum of 3-ft. long, with side branches attached.
- Use species that can tolerate having their feet wet, such as willows.

Installation

- Dig (by hand or machine) a v-shaped trench approximately 2-ft. deep, of any length. Be sure the ends of the trench are tied into something solid or keyed into the bank.
- Layer deciduous cuttings, a minimum of 40 branches per yd, in the trench leaning towards the stream.
- Place branches, bud ends up, in the trench.
- Expose one-third the length of each branch.
- Tamp native soil around cuttings so that they are in contact with the soil. This should not fill the entire trench.
- Backfill the trench with gravel and small rock. Safeguard against washout by topping the surface with larger rocks, coconut log, or a fascine.
- Wet the surface to wash soil down into the trench. Add more soil if necessary.
- Install a sacrificial row below the ordinary high-water mark or bankfull level, if necessary.

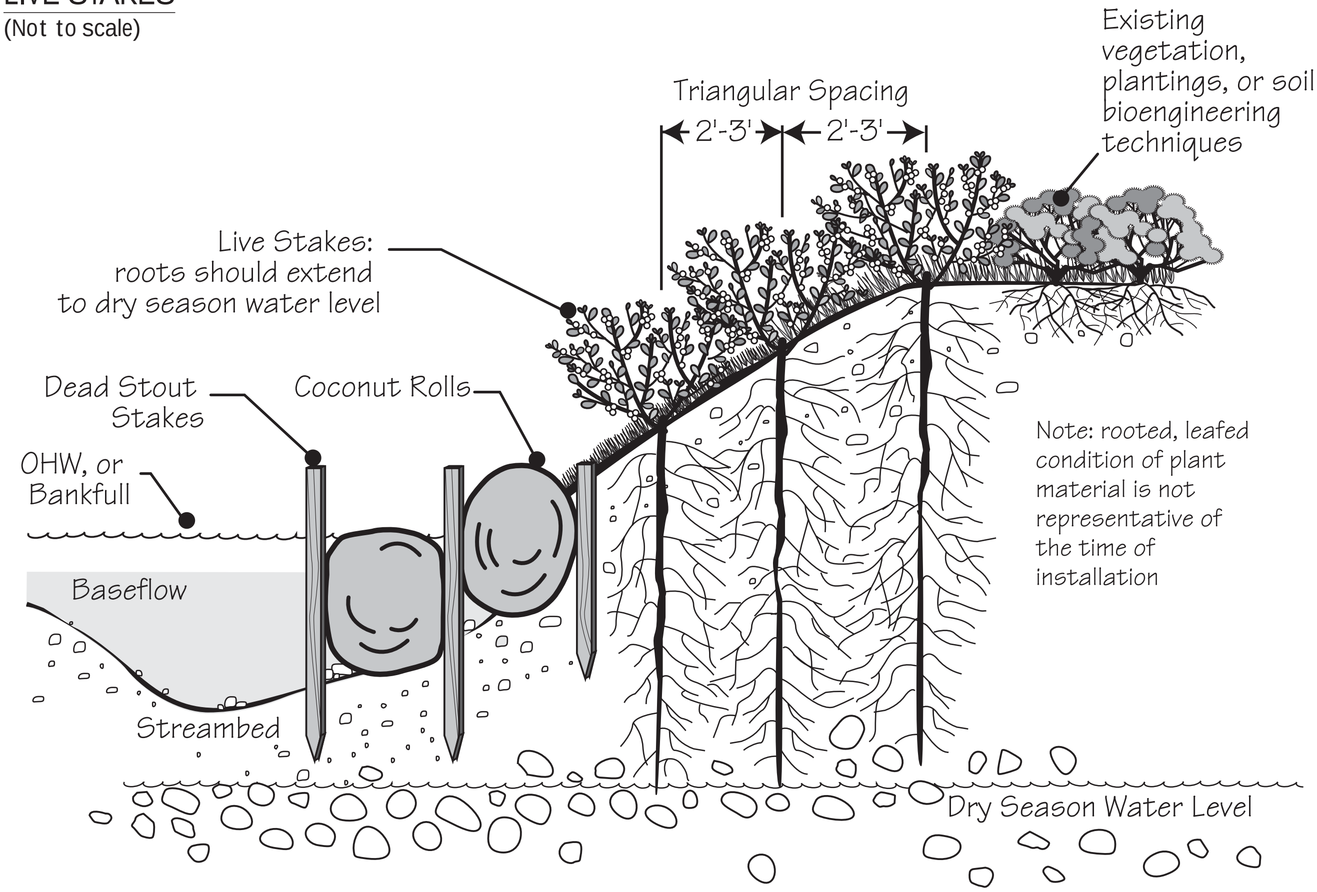
Robbin B. Sotir & Associates, Inc.

Live siltation construction system.

USDA Forest Service

Note visible rocks on the bank side of the installation, safeguarding against washout. Kenai River, AK.

LIVE STAKES
(Not to scale)



Live Stake

Live stakes create a living root mat that stabilizes the soil by reinforcing and binding soil particles together and by extracting excess soil moisture. Most willow species root rapidly and begin to dry out an excessively wet bank soon after installation. Live, rootable vegetative cuttings are inserted or tamped into the ground. If correctly prepared, handled, and placed the live stake will root and grow.

Applications and Effectiveness

Application

Use stakes in the wetted zone of banks or where precipitation is likely to keep the soil moist during growing seasons.

Effectiveness

- Provides a technique where site conditions are uncomplicated, construction time is limited, and an inexpensive method is needed.
- Repairs small earth slips and slumps that frequently are wet.
- Enhances the performance of geotextile fabric by serving as pegs to hold fabric down.
- Enhances conditions for natural colonization of vegetation from the surrounding plant community.
- Produces streamside habitat.
- Stabilizes areas among other bioengineering techniques, such as live fascines.

Construction Guidelines

Live material sizes

The stakes generally are 1 to 2 in. in diameter and 2- to 3-ft. long. The specific site requirements and available cutting source determine size.

Live material preparation

- Remove side branches, leaving the bark intact.
- Cut the basal ends at an angle or point for easy insertion into the soil. The top should be cut square.
- Install materials the same day that they are prepared.
- Place according to species. For example, along many western streams tree-type willow species are placed on the inside curves of point bars where more inundation occurs, while shrub willow species are planted on outside curves where the inundation period is minimal.


USDA Forest Service

Willow live stake.

Installation

- Orient buds up.
- Install a live stake 2- to 3-ft. apart using triangular spacing. The density of the installation will range from two to four stakes per square yard. Site variations may require slightly different spacing. A spacing pattern should allow for the variables of a fluctuating water level. The installation may be started at any point on the slope face.
- Install 4/5 of the length of the live stake into the ground and firmly pack the soil around it after installation.
- Remove and replace any stakes that split during installation.
- Use an iron bar to make a pilot hole in firm soil or waterjet stinger (Hoag, et al. 2001).
- Dig in live stakes unless the soil is fine and loose. Too many tamped-in stakes split or have their bark damaged by hammering and by hard rocky soils.
- Install the live stake slightly angled downstream.
- Tamp the stake into the ground with a dead blow hammer (hammer head filled with shot or sand).
- Install geotextile fabric (optional) on slopes subject to erosive inundation. Install the stakes through the fabric.
- Plant on banks that will be moist during growing seasons or install longer stakes that reach the dry season water level.

Lakeshore live stakes offer no stability until they root into the shoreline area; however, over time they provide excellent soil reinforcement. To reduce failure until the roots establish themselves, installations may be enhanced with a layer of long straw mulch covered with jute mesh or, in more critical areas, a geotextile fabric.


Robbin B. Sotir & Associates, Inc.

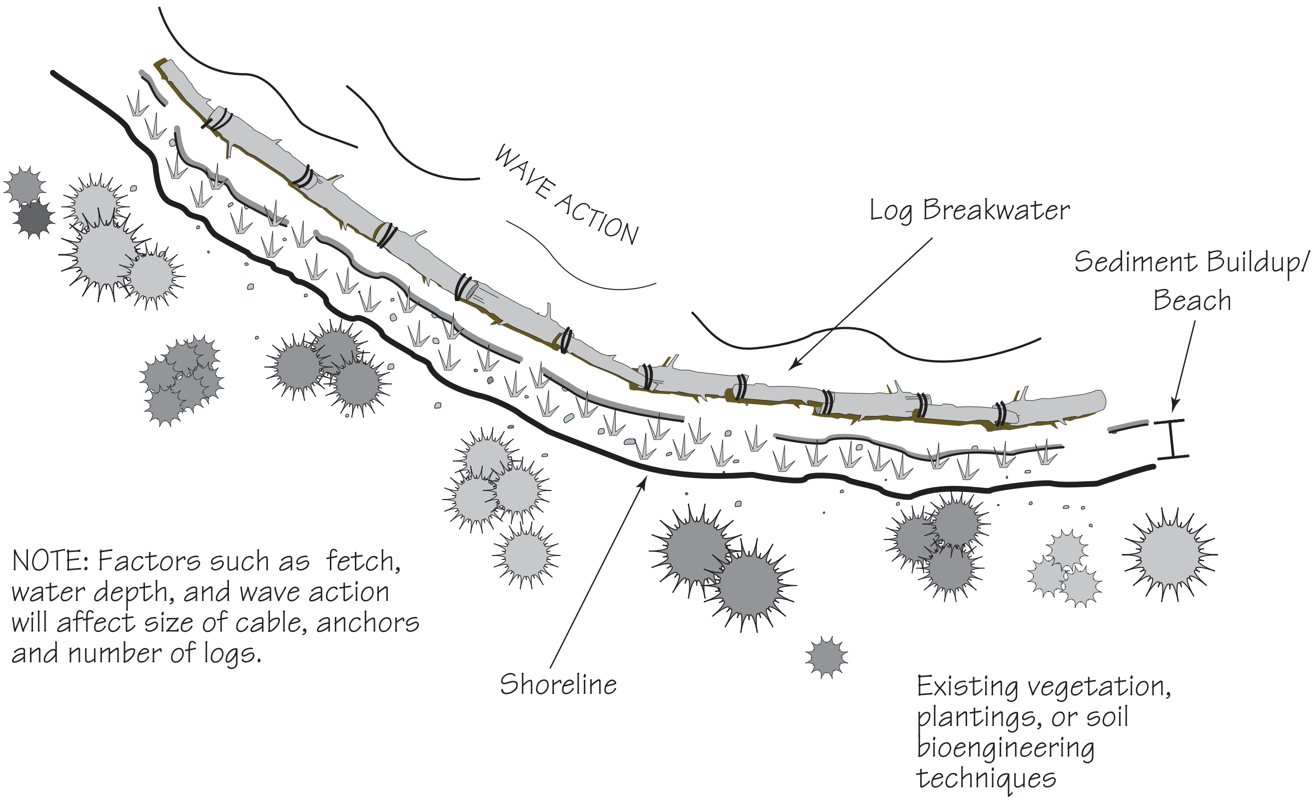
Prepared live stake.


