Minnesota Soil Bioengineering Handbook

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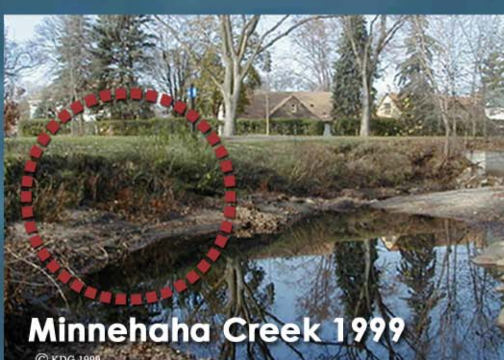
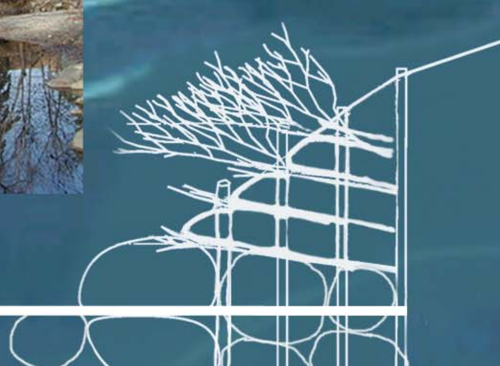
MINNESOTA
SOIL BIOENGINEERING HANDBOOK





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MINNESOTA DEPARTMENT OF TRANSPORTATION

About This Handbook

This book is inspired by **Leo Holm, P.E.** and **Dwayne Stenlund, CPESC**, who have worked steadily for decades to incorporate green and blue infrastructure such as soil bioengineering into transportation projects throughout the state of Minnesota.

This Minnesota Handbook of Soil Bioengineering is the latest publication in a series to assist public agencies, designers, engineers, and contractors, with the best available technology. This manual is a cooperative effort between Mn/DOT's Office of Environmental Services and The Kestrel Design Group, Inc.

The Kestrel Design Group, Inc. founded in 1989, is a Minneapolis-based firm specializing in sustainable landscape architecture, architecture, and environmental design.

Using This Handbook

This handbook is organized into six chapters. Chapter 1, a basic introduction to soil bioengineering is followed by Chapters 2 and 3 which explain how to design, construct and manage soil bioengineering projects. Chapter 4 covers built projects throughout the state of Minnesota. Chapter 5 is a resource list for names, addresses, and publications that you may need. Chapter 6 is a glossary of terms.

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CHAPTER 1. INTRODUCTION TO SOIL BIOENGINEERING

...the stake, which I had cut out of some trees that grew thereabouts, were all shot-out and grown with long branches, as much as a willow-tree usually shoots the first year after lopping its head...

From *Robinson Crusoe*, by Daniel Defoe, 1719

1.1 A NEW NAME FOR AN OLD TECHNIQUE

Soil bioengineering uses live and dead vegetation alone or in combination with natural support material to stabilize eroding and failing slopes (Schiechtl and Stern, 1997).

Hard Armor Versus Soft Armor

In America drastic land cover changes have occurred over the past two hundred years. Wetlands that filtered and protected larger bodies of water are gone. The amount of water and sediment that now reaches streams and lakes from stormwater runoff has increased as much as three to five-fold. Shear stress on stream banks and lakeshores is growing. Most deep-rooted streambank and lakeshore plants have been replaced with shallow rooted plants, such as turf or weeds. Many streams are severely eroded, degrading both water quality and aquatic habitat used by fish and other stream organisms.

In the past, erosion control problems have been addressed with a "**hard armor**" approach, such as the use of rock riprap, concrete channelized stream banks, and other traditional engineering practices (Fig. 1-1). Soil bioengineering with living vegetation is called "**soft armor**". It has many advantages over **hard armor.**

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Figure 1-1. Concrete channel hardening provides no habitat or biological benefits, and unlike "soft armor" soil bioengineering systems, decreases in strength with age.

Plant Roots are the Key

Soil bioengineering uses vegetation with deep roots. This includes **live cut branches**, shrubs, and herbaceous plants. Live branch cuttings act like giant living nails with side roots (called **adventitious roots**) that bind soil together (Fig. 1-2). Adventitious roots have a tensile strength greater than concrete! In contrast, the roots of most trees and turf grass (lawns) are found in the top twelve inches, providing little help in binding soil. Plants used in soil bioengineering, such as native prairie plants, evolved to absorb water deep below the surface with roots down to a depth of fifteen feet (Fig. 1-3, Weaver, 1969).

Advantages of Soil Bioengineering

Soil bioengineering is a self-repairing, self-sustaining system that strengthens with age. It has resilience and the potential to persist for decades because its strength comes from living plants which:

- will re-sprout if damaged by winter ice or a large flood, while **hard armor**, if moved by floods, cannot reposition itself.
- are an aesthetic amenity in contrast to structural approaches, which are often visually distracting.

- strengthen banks resistance to mass wasting by **transpiration** of water out of the soil, thus reducing forces leading to streambank collapse (Simon, 2002).
- are less disruptive to the stream hydrology and morphology than **hard armor**.
- slow water velocity, reducing flood peaks downstream because of increased channel roughness.
- provide wildlife habitat for mammals, birds, insects, fish and amphibians.
- shade water, keeping temperatures much cooler in summer; improving conditions for cool-water species such as trout.
- are less expensive to install and maintain than structural methods.
- protect homeowner's property investment by reducing soil loss.
- enhance water quality of stormwater runoff as microbes on plant roots break down pollutants before they reach their destination in lakes, streams, and rivers.
- are self-repairing, and strengthen with age.

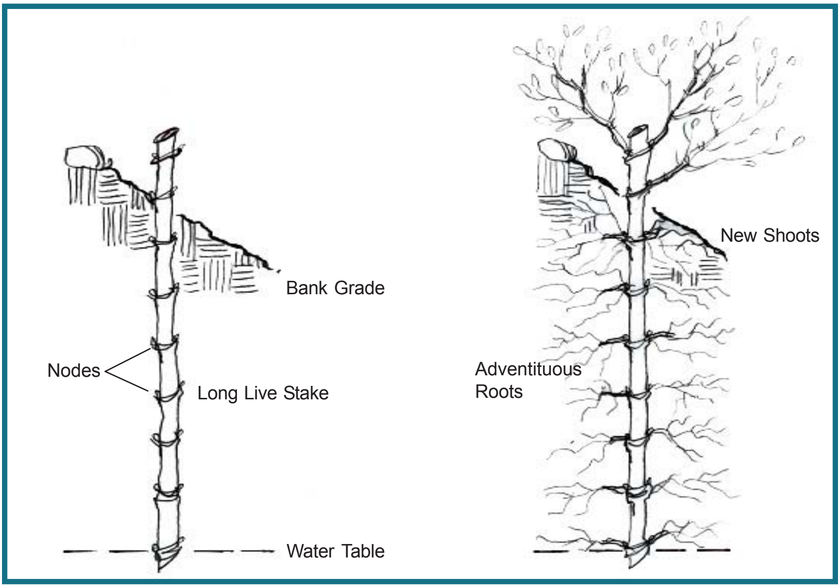

Figure 1-2. Deep adventitious roots hold soil and transpire bank moisture, which dries out the bank and prevents erosion.

Below the soil, deep roots act like giant nails and:

- buffer the shear stress of quickly flowing water.
- hold soil together through a fibrous network.
- anchor soil in place.
- increase the porosity of the soil matrix, allowing more water to infiltrate.
- increase resistance to sliding.
- have a tensile strength greater than concrete.

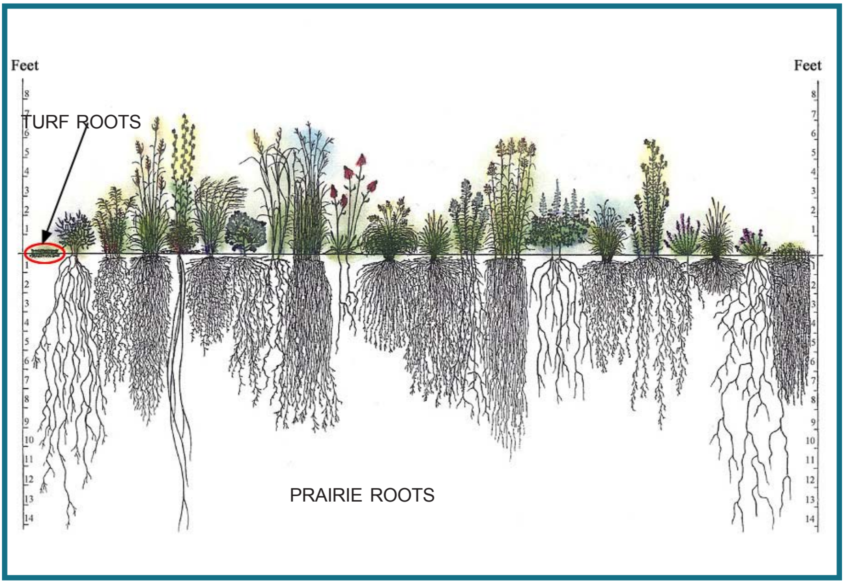

Figure 1-3. Turf vs. Prairie Roots. Notice that shallow turf roots have little soil holding power. CDF after Weaver.

Above the soil, leaves and stems:

- shield soil from rain, runoff and water currents.
- minimize the force of rain and wind.
- hold water until it evaporates; up to 30-40% of a rain event will not reach the ground, depending on tree species and storm type (Dunne & Leopold, 1996).
- reduce variations in temperature and moisture content, moderating effects of overly dry or waterlogged soils and minimizing breakdown of soil aggregates.