USDA Forest Service

Cottonwood live stake.

LOG BREAKWATER: PLAN VIEW

(Not to scale)



Log Breakwater

The log breakwater is used on lakes and reservoirs to reduce waves, deflect debris and ice, and trap sediment. It is 5- to 6-ft. wide. A breakwater is effective floating or tied to the lakebed. If tied to the bed, it will trap sediment more rapidly. In this case, the top of the logs should be at ordinary pool height. The installation technique is the same in either case. The breakwater is built with a series of log rafts. Stagger the logs in each raft. Then, when the rafts are strung end to end, the ends will mesh.

Applications and Effectiveness

Applications

- Use where the fetch is greater than 2 mi.
- Use logs gathered on site whenever possible.
- Use in combination with soil bioengineering techniques on shore.

Effectiveness

- Breaks waves. Do not use where ice scour is a known problem.
- Accumulates sediment between the breakwater and the shoreline.
- Is labor intensive to install.
- Requires monitoring, especially after storm events.

Construction Guidelines

Inert materials

- Logs that are 2 to 3 ft. or greater in diameter.

Tools

- Steel cable.
- Steel cable clamps to match the size of cable.
- Duckbill, screw-type earth anchors, or plate anchors. The type of anchor used depends upon the shear strength of the soil under the lakebed. The most secure anchor will be set in dry material under the lakebed. If that is not possible, use anchor plates.
- Hydraulic jet pump for setting anchors.

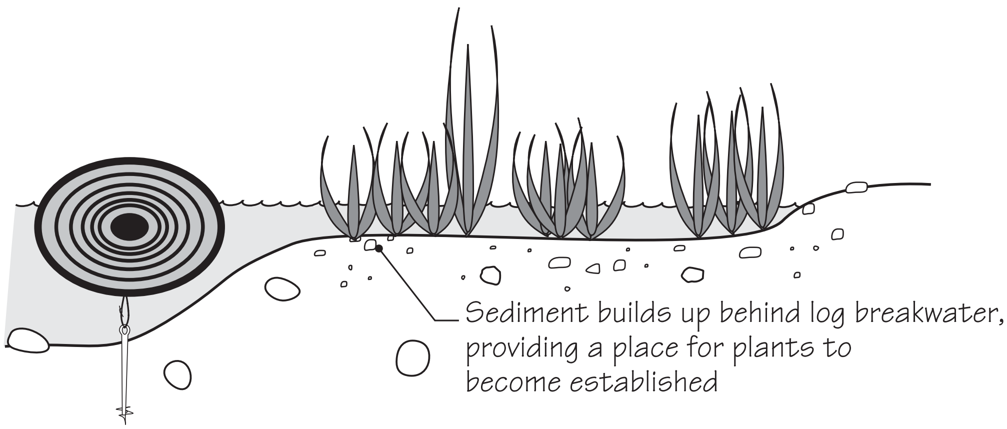
Installation

Duckbills will be used as anchors in this example.

- String the logs together to form a chain long enough to protect the shoreline. Overlap each log by several feet and wrap the cable around the ends to hold the logs together. Clamp the cable together.
- Run one long stringer cable the length of the log breakwater. Thread the cable between the log and the cable wrap.
- Locate the breakwater in 3 to 4 ft. of water. Install the duckbills into the substrate using the hydraulic jet pump at 8- to 10-ft. intervals.
- Use a cable clamp to form a small loop at the end of the duckbill cable.
- Thread a length of cable through the loop. Use this to tie the logs to the duckbills. (Cable needs to be long enough to accomodate changes in water levels.)
  - Thread this cable over the stringer cable.
  - Use a cable clamp to secure the stringer cable to the threaded cable.
  - Use a cable clamp on the threaded cable to form a loop.
- Float logs at the normal pool elevation of a lake or reservoir or tie to the bed.
- Install soil bioengineering techniques on the shore.

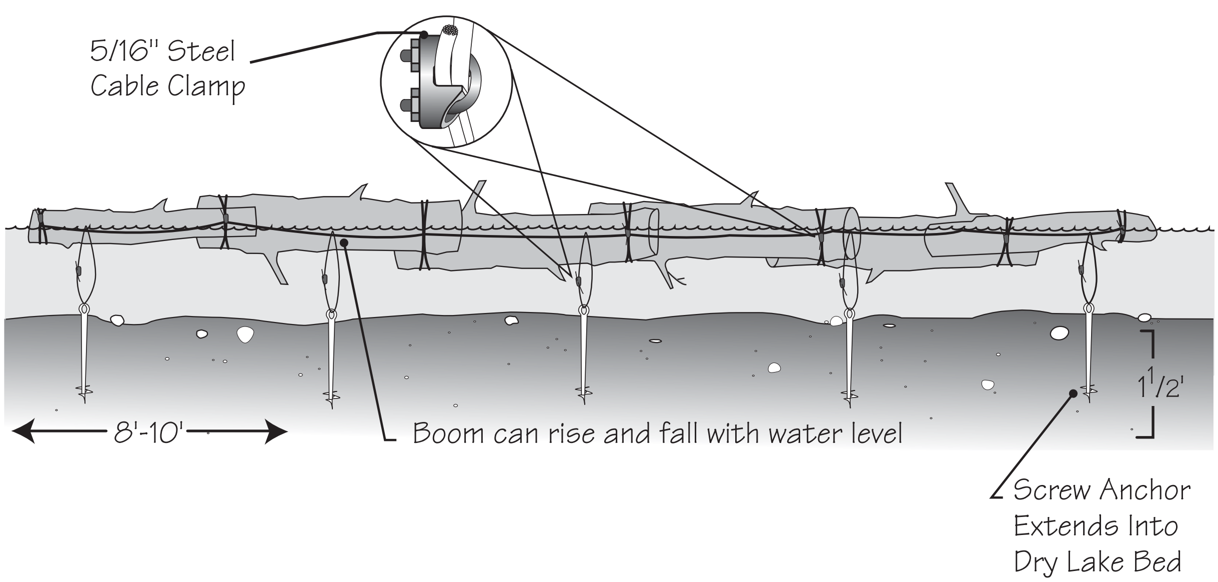
LOG BREAKWATER: SECTION A

(Not to scale)



LOG BREAKWATER: SECTION VIEW

(Not to scale)



Plant Mat

A plant mat provides an instant swath of herbaceous ground cover in much the same way that unrolling sod does. Use this technique on lakeshores and on quiet stretches of streams. The mats are 2- to 3-in.-thick nonwoven coconut fiber that are held together with organic latex and secured with a high tensile strength net backing. Herbaceous plants, such as sedges, and/or emergent aquatic plants are grown on a mat in a hydroponic setting, and then transported to the project site. A dry mat weighs approximately 45 lb. Hollow-stemmed or woody plants can be started on smaller mats called pallets. Some companies will collect wild seed, germinate the mat, and transport it to the site.

Applications and Effectiveness

- Requires many hours to collect and germinate seeds.
- Protects toe of slope. Place behind a revetment if protection from strong currents is needed.
- Transports easily; lightweight.
- Improves habitat instantly.
- Traps sediment and prevents surface erosion.
- Provides a good success rate for plant survival.
- Enhances conditions for colonization of native plants by providing protection and a culture conducive to seed germination.

U.S. Army Corps of Engineers Waterways Experiment Station

Emergent aquatic plants from seeded coconut mat.

U.S. Army Corps of Engineers Waterways Experiment Station

Plant mat being rolled up for transport.

Construction Guidelines

- Inert materials
- 2- by 4-in. lumber and nails for building frame.
- Waterproof liner.
- Dead stout stakes to secure the live fascines. Make dead stout stakes from 2.5- to 4-ft. long, sound, untreated, 2- by 4-in. lumber. Cut each length diagonally across the 4-in. face to make two stakes. Use only sound lumber. Discard any stakes that shatter upon installation.

Live materials

- Rushes, sedges, or flood-tolerant grasses are grown in 1- to 2-in. containers, and then plugged into a plant mat.
- Seed.

Preparation

- Grow native stock in 1- to 2-in. containers or use seed.
- Build a tray to hold the mat and water; size varies according to need. Build the frame of 2- by 4-in. lumber set on edge and line with a waterproof liner. Plant mats are 3- by 15-ft. and 2-in. thick, although they can be cut easily to a desired size.
- Plug plants into the mat at 10- to 20-in. apart or in a 12-in. grid, depending on the type and amount of plant material available. Seed may be used also. Evenly cover the mat with seed. Quantities of seed will vary by species.
- Fill the tray with water and, if desired, add nutrients.
- Grow plants for 4 to 6 weeks; stop adding nutrients 2 to 3 weeks before moving the mat.
- Change the neutral water to saltwater, gradually, 2 weeks before planting, if plants will be installed in saltwater.

Installation

- A finished mat weighs approximately 90 lb with the water drained out. If necessary, after the plants grow, the mat can be cut into manageable pieces using a tile knife or sharp hedge cutter.
- Roll the mat up if you are using herbaceous plants and turn the mat on edge to drain.
- Wrap the roll in plastic and transport it to the site. A roll can live for 3 days this way, a shorter time if the temperature is hot and dry or freezing.
- Loosen compacted soils on site.
- Unroll the mat at the site and stake the corners and middle with dead stout stakes.
- Cinch the mat down with twine. Wrap the twine around the stakes and pull.
- Wet the newly unfurled mat.

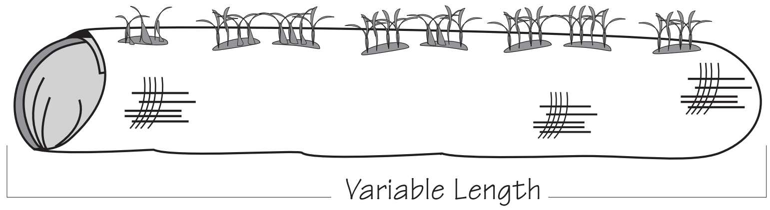

U.S. Army Corps of Engineers Waterways Experiment Station

The rolled plant mat being carried to a lakeshore site.

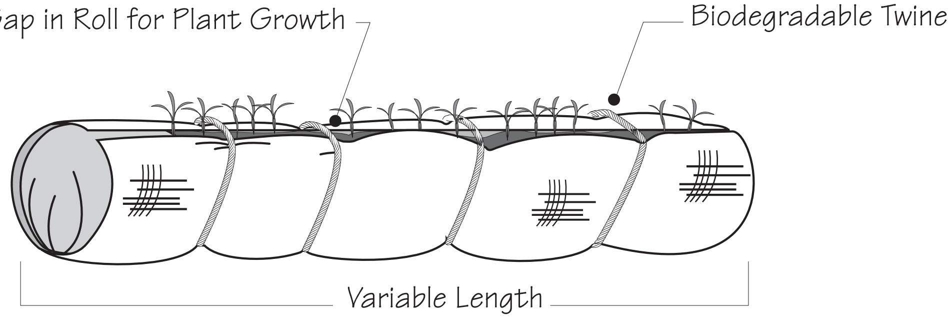
WRAPPED PLANT ROLL
(Not to scale)

Two methods of construction are illustrated.

EXAMPLE 1
The plants are wrapped in burlap or coconut fiber mat. Slits are cut along the top, and the leafy portions of the plants are pulled through.



EXAMPLE 2
Burlap is pulled snugly around the plants and secured by twine wrapped around the roll, or by hog rings holding the edges together.



Plant Roll
This technique introduces herbaceous vegetation to streambank and lakeshore sites while providing structural stability. Clumps of plants in sod are placed tightly in a sausage-like roll held together with burlap and twine. They are approximately 9- to 10-in. in diameter and can be 2- to 15-ft. long. They can be used alone or with other techniques, for example, at the base of a brush mattress instead of a live fascine.

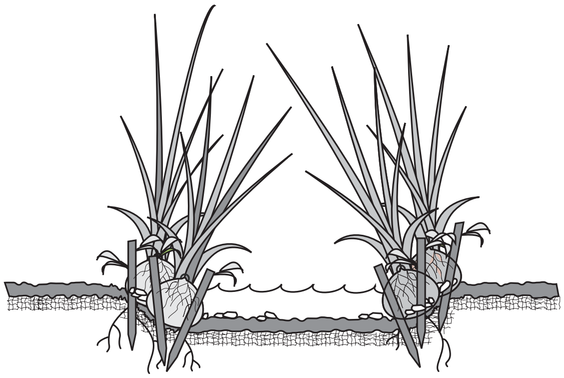
Applications and Effectiveness
Applications
- Constructed on site.
- Applied to banks that support mostly grasses and sedges and where seeding is impractical because of fluctuating water levels and other factors.
- Useful on shore sites where rapid repair of spot damage is required.

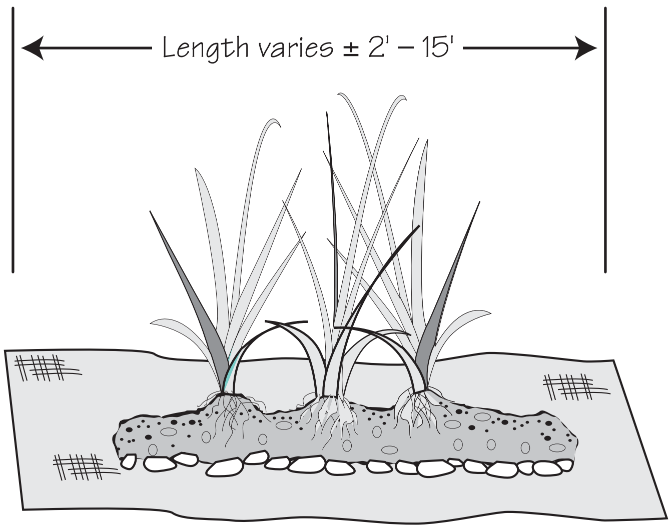
Effectiveness
- Grows in water and survives fluctuating water levels.
- Establishes sod, sedges, and reeds.
- Provides a microclimate conducive to plant growth and seed germination.
- Offers relatively inexpensive and immediate protection from erosion.
- Retains soil and transported sediment at the shoreline.
- Reduces a long beach wash into a series of shorter sections capable of retaining surface soils.
- Enhances conditions for natural colonization and establishment of vegetation from the surrounding plant community.
- Reduces toe erosion and creates a dense energy-dissipating reed bank area.

Construction Guidelines
Live materials
Cut and dig clumps of native sedges and grasses from nearby stable bank sites or grow in a nursery from native seeds. Take some soil with the plants, but not enough to cause instability to the area.

Inert materials
- Burlap, 5-ft. wide by the length of the roll.
- Untreated twine and/or hog rings.
- Dead stout stakes to secure the rolls. Make dead stout stakes from 2.5- to 4-ft. long, untreated, 2- by 4-in. lumber. Cut each length diagonally across the 4-in. face to make two stakes. Use only sound lumber. Discard any stakes that shatter upon installation.

PLANT ROLL
(Not to scale)





Option:
Rocks can be placed on the burlap to add weight to the roll.

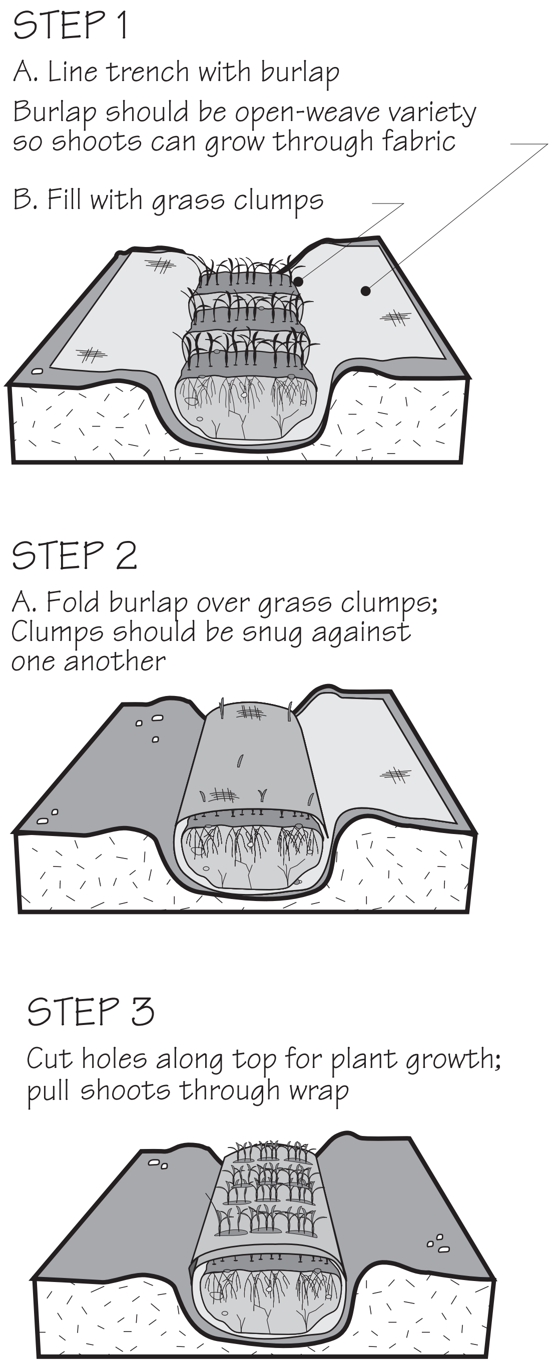
Installation

- Excavate a trench 2-in. wider and deeper than the size of the roll (5- to 30-ft. long) beginning at and parallel to the water's edge.
- Line the trench with a 2- to 3-ft.-wide strip of geotextile fabric before spreading a 1-in. layer of highly organic topsoil over the bottom of the trench.
- Center the plant clumps at 12-in. intervals along the bottom of the trench.
- Orient the growing buds in the same upright direction for correct placement into the trench.
- Fill in and around the plant clumps with highly organic topsoil and compact.
- Wrap the ends with geotextile fabric and tie them to keep soil from washing out.
- Wrap the geotextile fabric from each side, overlapping at the top.
- Cut slits in the fabric to expose the plants.
- Anchor the roll every 2 ft. with dead stout stakes. Drive stakes through the roll and into solid ground or wedge them above and below the roll.
- Pack excavated soil around the rolls to cover the fabric.
- Place the prefabricated plant roll in the excavated trench, secure it with dead stout stakes, and backfill as described above.
- Wet the surface.
- Tie or key the upstream and downstream ends to the bank, a rock outcrop, or large stable tree.
- Repeat the above procedure on lakeshores by excavating additional parallel trenches, spaced 3 to 6 ft. apart, toward the shoreline to produce a staggered spacing pattern.

Rolls can also be fabricated on the bank and rolled into the trench.

PLANT ROLL: CONSTRUCTION

(Not to scale)



Plant lifts and plant bags are generally planted in calm water on streams and on lakeshores.

Plant Lifts

- Construct a 4- to 6-in. high lift (soil wrapped in a natural geotextile) at water's edge and large enough to cover the area concerned.
- Anchor it with dead stout stakes.
- Use a rebar, a cutting knife, or an iron pole to punch or cut holes on the top side.
- Install sedges, reed clumps, or grasses through the holes.
- Tug each plant slightly to be sure that it has been properly planted.
- Wet the surface.

Plant Bags

- Make individual plant bags from 4- to 6-in. clumps of herbaceous plant material and from transplanted or rooted stock of water-loving plants.
- Wrap the roots in a natural geotextile (burlap) and plant them at the water's edge.

Robbin B. Sotir & Associates, Inc.

Completing installation of reed clump system.


USDA Forest Service

Transplanting sedges into a soil lift wrapped in coconut matting (erosion control fabric) on the Chena River, Fairbanks, AK.


USDA Forest Service

Plant bag, under gravel, with leafed-out willow on the Chena River, AK.

Willow planted from rooted stock to revegetate overgrazed Pine Creek on Cleveland NF.

Rooted Stock

Rooted stock provides instant leaf cover and habitat improvement. Rooted stock is a transplanted tree, woody shrub, or herbaceous plant with an established root system. It can be rooted cuttings balled with a burlap wrap, bare root, containerized plants, or sod or sedge harvested near the site and transplanted.

Applications and Effectiveness

Applications

- Use for plants that will not grow from cuttings, such as conifers, and for planting an understory in shaded habitat.
- Planning is crucial. Plan time for harvesting seeds and slips, potting, and growing.
- Use containerized plants in sandy soils.
- Use in conjunction with other bioengineering techniques.
- Use wild, transplanted stock or nursery-raised stock. Wild, transplanted stock establishes at a lower rate.
- Start plants from cuttings, such as live stakes, posts, and so on, if possible; nursery stock is more expensive.
- Use at stream level when flow is less than 3 cubic feet per second (cfs), and behind or in a coconut log revetment when flow is 5 cfs.
- Use on mid-bank to upper-bank and on the floodplain where natural precipitation is adequate for specific plants or where irrigation is available.
- Use where plants are not likely to be pulled out by grazing or recreation activities, frost heaving, erosion, or washout.