- act as sediment traps, preventing sediment from reaching streams which improves water quality.
- break up slope length into shorter runs, reducing speeds through frequent interruptions.

Disadvantages of Soil Bioengineering

Both the strengths and weaknesses in the system are related to the fact that living plants are used. The old gardener's motto that encourages patience is just as valid here, "First year they sleep, second year they creep, third year they leap." Plants take time to mature and look lush and natural. Immediately following installation soil bioengineering looks unfinished. Within one to two growing seasons, major growth occurs. By the fourth growing season the vegetation is flourishing.

Installation must be done in early spring. Cuttings must be installed when they are dormant which compresses the length of time available to install in any given growing season.

Soil bioengineering treatments are weakest at installation. Young plants are vulnerable to natural processes including adverse weather, disturbance, and herbivory by animals. Plants, like all living systems, may die or fail to perform to their potential. To offset fatalities, **live cut branches** are planted tightly together. If only a third of the branches survive the project will likely still be a success.

1.2 STRENGTH AND PERFORMANCE

Engineers who design stream restoration or erosion control projects must follow design guidelines that are based on quantitative research and testing. For many bioengineering materials, particularly **coir logs**, **erosion control blankets** and **geotextile fabrics** these figures are now available. Current research originates primarily from product vendors, although state-funded labs, such as the Texas Transportation Institute and Utah State University are testing soil bioengineering materials because of the cost-savings potential for publicly funded infrastructure projects.

Research conducted by the U.S. Army Corps of Engineers has demonstrated that bioengineering projects can provide resistance to erosion comparable to **hard armor**. Soil bioengineering techniques have been found to withstand water velocities up to 12 feet per second (fps) for **brush mattresses**, 9.5 fps for **coir rolls**, and 10 fps for a **log revetment** with coir geotextile roll seeded with grass (see Table 1.1, Allen and Leech, 1997). **Live stakes** have a permissible velocity of up to 10 fps.

Shear stress (the force exerted on the soil surface by flowing water) of up to 8 lb/ft^2 can be sustained by live **brush mattresses** and vegetated **coir rolls**. This is equivalent to the resistance provided by 18" riprap, according to stability thresholds developed by the U.S. Army Corps of Engineers Waterways Experiment Station (Fischenich, 2001).

Table 1.1 Strength of Soil Bioengineering Techniques

LOCATION	SOIL BIOENGINEERING TECHNIQUE	STREAM VELOCITY (FPS) SURVIVED
Roaring Fork River, CO	Log revetment with coir geotextile roll and grass seeding above roll. Logs anchored with cables	10.0
Snowmass Creek, CO	Root wads with large root pads (clumps) of willow	8.7
Upper Truckee, CA	Root wads with large root clumps of willow	4.0
Court Creek, IL	Dormant willow posts with geotextile roll and riprap at toe with cedar trees placed between willow rows.	3.1

Source of data: US Army Corps of Engineers (Allen and Leech, 1997)

TYPE OF MATERIAL	SHEAR STRENGTH (LB/FT²)
Rip-rap (boulder toe) with Live Stakes	6.10
Brush Mattress	6.10
Coarse Gravel with Live Stakes	5.08
12-inch Rock Rip-rap	4.00
Willow Brush Layer	2.84
Live Fascine	2.45
Live Stakes	2.26
Ideal Dense Sod	2.10
6-inch Rock Rip-rap	2.00
Grass and Legume Plot	1.40
1-inch Gravel	0.33

Source of data: "Planning Bioetechnical Streambank Protection." US Dept. of Agriculture, Agroforestry Notes #24, March 2002

1.3 HISTORICAL EXAMPLES

Soil Bioengineering Through History

Field and laboratory tests have verified what many cultures have known for centuries: plant root systems are a powerful tool for re-enforcement of soil strength. Soil bioengineering has a long history in many cultures:

- Soil bioengineering has been in common usage in England since Pre-Roman times – over 2000 years ago. During the Medieval period the English used living and dead willow bundles to construct low fences and walls.
- Chinese historians recorded the use of soil bioengineering for dike repair as early as 28 B.C. 14th century Chinese paintings show workers installing soil bioengineering on a mountainside.
- Photos document 100-year-old soil bioengineering projects in Alpine streams in Austria still stable today (Fig. 1-4).
- Wing dams constructed on the Mississippi River in the late 1800's to narrow and deepen the channel for navigation were built using brush bundles and with rock fill (Fig. 2-1).
- California forester Charles Kraebel used these techniques to stabilize clear-cut mountainsides in the California Sierras during the 1930's; still intact today.

Figure 1-4. A soil bioengineered riparian bank using deep live posts in the Alps of Europe that is over 100 years old. Schiechtl and Stern 1994

A Word About Wattles...

The medieval English wattle fences and hedgerows were some of the earliest soil bioengineering practices. The word "**wattle**" is from the Old English term "*watel*," which means a "hurdle," or to weave branches of wood into structures such as low fences for holding livestock, roofs, and walls (Fig. 1-5).

The term *wattle* is now used to describe several different soil bioengineering techniques, which also involve the weaving and intertwining together of branch cuttings, either live or dead. Because it is a non-specific term with several different, often interchangeable meanings, we avoid the use of the term *wattle* in this handbook as applied to specific techniques. Sometimes the term *wattle* is used to mean the same thing as **fascine** or **brush mattress**. Fascines and Brush mattresses are more specific and not to be confused with each other. However, it could be said that both of them are based on the idea of the wattle.

"***Some also with young Willow trees, set by certaine distances, and the drie black thorne (purchased from the wood) being bound in (between the spaces) so framed their inclosure*. . ." Thomas Hill, 1577

Figure 1-5. Medieval European gardeners and farmers used early versions of contemporary soil bioengineering techniques -- such as wattle fences made from willows and living hedgerows -- to enclose pastures, farmland, and gardens.

Image source: Bartolomeo Scappi, 1570

CHAPTER 2. SOIL BIOENGINEERING DESIGN AND PLANNING

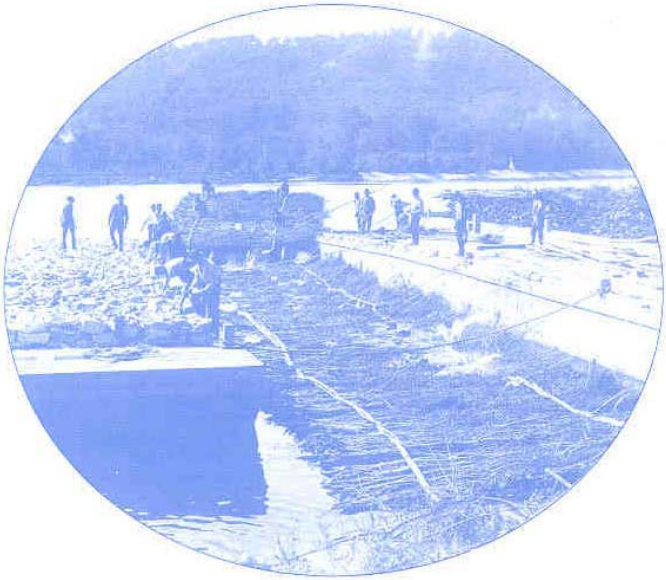

Figure 2-1. Building wing dams on the Mississippi River in Minneapolis circa 1890's. Note the use of brush mattresses.
Photo by H. Bosse 1890, in Neuzil 2001

2.1 BEGINNING YOUR PROJECT

Where to Use Soil Bioengineering

Soil bioengineering is used where slopes are failing and vegetation would be an appropriate solution such as stream banks, lakeshores, and high steep hillsides (Fig. 2-2). Soil bioengineering is not limited to rural locations, but can work in cities too. For high visibility locations, the aesthetics of using living plants is strongly favored by the public.

To begin, study the current condition of the site and identify the problems. Look at the whole watershed, particularly upstream. Stream channels are expressions of landscape and watershed processes and streambank erosion is often a symptom of upstream conditions.

Figure 2-2. Severe channel erosion including down cutting and mass wasting.
Pike Creek, Maple Grove, MN.

Permits and Legal Issues

Work in Easements

Drainage and Utility easements exist along streams and public ditches. Watershed districts or other local governments hold maintenance rights. Most public ditches in Minnesota have a 25' to 100' easement along both sides of the ditch, where the placement of permanent structures is prohibited. As long as work does not impede access to the stream or river for future maintenance, it should not conflict with most local regulations. Contact your local watershed district or local government unit (municipality, county) to determine which permits, if any, are needed.

Work in Public Waters

Most navigable waters (any stream that is large enough to float a canoe) are public waters owned by the state. Work in a public water that may impede flow (such as bridge construction), change the channel cross-section, or require water draw down during construction may require a permit from the Minnesota DNR Department of Waters and the U.S. Army Corps of Engineers.

2.2 SOIL BIOENGINEERING BASIC MATERIALS

Dead Stout Stake:

a stake cut from dimensional lumber with a sharp point to secure erosion control fabric and soil bioengineering materials to the ground.

Erosion Control Fabric:

a *permanent (synthetic fiber) or temporary (natural, biodegradable) textile, that protects soil from erosion forces, keeps seeds in place, supports seed germination and seedling growth until good vegetative cover is established.*

Coir:

a natural fiber made from the husks of coconuts, which is stronger than other natural fibers, and is biodegradable; used as a material to make twine and fiber rolls used in soil bioengineering.

Plant Amendments:

such as **rooting hormone**, **soil mycorrhizae**, *and* **super-absorbent polymer** *will help soil bioengineering plant material become established; fertilizer should be phosphorus-free and only used in low-nutrient mediums.*

Live Cuttings:

woody branch cuttings taken from live shrubs and trees during the **dormant** *season; inserted into the ground while dormant, will become established during growing season under suitable growing conditions; used as live material in many soil bioengineering applications such as* **fascines**, **brush mattresses**, *and* **live stakes**.