Effectiveness

- Offers immediate bank protection. The root system will invade the bank within weeks, as opposed to the months a cutting takes to establish a significant root system.
- May not reach the water table during the dry season because of short roots.
- Causes minimal site disturbance.
- Enhances conditions for natural colonization of surrounding plants.

Construction Guidelines

Plants should be from an adjacent site. If this is not possible, they should be indigenous to the area, from the same ecotone, watershed, or climate zone, from the same or nearly the same elevation, and from within 100 mi. of the site.

Native plants

- Select a random pattern for digging up native plants or for cutting slips.
- Collect individual plants, clumps, and cuttings away from public view; take only healthy plants and only one-third of the "mother plant" for cuttings. Remove any weeds.
- Dig no deeper than 6 in. when harvesting plants to allow roots in the ground to grow back. Transplant the same day or keep roots wet for next-day planting.
- Split clumps of sedges into individual plants. Be sure the stems have roots attached.
- Use cuttings and seeds to grow nursery stock.
- Cut several inches off the tip of the cuttings before planting. The bud end draws too much energy away from stored reserves, reducing the chance of survival. Trim off any side branches.

Nursery stock

- Use willows, other woody species, and herbaceous plants that can be propagated and grown by nurseries.
- Allow 2 years or more for plants to produce enough woody growth to survive in the wild.

Installation

- Plant sedges and grasses by punching a hole in the soil's surface or use a spade to lift the soil. Insert the plant and tamp the soil around the roots. Tug slightly on the stem to be sure that it is secure.
- Loosen the root ball and cut away any circling roots for planting. If roots are tight, score the sides. Willow, dogwood, and cottonwood can be planted with the crown buried. Some nursery stock will need to be planted with the crown 0.5- to 2-in. above the soil surface. (Ask a botanist.) One way to do this is to plant the crown at the soil's surface level. When the plant is watered, the soil level will drop, exposing the crown.
- Install plants in a hole as deep as the root ball and twice as wide; backfill the hole with the native soil that was removed and any soil loosened from the root ball. Do not add topsoil. Remove air pockets around the plant by tamping the soil.
- Build basins around the plants on slopes to catch rainfall. Wet the plants immediately after planting.
- Wet and tamp the soil to squeeze out air bubbles. Add more soil after wetting, but keep the crown above ground level.
- Clear weeds, grasses, and other competing plants in a 30-in. diameter around the stock to lessen competition.

ROOT WAD WITH FOOTER: SECTION

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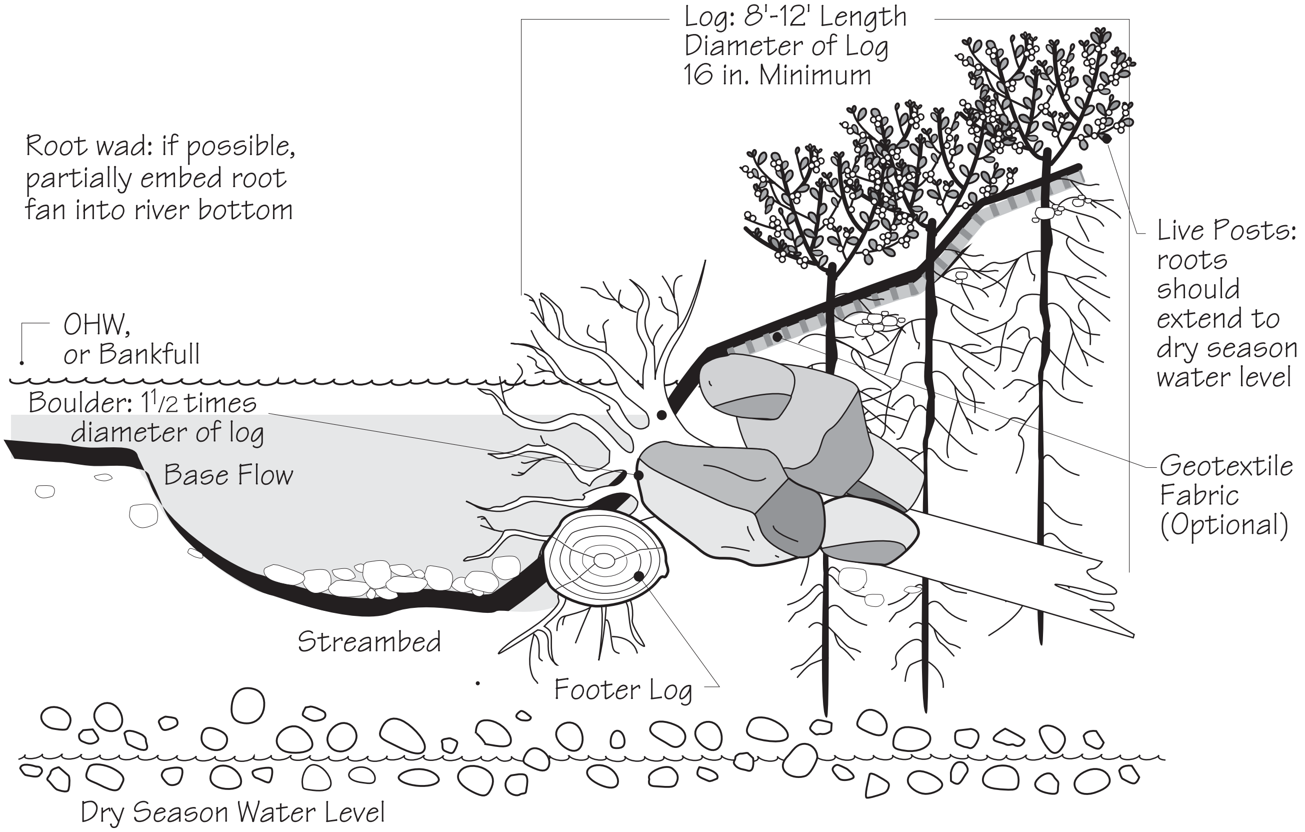

Root Wad

Root wads armor a bank by keeping the current off the bank. They should be used in combination with other soil bioengineering techniques to stabilize a bank. Use them on lakeshores to combat wind- and wave-erosion.

There are a number of ways to install root wads. The bole (trunk) can be driven into the bank, laid in a deep trench, or installed as part of a log and boulder revetment. Two methods are illustrated here.

Log, root wad, and boulder revetments are systems selectively placed in and on streambanks. These revetments can provide excellent overhead cover, resting areas, and shelters for insects and fish. Several of these combinations are described in Flosi and Reynolds (1991), Rosgen (1992), and Berger (1991).

Use tree wads that have a brushy top and durable wood, such as Douglas fir, oak, hard maple, juniper, spruce, cedar, red pine, white pine, larch, or beech. Caution: Ponderosa pine and aspen are too inflexible and alder decomposes rapidly.

Applications and Effectiveness

Applications

- Used for stabilization and to create and improve fish-rearing and spawning habitat.
- Used on meandering streams with out-of-bank flow conditions.
- Suited to streams where fish habitat deficiencies exist.

Effectiveness

- Tolerates high boundary shear stress when logs and root wads are well anchored.
- Enhances the diversity of the riparian corridor when used in combination with bioengineering techniques.
- Has a limited lifespan and may require preiodic maintenance or replacement, depending on the climate and durability of the species used. If natural vegetation does not take hold, revetments may need eventual replacement.
- Creates a lot of bank disturbance because of the machinery used to dig the trenches for the boles.

Construction Guidelines

Inert materials

- Trees that were downed with the roots intact. Root wad span should be approximately 5 ft. with numerous root protrusions. The bole (trunk) should be at least 8- to 12 ft. long.
- Boulders should be as large as possible, but a minimum one- and one-half times the log's diameter. They should have an irregular surface.
- Logs are to be used as footers or revetments. Use logs over 16-in. in diameter.

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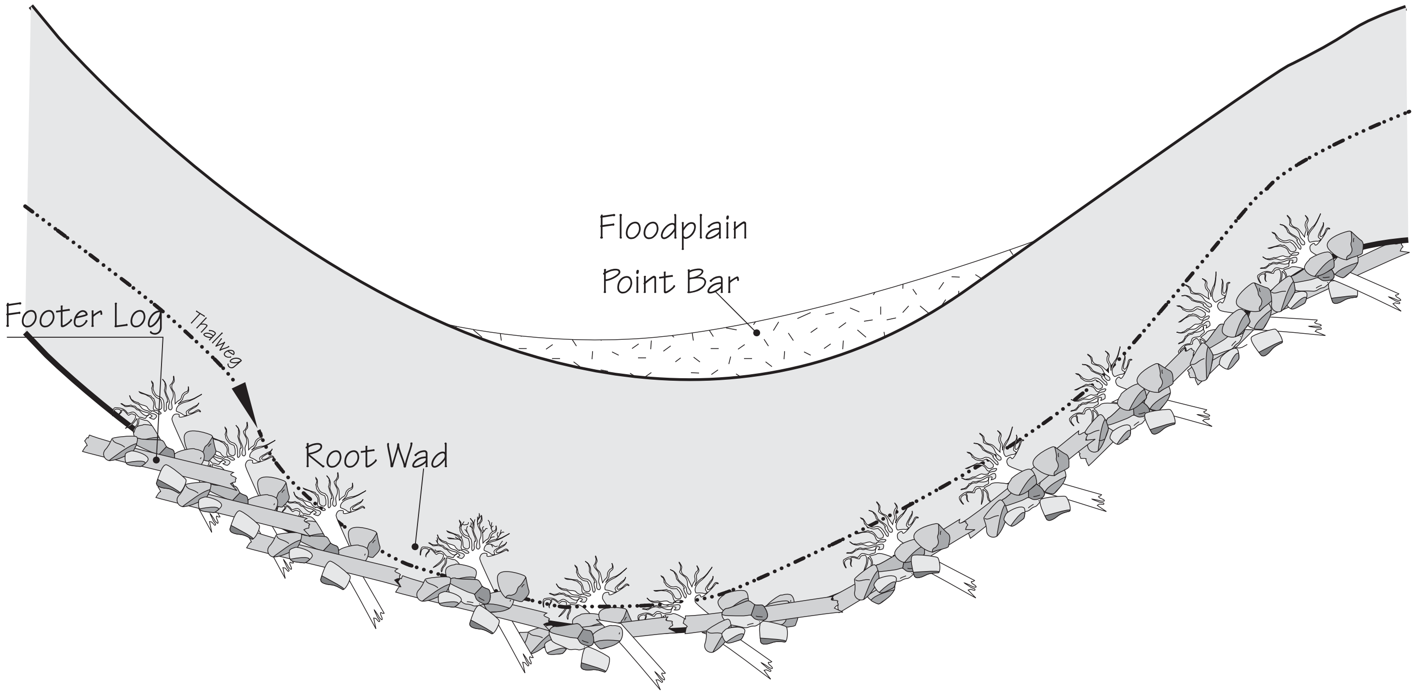
Root wad ready to be used.

ROOT WAD WITH FOOTER: PLAN VIEW

(Not to scale)



Installation

- Install a footer log, 12- to 18-ft. long at the toe of the eroding bank, by excavating trenches or driving it into the bank to provide a stable foundation for the root wad.
- Place the footer log to the expected scour depth at a slight angle away from the direction of the stream flow.
- Use boulders to anchor the footer log against flotation. If boulders are not available, logs can be pinned into gravel and rubble substrate using a 3/4-in. rebar, 54 in. or longer. Anchor the rebar to provide maximum pullout resistance. Cable and anchors (duckbills) may also be used in conjunction with boulders and rebars.
- Drive or trench and place the bole of root wads into the streambank so that the tree's primary brace roots are flush with the streambank and at a 30 to 45 percent angle to the bank, facing upstream, and slightly down towards the streambed. The wad should be below the ordinary high-water mark or bankfull level with some of the roots extending into the streambed, if possible.
- Backfill and use soil bioengineering techniques behind the root wad and on the bank. Live stakes and live posts can be installed in the openings of the revetment below the ordinary high-water mark or bankfull level.
- Install root wads perpendicular to the waves. Use a line of overlapping root wads to impede erosion and trap littoral drift, where wave action is a problem on a stream or lakeshore.

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An example of a usable root wad.

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An outside bend on Whittlsey Creek, WI, is armored by root wads at the toe. Fascines and live posts vegetate and secure the bank.

USDA Forest Service

Root wad faces the Kenai River, AK. Brush layering secures the bank behind it.


USDA Forest Service

Snow fence in place on Lake Sharpe, SD.

Snow Fence

A wooden snow fence can trap sediment and help restore natural stability to the shore. A fence is not soil bioengineering. It is suggested here as a temporary barrier to be used while soil bioengineering installations take hold.

Applications and Effectiveness

- Use where the fetch is 1/2 mi. or less.
- Limit use to lakes and reservoirs with very gentle slopes, 10:1.
- Use to break waves and trap sediment between the shore and the fence.
- Use only wooden snow fences.
- Apply soil bioengineering techniques on the shore.

Construction Guidelines

Inert materials

- Wooden snow fence.
- Steel fence posts.

Installation

- Ensure that the lake bottom is as gradual as is the shore.
- Install in knee-deep water parallel to the wave action.
- Space steel posts every 10 ft.
- Attach reflective buoys to the fence posts if the fence is submerged for part of the year.

Terraced Crib

This type of crib can be used to provide public access while stabilizing a bank. It stabilizes without laying the bank back or losing riparian habitat.

Applications and Effectiveness

- Provides planned access points.
- Is inexpensive.
- Requires monitoring and maintenance on the tread as use wears it down.
- Provides an esthetically pleasing access route.

Construction Guidelines

Inert material

- Logs range from 15- to 40-ft. long, 6 to 8 in. in diameter. The quantity and length of logs necessary is determined according to the size of the installation.
- Treated 6 by 6 in. timber can also be used. See http://www.treatedwood.com/news/transition_details.html
- Cobble stone for the toe or other stabilization method.
- 5/8-in. reinforcement bar for joining logs or timbers.
- Drill and 1/2-in. bit.

Installation

- Dig a trench; begin at the mean water level, or ordinary pool elevation in the lake, 2- to 3-ft. deep and 3 ft. back into the bank.
- Fill the trench with cobble 2 to 3 in. in diameter. An alternative to cobble would be a log revetment. The log should be set deep enough into the shore to avoid undercutting by waves. This log should be larger in diameter than the others.
- Place log or timber on top of the cobble or revetment parallel to the bank. All logs should be small in diameter, 6 to 7 in., because they form steps. Two logs can be placed one behind the other for greater stability or a wider tread.
- Place the next course of logs or timbers at right angles (perpendicular to the slope) on top of the previous course.
- Anchor the logs to each other and to the ground with a reinforcement bar. Drive a 5/8-in. rebar through predrilled 1/2-in. holes a minimum of 3 ft into the ground. Place anchors at all corners. Add additional anchors every 4 ft. on long spans. For distances shorter than 7 ft., split the difference.
- Countersink all exposed rebar.
- Place the next parallel log one to several feet behind the previous log depending on the steepness of the access.
- Build each course of the terraced crib in the same manner and secure it to the preceding course with reinforcement bars.

These two photos show a new access to a walk-in lake used primarily by canoers. Sunken Lake, Chippewa NF.

USDA Forest Service

This terraced crib was made of locally cut logs. Erosion control mat was laid on the edges to help prevent erosion. The Polaris vehicle was used to bring in materials because it has low-pressure, minimum-compaction tires.

USDA Forest Service

Terraced crib in relationship to the water.

- Fill the rectangular space between the logs with cobble or gravel, then top with soil to form a walkway.
- Fill pockets outside the tread with soil bioengineering techniques.
- Live stakes and posts need to reach the dry season water level.
- Stabilize and revegetate the outer edges of the terrace. The resulting vegetation provides stability and habitat, and helps keep people on the access route.

These photos illustrate construction of a terraced cribwall at Lichen Lake, Tofte RD, Superior NF. This is a “carry-down access” point off a forest highway. Erosion was caused by people backing trailers down to the water.


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Above and Below: The 6 ft by 6 ft timbers were installed from the bottom up.


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Finished cribwall, looking up towards the parking lot. Note the 2-foot dropoff at the top where the timbers form a retaining wall.


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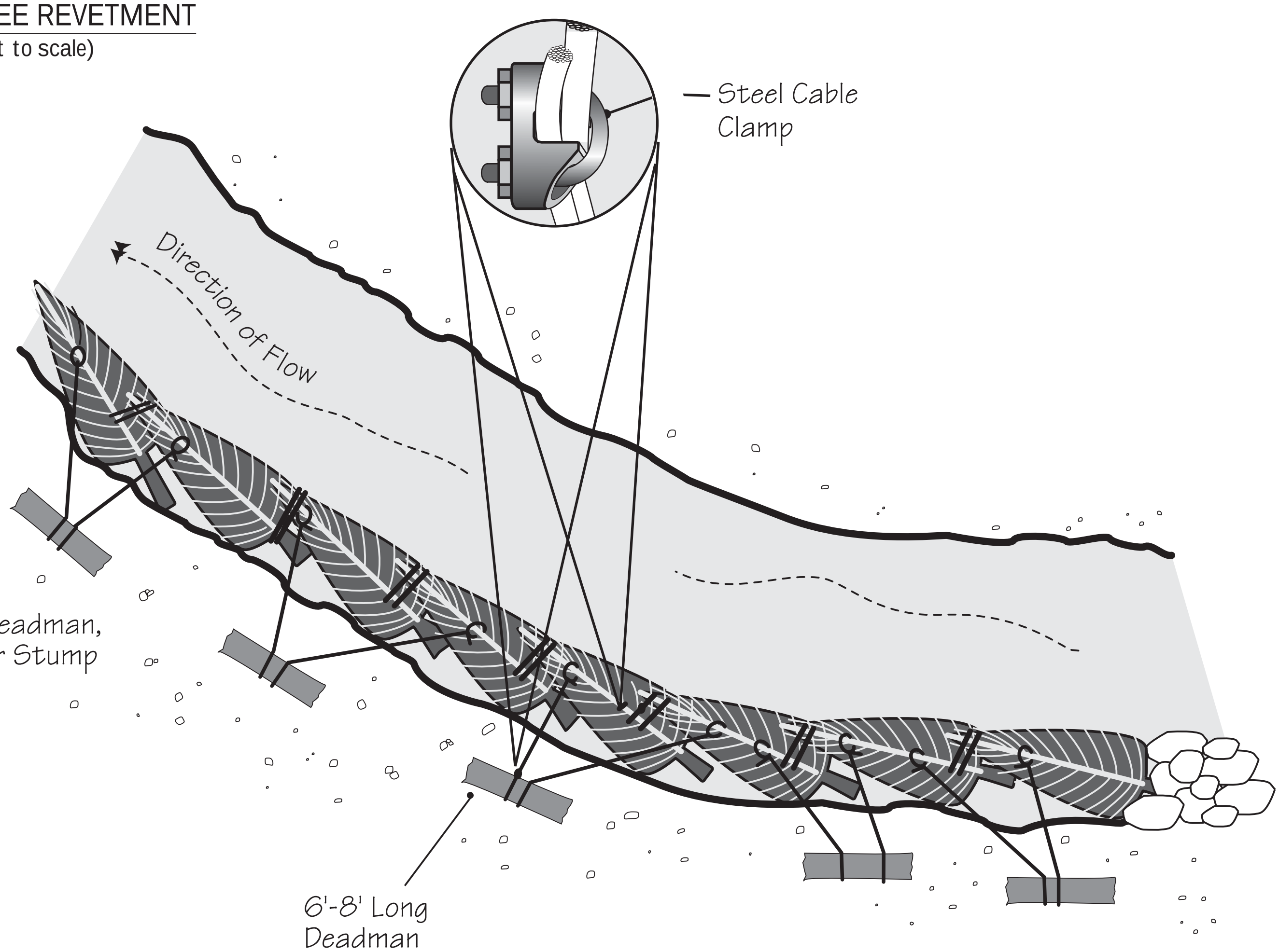
Finished view toward the water. Narrow top steps prevent vehicles from being driven down the slope.

TREE REVETMENT
(Not to scale)



Tree and Log Revetment

A tree revetment creates an armored bank. It is constructed from whole trees (minus the root wad), cabled together and anchored to the bank.

Log revetments are tree revetments with the branches removed. In certain instances, it may be necessary to remove some or all of the branches. This facilitates stacking the logs. It is always beneficial to leave the branches intact. Branches slow the rate of flow, catch sediment, and provide fish habitat.