Floating Silt Curtain:

an erosion control device that keeps sediment out of waterbodies with a membrane suspended from a floating element and anchored to the bottom of a pond or stream.

Live Plant Material:

includes potted plants, bare root trees and shrubs, and **herbaceous plugs**, *in addition to dormant* **live branch cuttings**.

Shredded Hardwood Mulch:

made from shredded hardwood or bark; reduces weeds during new plant establishment and enriches soil as it breaks down; one yard covers 80 ft² *to a depth of 4*".

2.3 TOP 11 MINNESOTA SOIL BIOENGINEERING TECHNIQUES

1. Boulder Toe - *boulders placed at the bottom of a slope or bank to increase stability, effective in combination with* **live stakes***,* **fascines**, *or* **brush mattress**.

Application: streambanks and shorelines

Effectiveness:

- Immediate and highly effective stabilization to streambanks.
- Toe extends to **bank full elevation** in stream channel.
- Does not provide wildlife habitat enhancement.
- Provides immediate protection for plantings while they establish in streams that are have highly erosive velocities or frequent, severe stormwater events.

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Figure 2-3. Boulder toe installation, before soil bioengineering plantings. Floating silt curtain is used to control sediment in the stream during construction. Minnehaha Creek, Minneapolis.

Material Preparation

- Stone should be round, undressed, with no sharp or flat surfaces.
- Stone is Class V Mn/DOT uncut, undressed field stone boulders in accordance with Mn/DOT 3601.2A, with no blast or shear marks.
- Use a minimum of 2 boulders 24" to 36" in diameter per linear foot throughout boulder toe.

Installation

- Install prior to soil bioengineering planting.
- Do not use treatment to fill in existing channel.
- Floating silt curtain may be required to keep sediment out of water body.

Boulder Toe Details

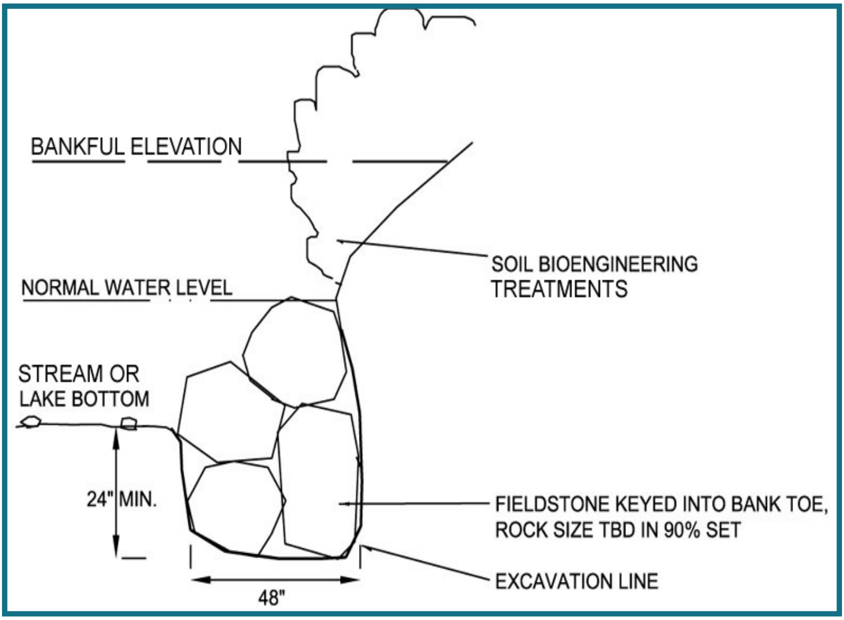

Figure 2-4. Boulder toe detail, cross-section, not to scale.

TOP 11 SOIL BIOENGINEERING TECHNIQUES:

2. Brush Bundles – **live cut branches** *placed in a trench excavated along bank contours above* **bank full elevation**. *Alternating layers of* **live cut branches** *and compacted backfill repair small holes in banks and create a filter that keeps sediment from washing into streams. Also known as* "**brush layering**" *or* "**branch packing**."

Application: streambanks and slopes

Effectiveness

- Forms an immediate, protective structure to reduce erosion on the slope.
- Can be combined with cut or fill grading to repair holes in a slope.
- Interupts the length of sheetflow on slopes and filters sediment out of runoff.
- Is a similar technique to **vegetated reinforced soil stabilization** (VRSS), but is simpler to install.

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Figure 2-5. The basal ends of brush bundle live cuttings are dipped in rooting hormone before installation.

Material Preparation

- Must be prepared immediately before installation and installed in dormant season.
- Group **live cut branches** into bundles that are 6"- 8" in diameter. Do not trim branch ends from cuttings.

Installation

- Dig shallow trench back into bank 18"- 24".
- Add 1 teaspoon of **super-absorbent polymer** and 1 teabag of **soil mycorrhizae** ammendment per linear foot of trench.
- Dip bottom 4" to 6" of basal ends into IBA **rooting hormone** (Rhizopon AA #2 or equal).
- Place brush bundles in trench 2' on center, basal ends into the bank with branch ends extending 1/4 of their length out from the bank.
- Backfill with soil to ASTM 50%-85% and keep moist.

Brush Bundle Details

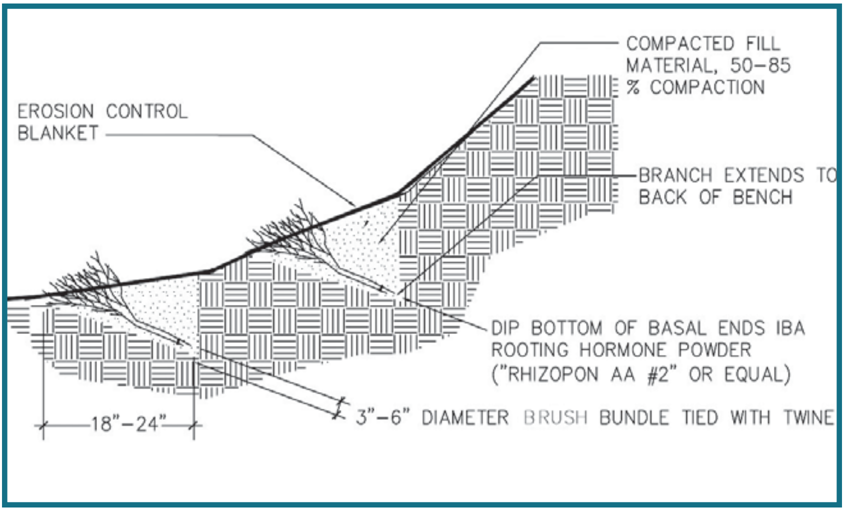

Figure 2-6. Brush bundle cross-section, not to scale. Brush bundles are also known as **brush layers or wattles.**

TOP 11 SOIL BIOENGINEERING TECHNIQUES:

3. Brush Mattress *– a mat or mattress created from woven wire, single strands of wire, or coir twine and* **live cut branches** *secured to a bank with stakes, wire and twine.*

Application: streambanks

Effectiveness

- Forms an immediate, protective cover over the streambank.
- Filters out sediment during flood conditions.
- Method of rapid revegetation and habitat restoration along streambanks.
- Enhances colonization by native plant species by creating a microclimate for germination.

Material Preparation

- branches up to 2.5" in diameter are cut 3' to 10' long.
- Must be prepared immediately before installation and installed in dormant season.

© Sonia Maassel Jacobsen, USDA-NRCS 2005

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Figure 2-7. Live branch cuttings (LEFT) and brush mattress installation (RIGHT).

Installation

- Grade slope uniformly to a maximum slope of 3:1.
- Use **live** and **dead stout stakes** to secure 8" thick mat of live branches.
- Wrap wire or biodegradeable coir twine around each stake no closer than 6" from ground, and stretch diagonally to each **dead stout stake**.
- Tamp and drive dead stout stakes into the ground until branches are tightly secured to the slope.
- Place **fascine** in trench at **bank full elevation**, over the basal ends of the branches; drive live or dead stakes into fascines and into the ground.
- **Boulder toe** may be installed at toe for protection along erosive streams.
- Cover with thin layers of soil in voids to promote rooting.

Brush Mattress Details

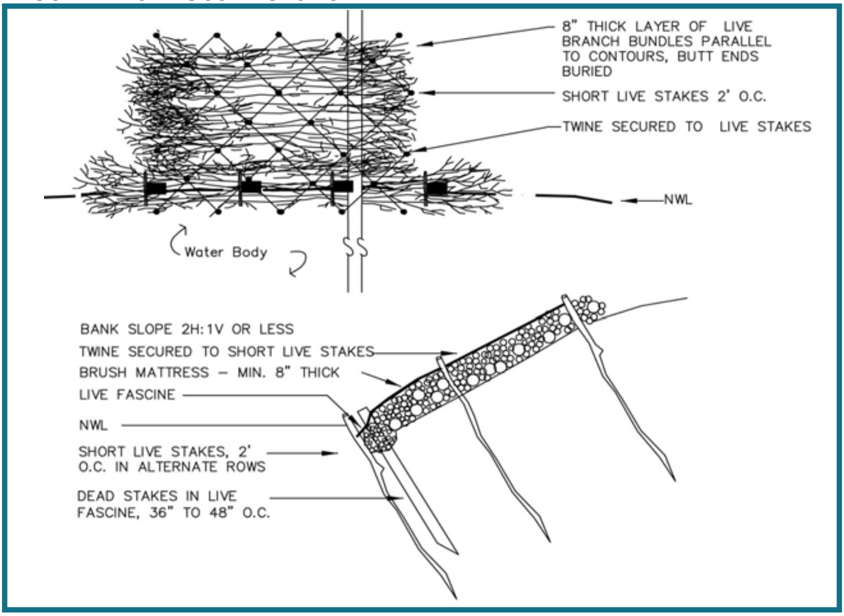

Figure 2-8. Brush mattress plan and cross-section, not to scale.