Christmas tree revetments are those made of smaller trees and are generally anchored into the bank using duckbill anchors.

Applications and Effectiveness

Applications

- *Do not use upstream of nearby bridges or other structures where there is high potential for downstream damage if the revetment dislodges during flood events.*
- Use in conjunction with live soil bioengineering techniques to establish a riparian plant community.

Effectiveness

- Secures the toe.
- Allows trees to be stacked.
- May be damaged in streams where heavy ice flows occur.
- Uses inexpensive, readily available materials to form semi-permanent protection.
- Has a limited lifespan and may require periodic maintenance or replacement depending on the climate and durability of tree species used. Replace damaged or deteriorating trees. Ideally, by the time the trees have deteriorated, native vegetation will have taken over and no revetment will be needed.

Construction Guidelines

Inert materials

- Steel cable to wrap trunks together and lead from trees to earth anchors.
- Steel cable clamps.
- Duckbill anchors, deadman anchors, or 7-1/2-ft. metal T-posts for anchoring trees.
- Rope.
- Trees that have a trunk diameter of 12 in. or larger. Smaller diameter trees can work in a small stream. Select trees that have a brushy top and durable wood, such as Douglas fir, oak, hard maple, juniper, spruce, cedar, red pine, white pine, larch, or beech. Some species, such as cottonwood, often sprout and accelerate natural colonization. *Caution:* Ponderosa pine and aspen are too inflexible, and alder decomposes rapidly.

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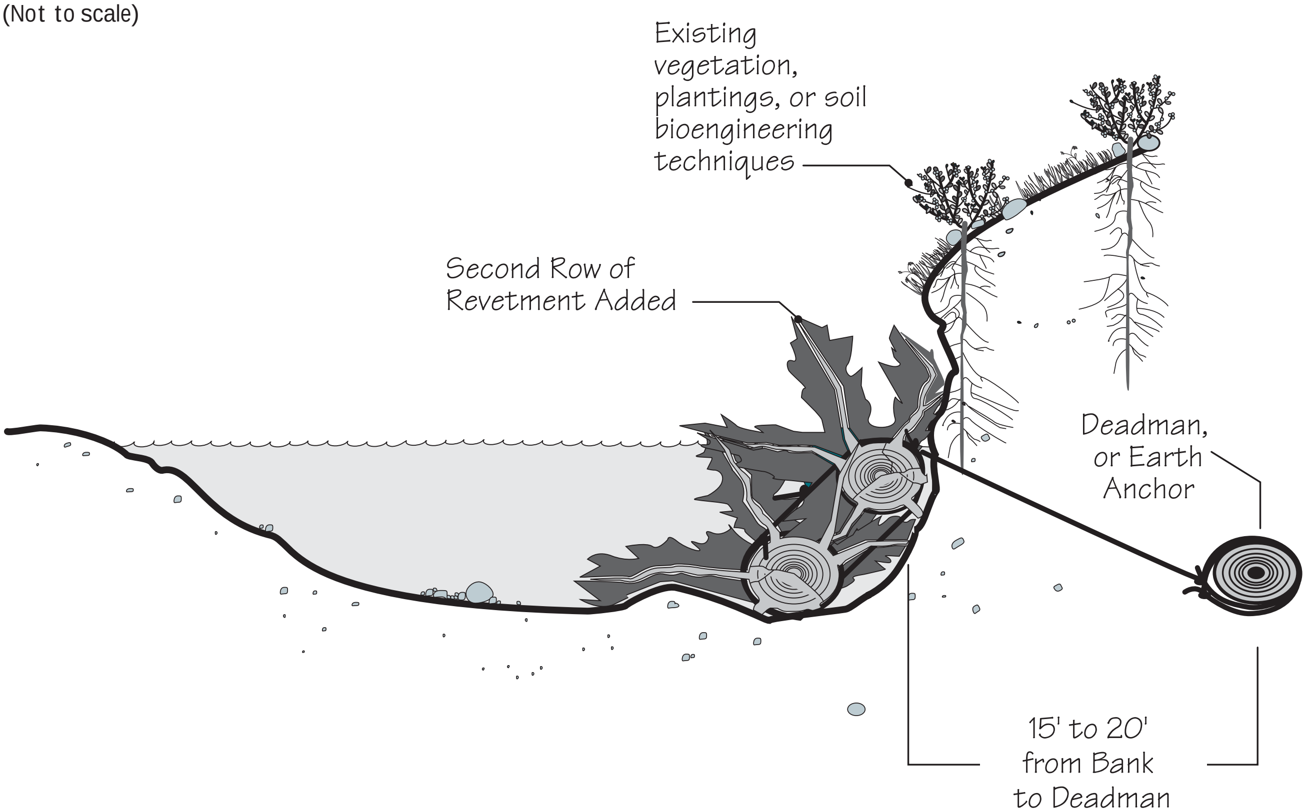
Small tree revetment stabilizing toe on Kenai River, AK. Note the healthy sedges.

TREE REVETMENT: SECTION VIEW

(Not to scale)



Installation

- Determine what type of anchor is needed. A large tree or log may need a deadman anchor buried deep into the bank, while smaller trees, or revetments placed in less turbulent water, may need a duckbill or some other type of earth anchor.
- Use a wood or steel deadman. Both are 6- to 8-ft. long. Steel pipe is 4- to 6-in. in diameter, logs are 8- to 10-in. in diameter, and timbers are 6- by 6-in. or greater.
- Lay the trees along the bank with treetops pointing downstream.
- Overlap the trees by one-third to one-half their lengths to ensure continuous bank protection.
- Extend installation of trees, one to three tree lengths upstream and downstream beyond the eroded bank. Upstream and downstream ends must be keyed into the bank.

A revetment may be installed in two ways. Weather, such as extreme temperature; size of trees; steepness and height of the bank; or the number of persons available to work may dictate which of the two techniques to use.

1. Put the trees at the bottom of the streambank, move them into place, cable them together, wrap the cable around them, run the cable ends through the clamp, cinch the cable down, and tighten the clamp.

or

2. Arrange the trees on the bank, wrap the cable around them, run the cable ends through the clamp, cinch the cable down, and tighten the clamp. Install t-posts on the upland side of these trees. Tie rope around the trees and to the t-posts. Lower them as a chain into the water and move them into place. The rope will help to keep the trees in place.

- Clip the anchor cable to the log cable or wrap it around the logs and through the clamp. The required cable size and anchor design are dependent upon many variables, including tree size, water force, and soil type, and should be customized to fit specific site conditions.
- Cinch trees as close to the soil as possible.

For large trees use the recommendations for deadman size.

On a Christmas tree revetment:

- Insert the duckbill at a 45° angle into the bank to help assuage pull from rising, dropping, and rushing water. Hammer the duckbill into the soil as deeply as possible.
- Use inexpensive t-posts with smaller trees, 4 to 6 in. in diameter, to supplement duckbill anchors. They must be driven into the bed, on the streamside of the trees, well below the point of maximum bed scour.

If replacement becomes necessary:

- Cable the new tree directly over the original tree.
- Use soil bioengineering techniques within and behind revetments to restore stability and establish a riparian community.

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Tree revetment in Vermont.

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Excavator with bucket and thumb lowers first tree into river to secure toe. Chena River, AK.

USDA Forest Service

Willows are growing through this log boulder revetment and beginning to shade the water.

USDA Forest Service

The second tree in place with rock fill behind it. A vegetated geogrid was built on top of this foundation. Note that the branches were left intact on the waterside.

USDA Forest Service

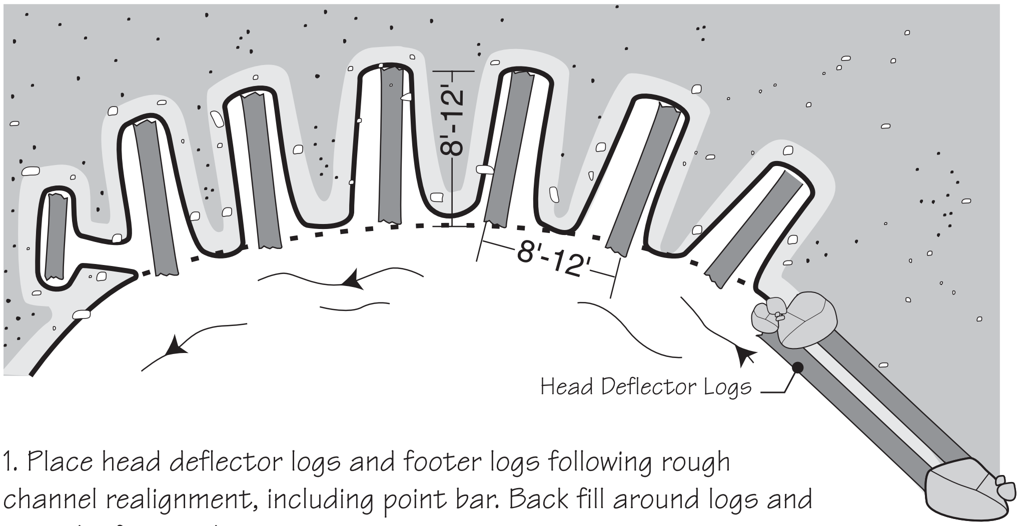
Log revetment with large boulders and root wads. Plumas NF.

Log Revetment

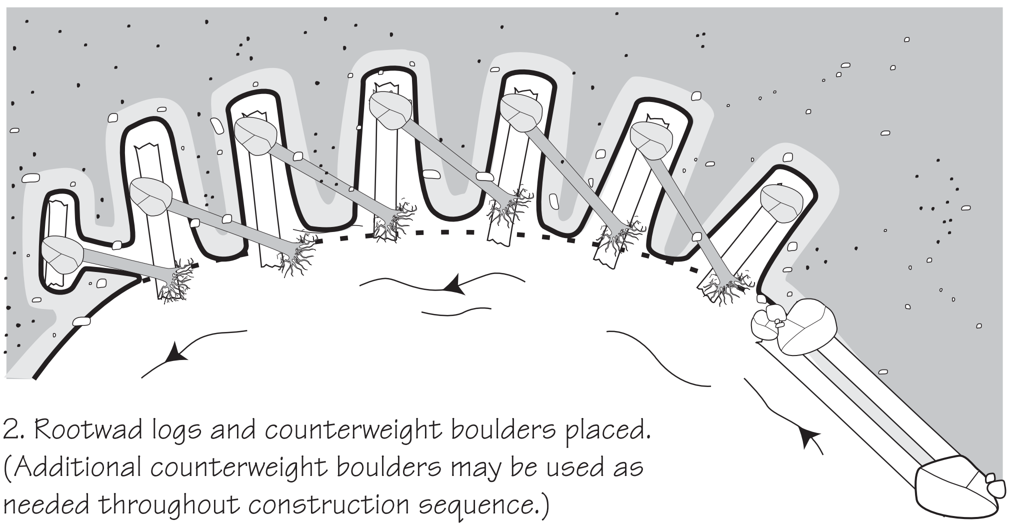
A log revetment is similar to a tree revetment. Generally, the branches are removed, and the logs are larger in diameter. Root wads and boulders can be incorporated into the design. The log revetments can be installed as previously described using a deadman and cables. The following six steps illustrate another way to assemble a log revetment.