TOP 11 SOIL BIOENGINEERING TECHNIQUES:

4. Fascine – *long bundles of* **live branch cuttings** *placed in shallow trenches parallel or diagonal to stream banks, and secured with* **dead stout stakes** *into the soil, at or just above base*
flow elevation. Used in combination with **erosion control fabric**.

Application: streambanks or slopes

Effectiveness

- Structural system offers immediate reduction in surface erosion.
- Effective treatment for streambanks.
- Enhances colonization of native plant species by creating a microclimate for germination.
- Provides cooling shade for coldwater streams.
- Apply above **bank full elevation** in most cases.

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Figure 2-9. Live fascines installed at the toe and diagonally across an urban streambank to repair severe erosion.
Minnehaha Creek, Minneapolis.

Material Preparation

- Prepare **live stakes** and **fascines** immediately before installation, during dormant season.
- Group live cuttings together into bundles, 5' to 10' long, with **coir twine**.
- Wrap twine around fascine 1' on center.

Installation

- Place fascine in shallow trench on contour at or above bank flow elevation or diagonally across slope.
- Drive **dead stout stake** 3' on center through fascine, with top of stake flush with top of fascine.
- Live stake can be driven through or adjacent to stake.
- Cover fascine with soil to fill loose voids.

Fascine Details

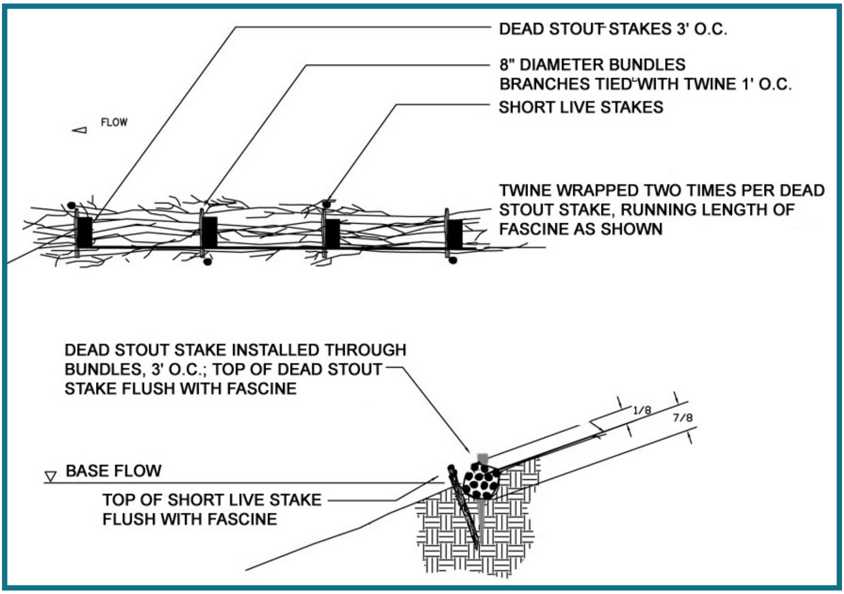

Figure 2-10. Fascine details, plan and cross-section. Not to scale.

TOP 11 SOIL BIOENGINEERING TECHNIQUES:

5. Fiber Roll *– pre-fabricated, high-density coconut fiber products that provide erosion protection along shorelines, creating a microhabitat for establishment of bank stabilizing vegetation – also known as* **coir** *rolls or fiber logs*

Application: pond and lake shore

Effectiveness

- Breaks up wave energy perpendicular to the bank.
- Flexible product can fit tightly to the bank.
- Rapid stabilization without much site disturbance.
- Not appropriate for sites with flows that are parallel to the bank, such as streams.
- Not appropriate for sites with large ice build-up.
- Can be used out in the water to protect the shoreline from wave energy.
- Manufacturer's estimate product effectiveness for 6 to 10 years.

Figure 2-11. Fiber rolls after installation on a lake shore.

Installation

- Excavate shallow trench at toe of slope to a depth slightly below channel depth.
- Place fiber rolls in the trench and drive **dead stout stake** through the roll into the ground.
- Space stakes 2' to 4' on center, on both sides of the roll. Anchor rolls firmly with **dead stout stakes**, as the rolls are bouyant.
- Stretch twine diagonally across roll from stake to stake.
- If planting fiber rolls with **herbaceous plugs** or **live stakes**, roots or stake must extend to water table for plant establishment. Plants will not survive if the roots are not in contact with water table and substrate below fiber roll.

Fiber Roll Details

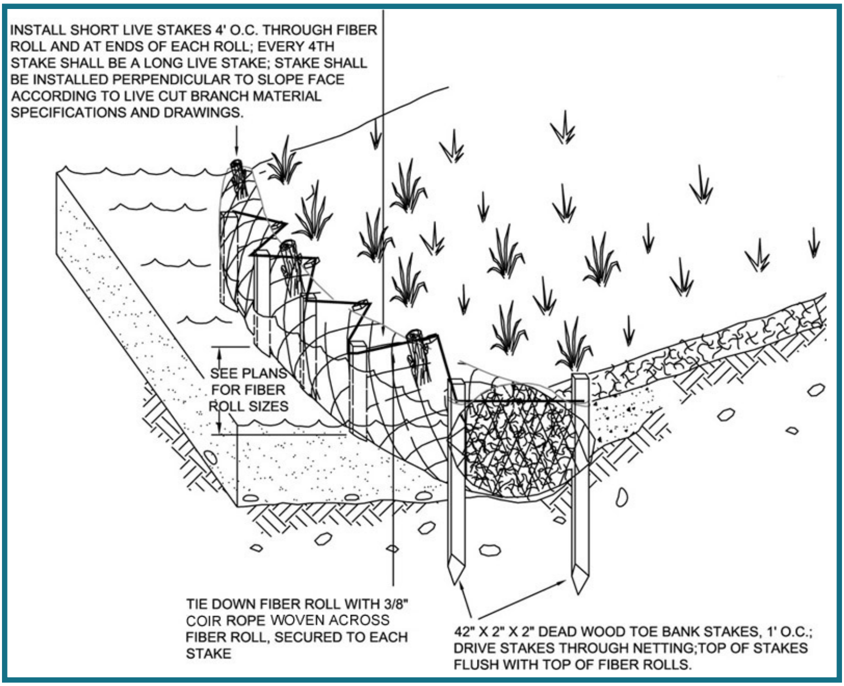

Figure 2-12. Fiber rolls detail, not to scale.

TOP 11 SOIL BIOENGINEERING TECHNIQUES:

6. Live Stake – *live, rootable woody vegetative cutting inserted into the ground; creates a living root mat that extracts excess soil moisture through plant* **transpiration**.

Application: slopes, streambanks, and shorelines

Effectiveness

- Effective streambank stabilization technique that is simple, inexpensive, and easily installed with little site disturbance.
- Can be used as a stake system to pin down and secure surface erosion control treatments.
- Stabilizes areas in between other soil bioengineering treatments.
- Provides streamside habitat and cooling shade.
- Best used in areas where stakes are in contact with water table or moist soil to promote rooting.
- 75% - 90% survival rates with proper installation.

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Figure 2-13. Installation of live stakes during the dormant season with a backhoe. Pike Creek, Maple Grove, MN

Material Preparation

- Use healthy, straight, live wood at least one year old.
- If live stakes cannot be installed within 24 hours of harvesting, they may be placed in cold storage (35° F) and kept moist and alive.
- Soak stakes in water for 24 hours prior to installation.
- Stakes are generally 0.5" to 1.5" in diameter and 3' to 6' long. Live posts are stakes up to 6" in diameter.
- Prune basal ends at 30° to 45° and cut top ends square and clean at 90°.

Installation

- Dip bottom 4" to 6" of basal ends into IBA **rooting hormone** (Rhizopon AA #2 or equal).
- Install stakes 2' to 3' on center in a triangular pattern.
- Create pilot hole if needed with metal bar moved back and forth.
- Install stakes and posts by hand into soft earth, or with tools such as hand mallets and machinery.
- Expose 2 to 5 buds above soil, oriented upward.
- Secure **erosion control fabric** with live stakes.
- Do not split stakes during installation. Split stakes should be removed and replaced.

Live Stake Details

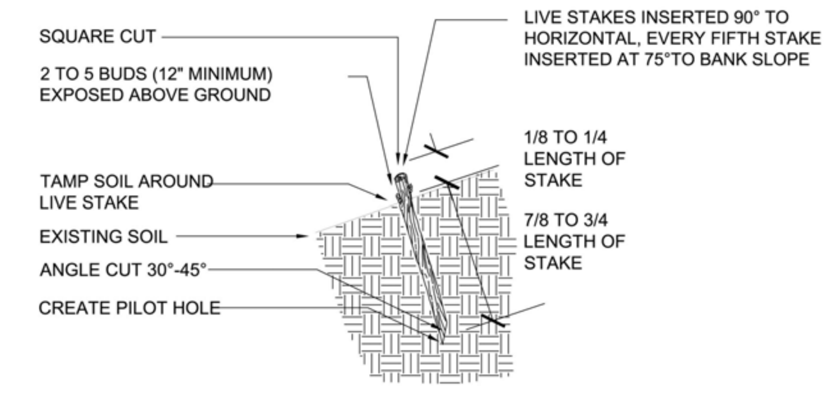

Figure 2-14. Live stake detail, cross-section, not to scale.

TOP 11 SOIL BIOENGINEERING TECHNIQUES:

7. Rock Vane – *structure made of boulders, placed in stream channel in the shape of a "V" to direct current towards the center of the channel and reduce bank erosion. This is an alternative to other hard armor stream engineering techniques such as weir structures and gabions.*

Application: channels, streams, and rivers

Effectiveness

- Provides immediate, effective stabilization to stream banks.
- Good replacement for aging weir and gabion structures with a longer lifespan and fewer long term costs.
- A naturalistic alternative to traditional engineering practices.
- **Riffles** and pools can be constructed to increase stream oxygenation and habitat.

Figure 2-15. Rock vane installation. Pike Creek, Maple Grove, MN

Material Preparation

- Boulders should be round granitic stones, uncut, free from blast marks, no square faces.
- Limestone should not be used because it is not durable.

Installation

- Install during low flow stream conditions.

Figure 2-16. Rock vane and riffles after soil bioengineering construction.

Rock Vane Details

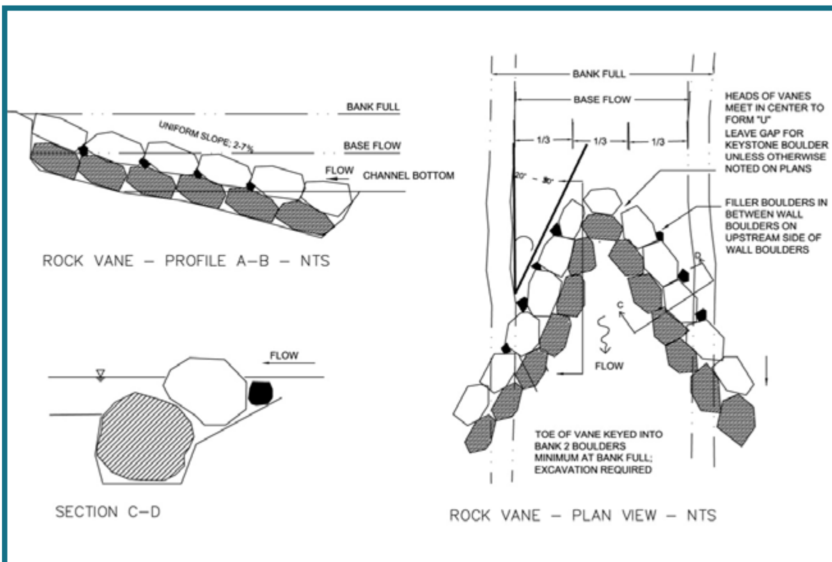

Figure 2-17. Rock vane plan and cross-sections, not to scale.

TOP 11 SOIL BIOENGINEERING TECHNIQUES:

8. Root Wad *– a large tree trunk and root flare buried into a streambank to provide armored protection against erosion and create habitat for aquatic organisms, especially juvenile fish.*

Application: streambanks

Effectiveness:

- Well suited for higher velocity rivers and streams.
- Provides toe support for bank revegetation techniques and collects sediment and debris that will enhance bank structure over time.
- Stabilization of stream banks at points that receive the highest erosive flow velocities.
- Root wads are economical, and can be harvested and reused from trees on site.

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Figure 2-18. Rootwad installed in stream. Washington County, MN.

Material Preparation

- 14' to 20' long tree with root wad, minimum 12" diameter trunk.
- Footer boulders shall be 350 to 450 lbs, 24" to 30" in diameter uncut, undressed boulders, in accordance with the applicable provisions of Mn/Dot Specifications Section 3601.2A.

Installation

- Support root wad with footer log.
- Bury footer boulder to anchor root wad in place.
- Bury trunk in streambed, root end into the stream, with a backhoe.
- Extend root wad vertically from streambed to a minimum bank full elevation.
- Install at a slope of 2" of rise per 12" of run from back to front (towards root) – higher on stream side than bank

Root Wad Details

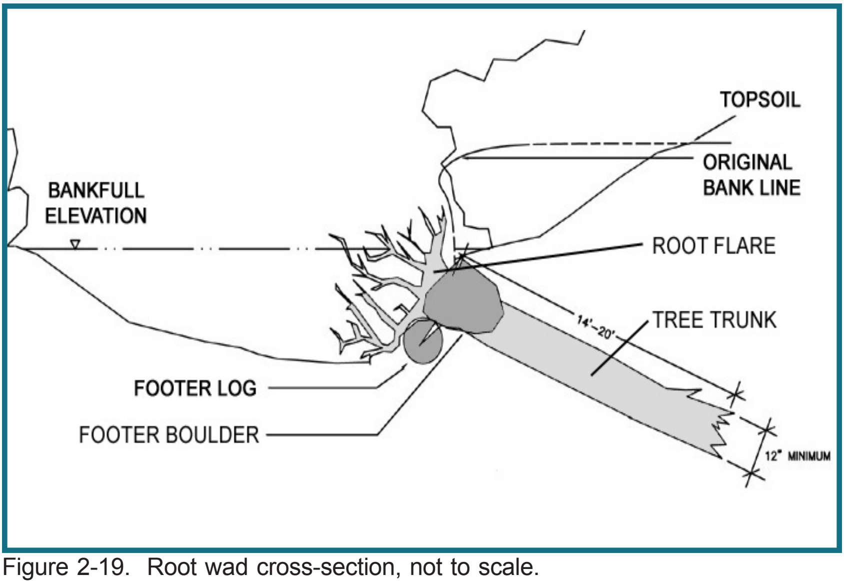

Figure 2-19. Root wad cross-section, not to scale.

2.0 DESIGN AND PLANNING

TOP 11 SOIL BIOENGINEERING TECHNIQUES:

9. Upland Buffer – *planting the area along a stream or wet area with a band of seeds or herbaceous live plants to stabilize soil and prevent erosion.*

Application: upland areas adjacent to water bodies

Effectiveness

- Effective at slowing or stopping surface runoff, keeping sediment and pollution out of water bodies.
- Stabilizes soil along a waterbody or in the watershed.
- Studies show that undisturbed native prairie can infiltrate up to 9" of water per hour.

Installation

- Seed large areas; use **herbaceous plugs** for small areas.
- Cover crop of oats, rye, Re-Green®, or black-eyed Susan.
- Excavated muck soils can be spread and planted in the buffer.
- Use shredded hardwood or straw mulch in live plantings.

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Figure 2-20. Installing herbaceous prairie seed with a no-till drill.
Lake Nokomis Stormwater Wetlands, Minneapolis.

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Figure 2-21. Upland wetland buffer three years after planting.
Lake Nokomis Stormwater Wetlands, Minneapolis.

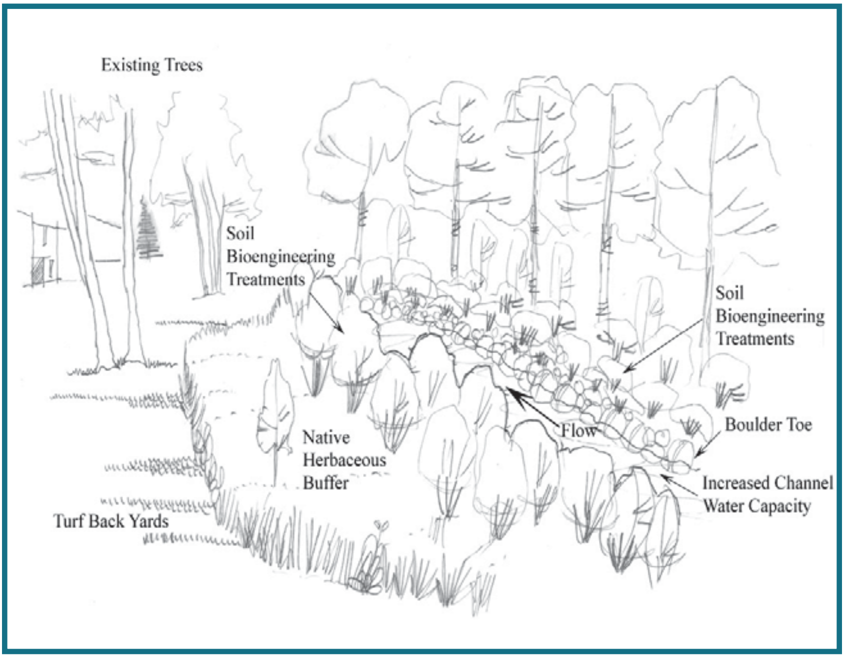

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Figure 2-22. Upland buffer and streambank soil bioengineering techniques.

2.0 DESIGN AND PLANNING

TOP 11 SOIL BIOENGINEERING TECHNIQUES:

10. Vegetated Geotextile – *natural or synthetic* **erosion control fabric** *anchored to the ground with live woody plant material, such as a combination of* **live stakes**, **fascines**, *potted and bare root shrubs. The system is reinforced with* **dead stout stakes** *and* **coir** *twine. It can also be supplemented with live* **herbaceous plugs**.

Application: streambanks, shorelines, and slopes

Effectiveness:

- Immediate surface erosion protection until vegetative cover matures.
- Useful for stream bank buffer and slope stabilization.
- Becomes stronger and more effective with age.

© KDG 2002

Figure 2-23. Vegetative geotextile including fascines and live stakes.
Minnehaha Creek, Minneapolis

Material Preparation

- Vegetation preparation will vary depending on the **live cutting** technique that is used.
- Live cutting component must be installed during **dormant** season.