LOG, ROOT WAD, BOULDER REVETMENT

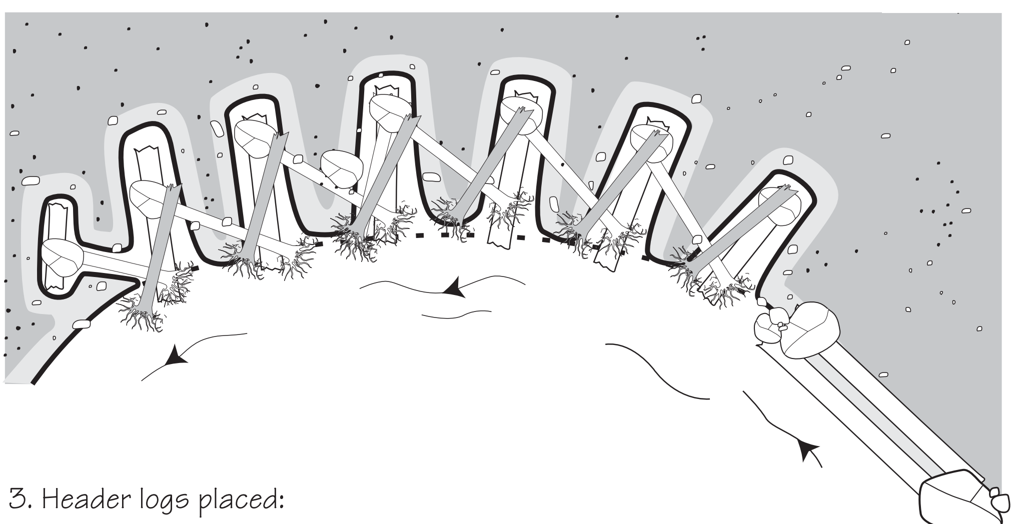
(Not to scale)



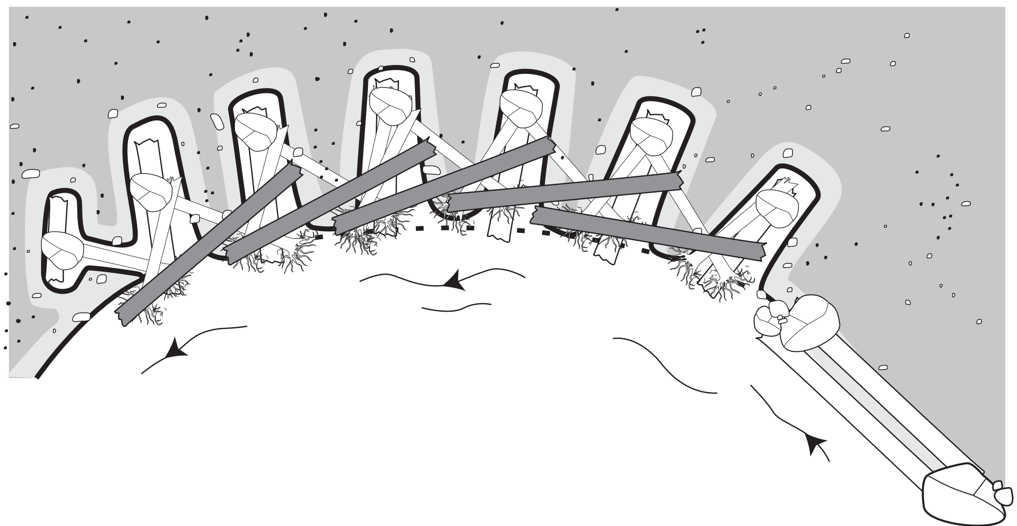
1. Place head deflector logs and footer logs following rough channel realignment, including point bar. Back fill around logs and or rock after each sequence.
(Note: actual construction sequence may vary from schematic.)



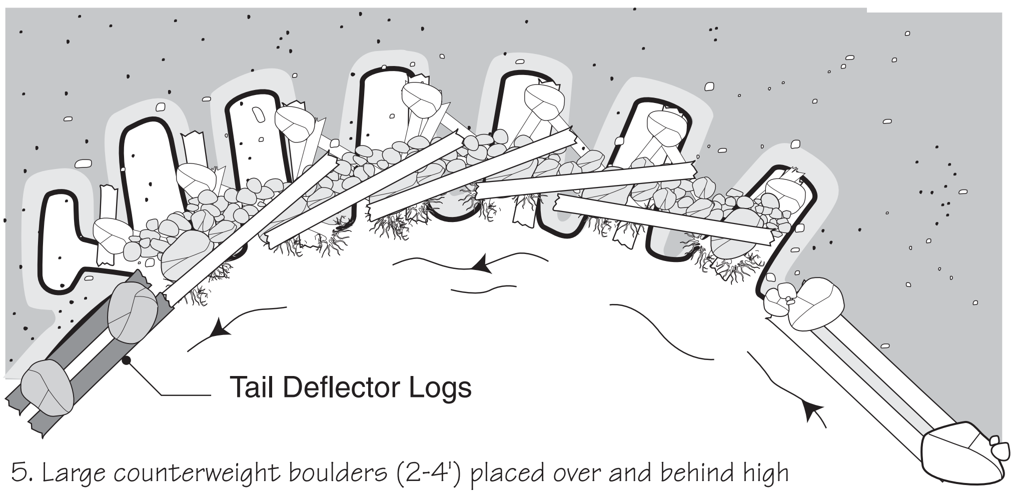
2. Rootwad logs and counterweight boulders placed. (Additional counterweight boulders may be used as needed throughout construction sequence.)



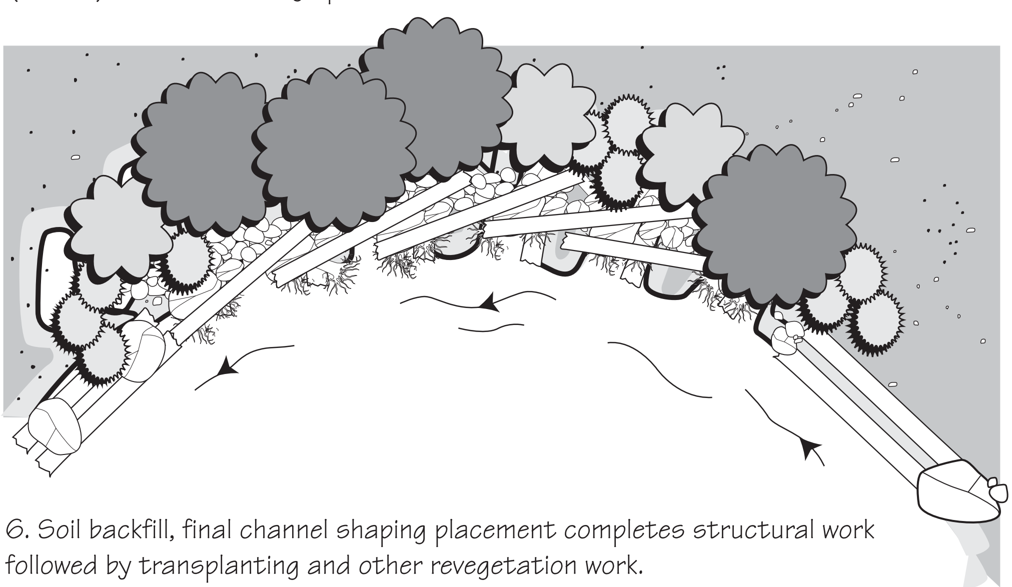
3. Header logs placed:
Used for more severe erosion during high flows.



4. High stage deflector logs placed.

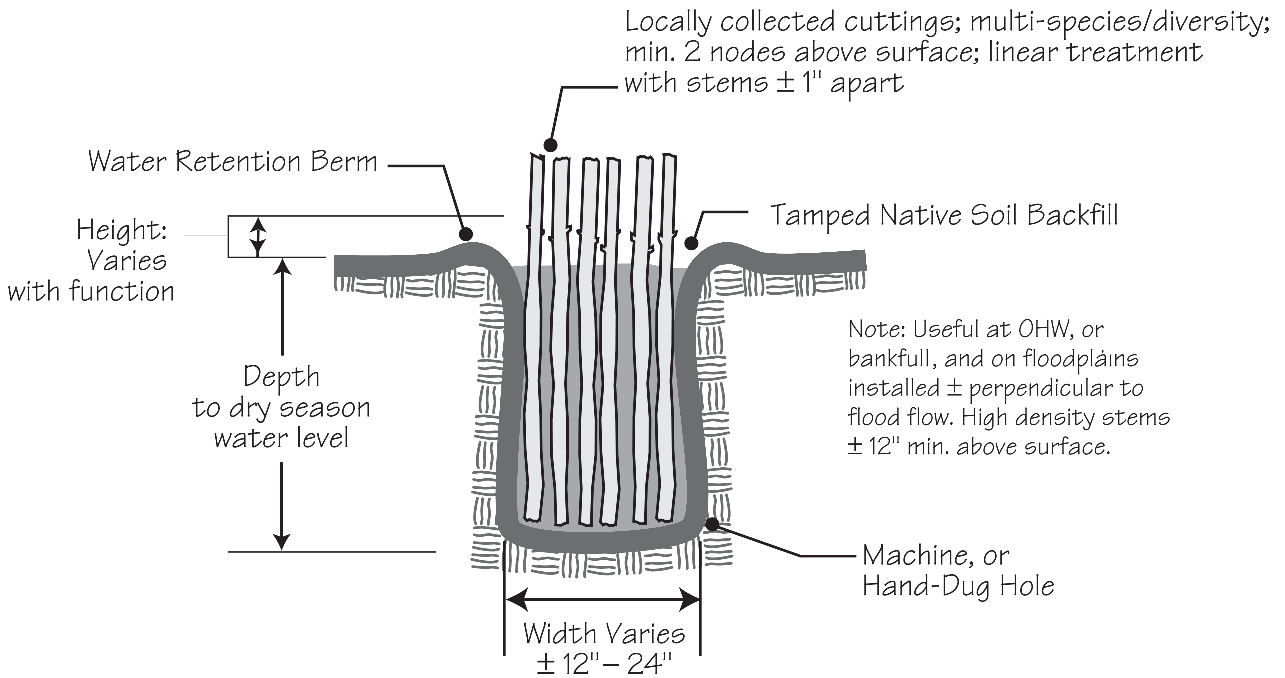


5. Large counterweight boulders (2-4') placed over and behind high stage deflector logs, followed by placement of smaller, cut-off rock (4"-12".) Tail deflector logs placed.