Installation

- Install erosion control blanket.
- Install **wattles** at the base flow and **bank full** streambank elevations.
- Secure **erosion control blanket** with **dead stout stakes** driven through wattles and blanket and into the ground.
- Cut an "X" in the blanket where potted plants will be installed.

2.0 DESIGN AND PLANNING

Vegetated Geotextile Details

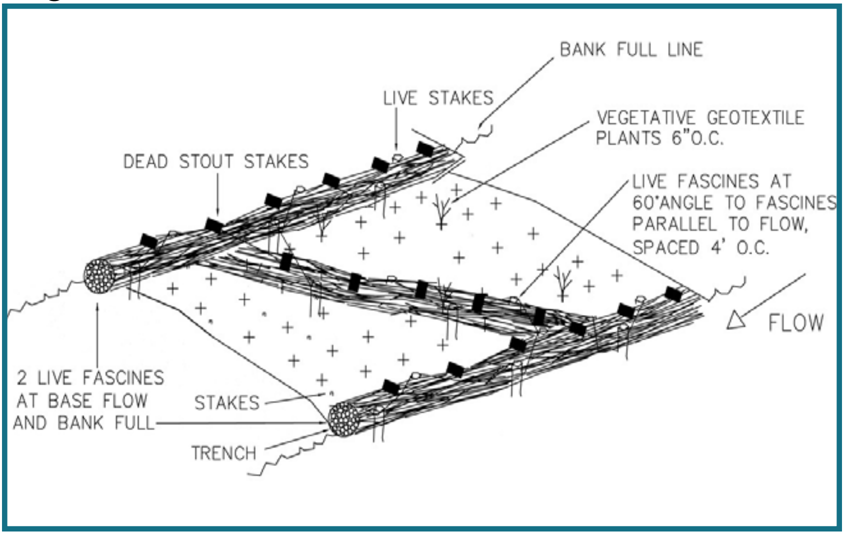

Figure 2-24. Vegetated geotextile details, axonometric, not to scale.

TOP 11 SOIL BIOENGINEERING TECHNIQUES:

11. Vegetated Reinforced Soil Stabilization (VRSS) – *made from* **live cut branches**, **bare root**, *and container plant stock in combination with rock, and* **erosion control fabric**. *The system provides immediate structural stabilization that increases as the plant material roots and matures.*

Application: streambanks

Effectiveness

- Used above and below **bank full elevation**.
- System must be constructed during low flow stream conditions.
- Useful in stabilizing outside stream bends, where erosive forces are strongest.
- Produces rapid vegetative growth and stabilization.
- Benefits are similar to **brush mattressing**, but can be built at a greater than 1:1 slope.

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Figure 2-25. Vegetated reinforced soil stabilization planting.
Minnehaha Creek, Minneapolis

Material Preparation

- Vegetation preparation will vary depending on the **live cutting** technique that is used.
- Live cuttings must be installed during **dormant** season.

Installation

- Excavate a trench at the base of the streambank and compact to ASTM Proctor 87% to 90%.
- Install first **geotextile** lift and stake back at bank.
- Cover layer of cuttings with geotextile leaving an overhang. Place a 12" layer of soil suitable for plant growth on top of the geotextile before compacting it to ensure good soil contact with the branches.
- Wrap overhanging portion of the geotextile over the compacted soil to form the completed geotextile wrap.
- Alternate layers of cuttings and geotextile wrap until the bank is restored to its original height, which should match original slope.

Vegetated Reinforced Soil Stabilization Details

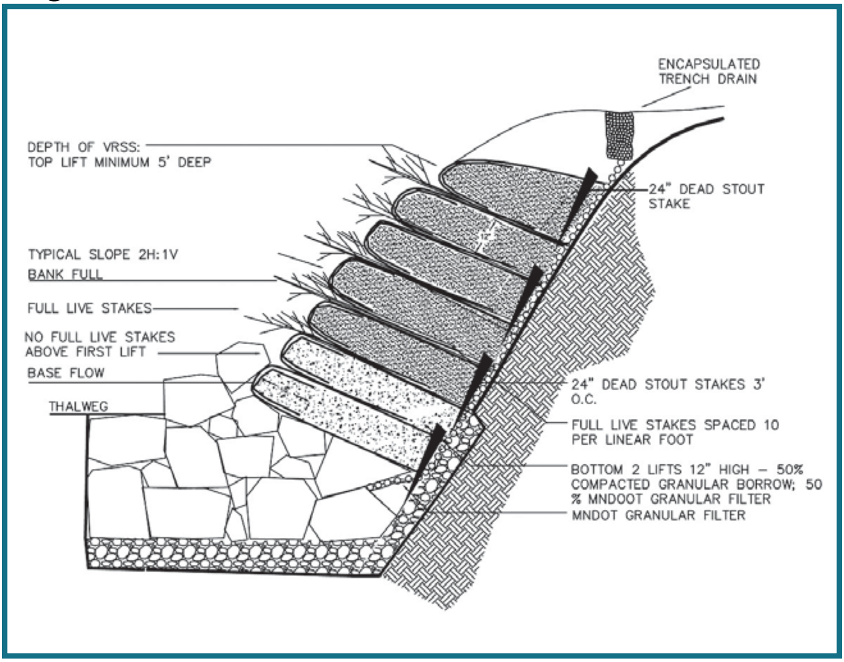

Figure 2-26. Vegetated reinforced soil stabilization detail, cross-section, not to

2.4 PLANTING DESIGN AND SELECTION

Care must be taken in selecting plants for the soil bioengineering system (Table 2.1). The most important criteria:

- Plants that can grow and maintain root systems under seasonally flooded conditions.
- Plants that will quickly develop extensive, fibrous roots.
- Plants adapted to the sites hydrological conditions.
- Plants adapted to the sites sun exposure.

Three groups of woody plants most commonly used are:

- Willow (*Salix spp*.)
- Dogwood (*Cornus spp*.) (Fig. 2-27)

Figure 2-27. Redosier dogwood is a very common shrub in Minnesota, and one of the most useful soil bioengineering plant species.

Table 2.1 Minnesota Soil Bioengineering Plant Species

Common Name	Botanical Name	Size/Form	Wetland Indicator	Growth from Cutting	Growth Rate	Shade Tolerance	Flood Tolerance	Drought tolerance	Technique*
Black Chokeberry	Aronia melanocarpa	medium shrub	FACW	poor to fair	fast	fair	good	moderate	1
Buttonbush	Cephalanthus occidentalis	medium shrub	OBL	fair to good	slow	good	good	moderate	1,2,3
Pagoda Dogwood	Cornus alternafolia	large shrub	NI	good	medium	good	good	moderate	1,2,3,4,5,
Silky Dogwood	Cornus amomum	medium shrub	FACW	good	fast	moderate	good	moderate	1,2,3,4,5
Gray Dogwood	Cornus racemosa	large shrub	NI	fair	medium	moderate	low	good	1,2,3,4,5
Redosier Dogwood	Cornus sericea	large shrub	FACW	good	fast	low	excellent	moderate	1,2,3,4,5
Downy Hawthhorn	Crataegus mollis	small tree	FACW	poor to fair	medium	fair	low	moderate	1
Ninebark	Physiocarpus opulifolius	medium shrub	FACW	fair	slow	moderate	low	good	1,2,3,4,5
E. Cottonwood	Populus deltoides	large tree	FAC+	very good	fast	low	excellent	good	1,2,3,4,5
Quaking Aspen	Populus tremuloides	medium tree	NI	poor to fair	fast	low	poor	fair	1,3,6
Blackberry	Rubus allegheniensis	small shrub	FACU+	good	fast	fair	low	good	1
Red Raspberry	Rubus ideas ssp. strigosus	small shrub	FACU+	good	fast	fair	low	good	1
Peachleaf Willow	Salix amygdalgoides	medium tree	FACW	excellent	fast	low	excellent	low	1,5,6
Beaked Willow	Salix bebbiana	large shrub	FACW	moderate	fast	very low	good	low	1,2,3,4,5
Pussy Willow	Salix discolor	large shrub	FACW	excellent	very fast	moderate	good	low	1,2,3,4,5
Sandbar Willow	Salix exigua ssp. Interior	medium shrub	FACW+	excellent	medium	moderate	good	low	1,2,3,4,5
Prairie Willow	Salix humilis	medium shrub	FACU	good	medium	moderate	good	good	1,2,3,4,5
Shining Willow	Salix lucida	large shrub	FACW+	good	very fast	low	good	low	1,2,3,4,5
Black Willow	Salix nigra	small tree	OBL	excellent	fast	low	excellent	low	1,2,3,4,5,6
Slender Willow	Salix petiolaris	large shrub	FACW+	moderate	medium	low	good	low	1,2,3,4,5
Streamco Willow	Salix purpurea	medium shrub	FACW	excellent	fast	modeate	good	low	1,2,3,4,5
Banker's Willow	Salix x cottetii	small shrub	N/A	very good	medium	low	good	low	1,2,3,4,5
American Elder	Sambucus canadensis	medium shrub	FACW-	good	fast	moderate	fair	good	1,4
Red Elder	Sambucus pubens	medium shrub	FACU+	fair to good	fast	good	fair	good	1,4
Meadowsweet	Spiraea alba	small shrub	FACW+	fair to good	medium	low	good	low	1
Steeplebush	Spiraea tomentosa	small shrub	FACW	poor to fair	medium	low	good	low	1
Snowberry	Symphoricarpos albus	small shrub	FACU-	good	very fast	low	low	good	1
Arrowwood	Viburnum dentatum	large shrub	FAC+	good	fast	good	fair	good	1,3,5
Nannyberry	Viburnum lentago	large shrub	FAC+	fair to good	fast	moderate	fair	good	1,4,5
Highbush Cranberry	Viburnum trilobum	large shrub	FACW	poor	medium	moderate	fair	fair	1,3

*TECHNIQUE
1 LIVE PLANTS
2 BRUSH MATTRESS
3 BRUSH LAYERING
4 FASCINES
5 LIVE STAKES
6 LIVE POSTS

Developing a Plant Palette

Planting species in groups is the key to success. Aggressive species will out-compete other desirable species, lowering project diversity. However, aggressive native species are often necessary to ensure stabilization. To counter these effects, install plants in groups. Install aggressive species groups on the most critical locations of the project, places where soil is most erodible. Avoid single species groups to prevent gaps in the system if a particular species fails. Designers must be aware of the true nomenclature (scientific botanical name) of the supplied plant material.

Allow the contractor to select from a specified list of acceptable species and establish a minimum diversity for aggressive vs. non-aggressive species. The plants can be categorized by moisture needs with several species as possible alternatives.

Top 10 Minnesota Species for Soil Bioengineering:

- Sandbar Willow (*Salix exigua*)
- Streamco Willow (*Salix purpurea*)
- Bankers Willow (*Salix x cotelli*)
- Redosier Dogwood (*Cornus sericea ssp. stolonifera*)
- Peachleaf Willow (*Salix amygdaloides*)
- Black Willow (*Salix nigra*)
- Eastern Cottonwood (*Populus deltoides*)
- Silky Dogwood (*Cornus amomum*)
- Shining Willow (*Salix lucida*)
- American Elderberry (*Sambucus canadensis*)

Acquiring Plants

Dormancy Period

- Dormancy begins about November 1st, when the average daily high temperature is under 48º F, to March 15th when sap rises or buds break.
- Live cuttings can be harvested and installed during the dormant period or harvested and refrigerated and then installed during growing season.

- Do not install after heavy frost sets into the ground.
- Many of these species, especially individual willow (*Salix* species), are very difficult to identify during the dormant period. Identify plants during the growing season for later harvest.

Table 2.2 Soil Bioengineering Planting List for Minnesota

Mock Planting List For Full Sun Streambank Stabilization	Name Common (botanical)	Rooting Ability From Cutting	Local Availability
- 45% of the following; - Minimum diversity of 4 species - One of which must be a Cornus	Sandbar Willow (*Salix exigua*)	Excellent	Very Common
	Streamco Willow (*Salix purpurea*)	Excellent	Common
	Bankers Willow (*Salix x cotelli*)	Very Good	Common
	Red Osier Dogwood (*Cornus sericea ssp. stolonifera*)	Very Good	Very Common
	Peachleaf Willow (*Salix amygdaloides*)	Very Good	Common
- 20% of the following; - Minimum diversity of 2 species	Black Willow (*Salix nigra*)*	Very Good	Very Common
	Eastern Cottonwood (*Populus deltoides*)*	Good	Very Common
- 35% of the following; - Minimum diversity of 2 species	Silky Dogwood (*Cornus amomum*)	Good	Common
	Shining Willow (*Salix lucida*)	Good	Common
	American Elderberry (*Sambucus canadensis*)	Good	Very Common

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Figure 2-28. Sandbar willow is among the most common willows in Minnesota and most effective for soil bioengineering.

*USDA-NRCS PLANTS Database / Britton, N.L., and A. Brown. 1913. *Illustrated flora of the northern states and Canada*. Vol. 1: 594.

Harvesting Live Stakes

Live stakes are the simplest system and easiest to install. The majority of plant material used on local soil bioengineering projects is harvested locally. They may be harvested on-site or on public lands (Fig. 2-29). Collect live cuttings on-site to reduce transportation costs. A power trimmer is an effective tool to remove stems without disturbing roots and ground surface. Handsaws or loppers are useful for small quantities. Harvesting willows may also be done on some DNR lands with permission.

Harvest Sites

- Collect genetically adapted plants from locations within 75 miles of the site.
- Collect from more than one site.
- In the wild, most willows and dogwoods are readily available. Other useful species may be difficult to locate.

Harvesting Specifications

- Collect cuttings during the dormant season (Fig. 2-30).
- Obtain the "green wood" portion of source plant rather than the older mature stems.

Figure 2-29. Live willow stake harvesting.

- Do not use plant suckers - as they have poor rooting ability from cuttings.
- Bind and tag plant cuttings on site for easy identification.
- Cut and transport entire stems to divide later into individual cuttings, as smaller cuttings dry out faster.
- Cut at a clean blunt angle 6" to 10" above the ground to assure that the source sites will successfully regenerate.
- It is the contractor's responsibility to locate harvest sites, gain permits for public lands, and compensate landowners.

Purchasing from Nurseries

Many nurseries that sell plants native to Minnesota will supply willows, dogwoods, elderberry and other species as container grown stock. There is increasing demand for live cutting material, however, live stakes are not yet available from local nurseries, but must be harvested directly. For information on suitable plant vendors, contact:

- Minnesota Native Plant Society at http://www.stolaf.edu/depts/biology/mnps
- Wisconsin Department of Natural Resources at http://www.dnr.state.wi.us

Figure 2-30. Harvest and transport of dormant willow stakes.

Planning for Public Acceptance

The current open meeting laws and public information process for land development for public agencies, utilities and landowners encourage a proactive approach to designing with the community. This process informs and allows feedback but does not abdicate design responsibility to the community (Fig. 2-31).

Soil bioengineering projects in Minnesota often involve publicly protected waters. Projects usually involve both public and private stakeholders.

During and after installation, communication strategies can help the public to understand the purpose and function of a soil bioengineering project. Something as simple as a sign placed at a project site will alert the public that a soil bioengineering project is an intentional, beneficial natural system and not just an unkempt landscape (Fig. 2-32). Use signage, fencing, and neat edges that establish “cues to care” which will foster public acceptance. These identify the project as an intentional landscape.

Develop a communication plan at the beginning of the project by establishing:

- Milestone Dates
- Public Meetings
- Press Releases
- Letters to Stakeholders
- Site Signs

Maintain open channels of communication with public and private itnterests throughout the entire process, from planning to construction.

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Figure 2-31. Volunteer youth planting crew at a shoreline restoration site. Engaging the community will promote public acceptance of a project and provide opportunities for education.

Source: Available from Minnesota DNR

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Figure 2-32. Graphic signs for soil bioengineering project. A sign available from the MN DNR (LEFT) and one that was custom designed (RIGHT).

CHAPTER 3.
SOIL BIOENGINEERING INSTALLATION & MANAGEMENT

3.1 HANDLING OF PLANT MATERIAL

Handling and Preparation of Live Cuttings

- Protect live cuttings from drying at all times!
- Handle and transport with the utmost care - do not scrape, wound or damage.
- Soak for a minimum of 24 hours prior to planting.
- Install within 48 hours of harvest.
- When cuttings are harvested near or outside the dormancy window, install on the day branches are cut rather than wait for a cooler period.
- Cuttings that are stored outside should be heeled in, protected from sun and winds and kept moist.
- If air temperatures are above 48º F the cuttings should be refrigerated or kept in cold storage - refrigerate at 35º F with 90% humidity.
- Transport cuttings in an enclosed trailer - refrigerated if air temperatures are above 48º F.

Use of Amendments

Amendments are used to supplement planting medium deficiencies. Complete a soil test to determine lacking macro and micronutrients. Positive results have been witnessed from using the following amendments with soil bioengineering plantings.

Rooting Hormone

- Aids in adventitious rooting of cuttings.
- Applied by dipping the basal ends of live cuttings into container of material (Fig. 3-1).

Mycorrhizal Inoculum

- Soil mycorrhizae are beneficial fungi for nutrient deficient soils that lack the native fungi.
- Improves the ability of the plants to utilize soil resources, increases drought resistance and increases growth.
- Reduces the need for fertilizer.

Fertilizer

- Provides necessary nutrients for cuttings in sterile planting mediums during establishment period.
- Use slow release organic type, which releases nutrients over 2+ years.
- Do not add phosphorus because it degrades water quality.

Super-absorbent Polymer

- Water binding agent, which provides necessary moisture to cuttings in dry planting mediums during establishment.
- Use organic based polymers.

Figure 3-1. Dipping basal ends of live cuttings in rooting hormone (LEFT), and "tea bag" mycorrhizal innoculum (RIGHT).

3.2 ENSURING SUCCESS: INSPECTION AND QUALITY CONTROL

Quality control is a necessary step to ensure success in a project from pre-design through the end of the plant establishment period. To ensure the health and vitality of a soil bioengineering project, follow these steps:

Pre-construction Design and Planning

- Review reference sites and establish needs.
- Select soil bioengineering methods for conformance to requirements.
- Select plant species for conformance to requirements.
- Locate and secure source sites for harvesting.
- Inspect structure and fertility of planting medium.
- Hold training workshop.
- Review all product submittals.

During Construction

- Inspect harvested and procured plant material.
- Inspect plant material storage area.
- Inspect and ensure each installation component.
- Make field adjustments accordingly.

Establishment/Maintenance Period

- Establish and follow through with maintenance plan.
- Inspect biweekly for first 2 months after bud break - note infestations, soil moisture and so on.
- Inspect monthly for remaining of growing season - note unacceptable and acceptable growing conditions.
- Provide direction for reestablishment work for next 2 to 5 years.
- Additional inspections should be made during periods of extreme drought, flooding.

3.3 PROJECT MAINTENANCE

Soil bioengineering systems are self-repairing systems that become stronger with age. Contrary to popular opinion, native plantings are not maintenance free. The plant establishment period is the most critical, and once successfully established most soil bioengineering systems require very little maintenance.