6. Soil backfill, final channel shaping placement completes structural work followed by transplanting and other revegetation work.

TRENCH PACK
(Not to scale)



Trench Pack

Trench packs act to break the force of moving water, and trap sediment. They are deciduous branch cuttings placed vertically in trenches or holes. Plant cuttings should be selected from the same zone in which they will be planted, such as at stream's edge, on the bank, or on the floodplain.

Applications and Effectiveness

Applications

- Install at ordinary high-water mark or bankfull level to stabilize the toe and to provide good fish habitat (follow the contour of the bank), on floodplains perpendicular to or in the direction of the flood flow.
- Use on lakeshores to combat wind and waves.
- Pack into gullies to catch sediment.

Effectiveness

- Traps sediment.
- Reduces velocities of wind and water.
- Provides a good barrier for rooted stock.
- Dries excessively wet sites through evapotranspiration.
- Reinforces soil with unrooted branch cuttings and with deep roots, adding resistance to sliding and shear displacement.
- Enhances conditions for colonization of native vegetation by creating surface stabilization and a microclimate conducive to plant growth.

Construction Guidelines

Live materials

- Use live deciduous material known for its good rooting structure.
- 1 to 1.5 in. in diameter, with side branches attached. Mix species if appropriate.
- Use cuttings long enough to reach the dry-season water level.

Fall planting: Branches should extend 2- to 3-ft. above ground to provide immediate bank protection. In spring, trim the branches back to two buds above ground to stimulate root growth.

Spring planting: Plant with branches extending no more than 12 in. above ground or branches with at least two buds.

Inert material

- Augment the pack with dead material, such as conifer branches, if live plant materials are unavailable to provide structural stability while the live material roots.
- Plant branches 3- to 4-ft. deep if the planting is subjected to moving, erosive water. In other situations, at least one-half the length of the cutting should be in the ground.

Installation

- Dig, by hand or machine, a hole or trench 12- to 24-in. wide to dry-season water level of the stream or lake. The trench can be any length, however, the ends of the trench must be tied into something solid or keyed into the bank.
- Place the branches in the trench, bud ends up. Pack branches to a 4-in. thickness.
- Tamp native soil around packed branches to ensure that they are in contact with the soil and not the air; air contact will stop growth.
- Construct a 2- to 4-in. water retention berm or basin on either side of the trench.
- Wet the surface to wash soil down into the trench. Add more soil, if necessary, so that there is good soil-to-stem contact throughout.


Rob Russell, Quincy, CA.

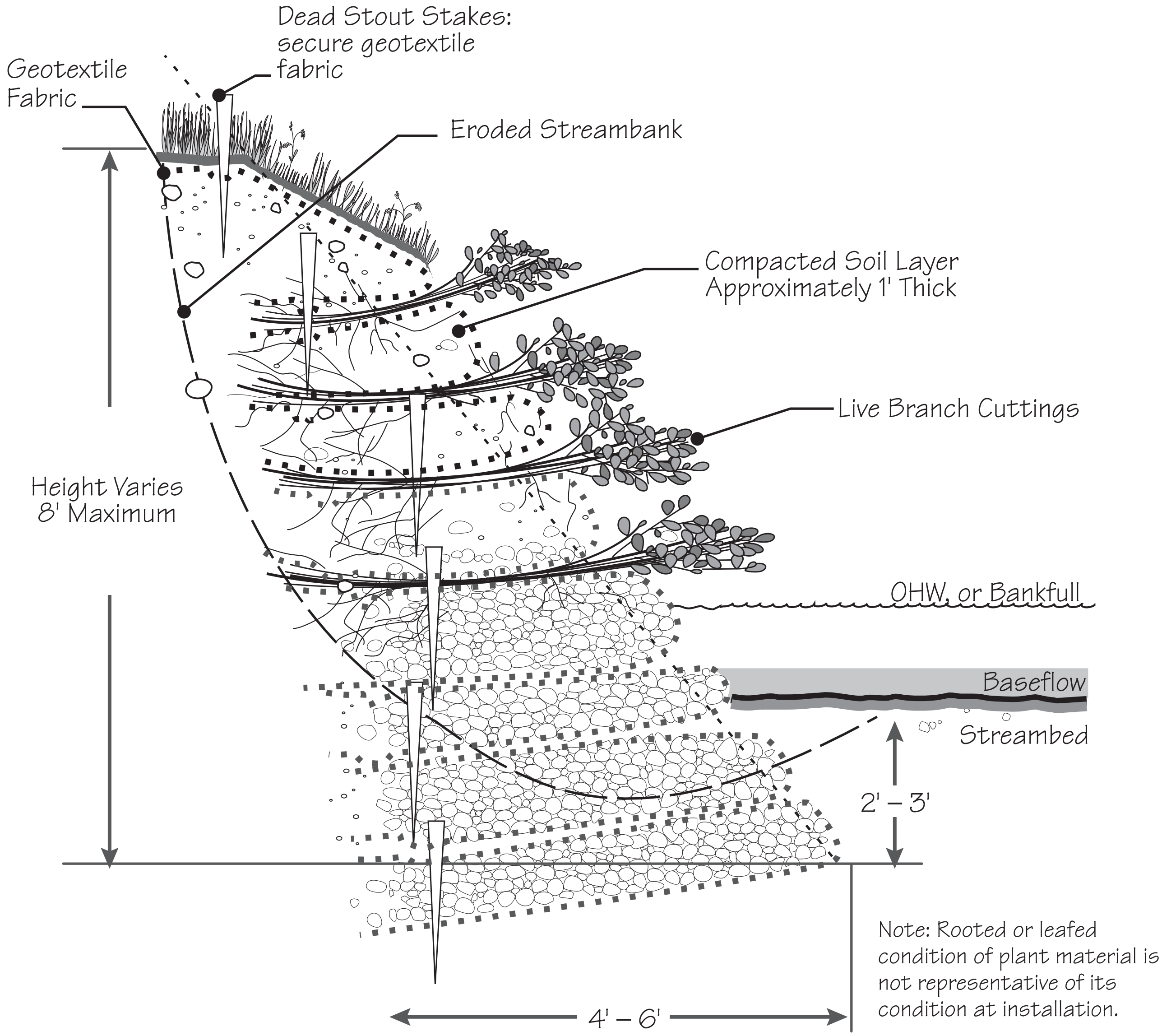
Trench packs in a gully with new spring growth. These were planted in the fall. They are approximately 1 in thick and 5 ft across. The cuttings are buried in 18 in of soil.


Rob Russell, Quincy, CA.

Trench pack, prior to leaf-out, on the edge of a flood plain.

VEGETATED GEOGRID

(Not to scale)



Vegetated Geogrid

Vegetated geogrids are used to rebuild a bank. They are similar to the brush layering fill technique except that an erosion control fabric (geotextile) is wrapped around each soil lift. Live branch cuttings are laid between the layers.

Applications and Effectiveness

Applications

- Benefits are similar to those of brush layering. Place a vegetated geogrid on a 1:1 or steeper streambank or lakeshore.
- Use above and below the ordinary high-water mark or bankfull level.
- Build only during low flow conditions.
- Use in restoring outside bends where erosion is a problem.

Effectiveness

- Produces a newly constructed, well-reinforced streambank.
- Captures sediment to further stabilize the streambank.
- Enhances conditions for colonization of native vegetation.
- Produces rapid vegetative growth.
- Can be complex and expensive.
- Functions immediately.


USDA Forest Service

Vegetated geogrid and light-penetrating elevated walk on Kenai River, AK.

Construction Guidelines

Live materials

- Use live branch cuttings that are brushy and root readily.
- Use cuttings 0.5 to 2 in. in diameter and 4- to 6-ft. long.

Inert material

- Biodegradable erosion control fabric is required.
- Soil suitable for plant growth.
- Batter board (4 by 12), the length of the geogrid, optional. This helps define the front edge of the lift during construction.
- Dead stout stakes to secure the live fascines. Make dead stout stakes from 2.5- to 4-ft. long, untreated, 2- by 4-ft. lumber. Cut each length diagonally across the 4-in. face to make two stakes. Use only sound lumber. Discard any stakes that shatter upon installation.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Second layer of a vegetated geogrid. Note first layer resting on top of tree revetment, Chena River, AK.

Installation

Rock Toe

- Dig a trench that is 2- to 3-ft. below streambank elevation and 3- to 4-ft. wide.
- Measure the width and length of the trench (layer), double the width, and add 12 in. (height of the layer) to the width. Cut a length of cloth. Install one layer before cutting all the pieces to be sure the lengths are correct.
- Fill the trench area 12 in. high with 2- to 3-in. diameter rocks.
- Fold the fabric over the rock and stake every 2 ft. along the length of the layer.

Branch cuttings

- Place, at the ordinary high-water mark or bankfull level, a 6- to 8-in. layer of live branch cuttings on top of the rock-filled geogrid with the growing tips at right angles to the streamflow. The basal ends of branch cuttings should touch the back of the excavated slope.
- Cover the branches with a layer of soil. Wet the surface to wash soil down in between the branches. Add more soil until the majority of stems are covered.
- Lay a batter board on edge at the front edge of a new lift. This is optional.
- Cover this layer of cuttings with cloth, leaving an overhang. Place a 12-in. layer of soil suitable for plant growth on top of the cloth before compacting it to ensure good soil contact with the branches. Wrap the overhanging portion of the cloth over the compacted soil to form the completed cloth wrap. Once the cloth is pulled up over the soil, adjust the cloth to ensure that it forms the desired contour without overhanging the layer below. Stake down the cloth. Remove the batter board. After each layer is formed, place cuttings.
- Continue this process of rebuilding the bank with lifts, alternating layers of cuttings and cloth wraps until the bank is restored to its original height.
- Limit this system to a maximum of 8 ft. in total height, including the 2- to 3-ft. below the bed. An engineering analysis should determine appropriate dimensions of the system.
- Match the final installation to the existing slope. Branch cuttings protrude only slightly from the lifts.