Newly installed live branch soil bioengineering plantings should be periodically inspected throughout the first growing season. Damage to the soil bioengineering planting either before or after the establishment period may be caused by adverse weather, animals, or people. If a portion of the planting does not establish during the first season, it should be replanted. After the first growing season, a successful planting will regenerate and become self-repairing in most circumstances.

Maintenance may include removing undesirable or invasive vegetation, light pruning, or cutting back the plantings. Once established, willows and dogwoods can be cut back during the dormant season without damage to the plantings.

Upland Buffer Maintenance
For herbaceous buffer plantings, the establishment period will take 2 to 5 years if planted by seed. The young plants spend most of their energy the first two seasons sending down deep roots into the soil. Planting a cover crop with the seed will help keep out weeds and provide a suitable microhabitat for seeds to germinate and grow. During that period, it is important to control weedy vegetation. Once established, the planting will benefit from periodic controlled burns or mowing to control weeds and encourage growth of the native plants.

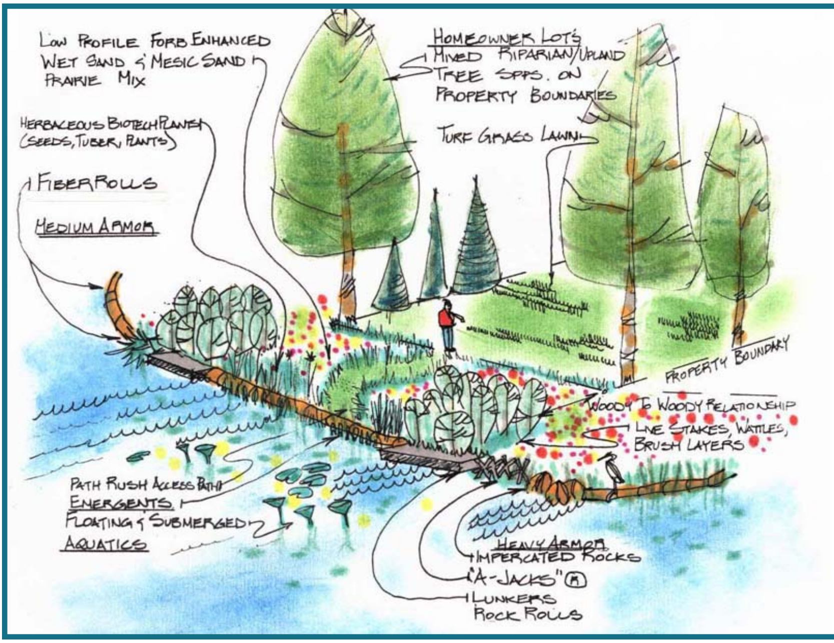

Figure 3-2. A shoreline stabilization project at Cedar Lake in Minneapolis that used multiple soil bioengineering techniques.

3.4 TYPICAL COSTS

Soil bioengineering costs vary widely from project to project, depending on many factors including location, plant species, complexity, and size of the project.

The following costs are typical for projects in the Twin Cities Metropolitan area in 2005.

Table 3.1 Typical 2005 Soil Bioengineering Costs

ITEM	UNIT COST
Seeding	$125 per 1,000 s.f.
Planting	$2.50 per plug
Live stakes with erosion control fabric	$25 per square yard
Vegetated Geotextile - herbaceous plants	$80 per square yard
Vegetated Geotextile - woody plants	$100 per square yard
Coir Rolls	$20 per linear foot
Fascines	$12 per linear foot
Boulder Toe	$90 per cubic yard
VRSS	$150 per square yard

CHAPTER 4. SOIL BIOENGINEERING CASE STUDIES

VISITING PROJECTS STATEWIDE

4.1 SOUTHEAST MINNESOTA

Whitewater State Park, Elba
A four-mile **reach** of the Whitewater River had been channelized into a straight ditch in the 1950's and was suffering from severe streambank erosion and poor fish habitat. The Minnesota DNR selected a stable channel design using streams in the region that remain healthy and undegraded as a template. The channel was excavated and stabilized using willow stakes and **root wad revetments** to prevent **undercutting** of the streambanks. The root wad revetments deflect streamflow from the banks reducing velocities near the bank while providing fish with habitat variety. The result is a more natural, meandering channel design and improved trout habitat.

4.2 SOUTHWEST MINNESOTA

Pomme de Terre River, Appleton
A dam removal project in the town of Appleton was undertaken by the MN DNR to reduce sedimentation and restore fish habitat (Fig. 4-1). Upon dam removal, large quantities of sediment that were stored behind the dam were exposed requiring stabilization. A natural channel design approach constructed a stable, meandering channel. Rootwad revetments improved fish habitat and slowed water velocity on the outside of the stream bend, contributing to bank stability. **Rock vanes** were added for grade control, which also created **riffles** for fish habitat and enhanced aesthetics.

Figure 4-1. Dam removal and natural channel construction restored ecological and hydrological function to this stretch of the Pomme de Terre River in Appleton, MN. Photo courtesy of Luther Aadland, MN DNR.

Elm Creek, Martin County

The Natural Resource Conservation Service (NRCS) used soil bioengineering in combination with a **boulder toe** to stabilize a badly eroding stream channel in a highly agricultural watershed.

Approximately 400' of channel at a 2.5 to 1 slope was excavated. Rock was placed at the base of the streambank, soil backfilled and plant materials installed. Sandbar willows were harvested from public lands. **Brush mattresses** were laid to create a stable grid on which to stake live willow **posts** and **fascines** (bundles of willow branches placed horizontally across the streambank). A total of nine trailer loads of willows were harvested and used for 50' of **brush layering**, 200' of brush mattresses, 100' of live **fascines** and **live willow stakes** placed intermittently. The project has stabilized the channel, decreased sedimentation of the stream and improved water quality as well as the natural beauty of the site.

4.3 NORTHWEST MINNESOTA

Clearwater River, Greenwood Township, Clearwater County
Streambank stabilization, grade control, enhanced floodplain function and fish passages were accomplished in this project carried out by the Red Lake Watershed District with a grant from the Minnesota Pollution Control Agency. Eroding streambanks were stabilized using a combination of willow **posts**, willow **bundles** and biodegradable **geotextile fabrics** with rock placed at the streambank toe for extra stability. Completed in 2001, this project has improved water quality, reconnected floodplain and increased fish passage in this tributary of the Red River of the North.

4.4 NORTHEAST MINNESOTA

Little Fork River, 20 miles from International Falls
After collapse of a railroad bridge, extreme erosion was occurring around the bridge abutments and stream stabilization was badly needed on this tributary of the Rainy River. MnDOT and the local Soil and Water Conservation District worked together to develop a plan to stabilize the banks using natural materials. Through a combination of geotextile **fabric** with willow **posts** applied after grading, the streambanks were successfully stabilized.

4.5 TWIN CITIES METRO AREA

Pike Creek, Maple Grove
A quarter mile section of Pike Creek, running through a residential section of Maple Grove, was restored using bioengineering and natural channel design strategies. The stream suffered from excessive runoff, sediments and pollutants. As a result, mass wasting and streambank **undercutting** were occurring, degrading stream habitat while creating a visual eyesore for the neighborhood (Fig. 4-2). Pre-project modeled velocities at 100 year/24 hour storm event were 8.9 fps. To

address these issues, a combination of channel widening to increase storage capacity, stream gradient control, **hard armor** protection where the greatest erosive forces occurred, and soil bioengineering techniques that protect streambanks with deep-rooted native vegetation were used to improve aesthetics, water quality and stream health over a quarter mile long section. Bioengineering techniques employed included **root wads**, **live stake** installation and vegetated **jute blankets** with **boulder toes** used for toe stability. Funded by the City of Maple Grove, City of Plymouth, and Hennepin County Conservation District.

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Figure 4-2. Pike Creek, BEFORE (above) and AFTER (below) soil bioengineering.

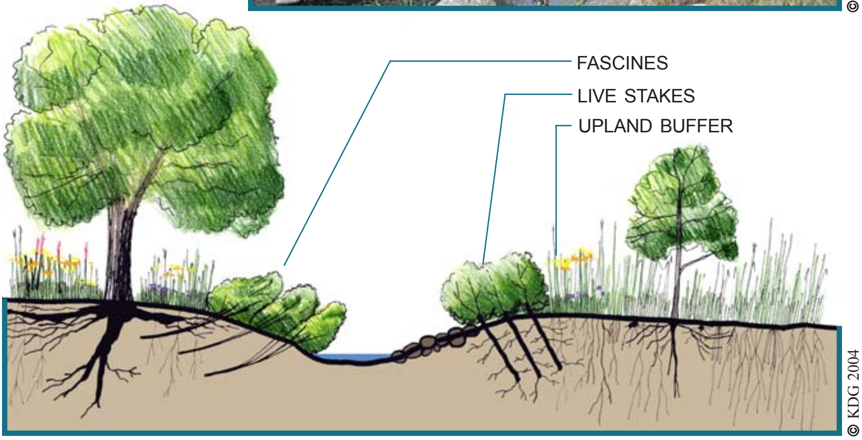

Figure 4-3. Pike Creek conceptual cross section. A range of soil bioengineering techniques were used, including fascines, live stakes, and upland buffer planting with native prairie seeds, bare root shrubs, and trees. A vegetation management plan was developed for the site that will maintain it as an open savanna community.

Trout Brook, Douglas Township, Goodhue County

Dakota County Parks in partnership with the NRCS and the Dakota County SWCD, worked to stabilize an eroding streambank and restore important trout habitat (Fig. 4-4). A critical design element preserved trees at the top of a near-vertical streambank to provide a visual barrier to recently constructed park buildings. After reviewing multiple options, a **vegetated reinforced soil stabilization** (VRSS) technique was selected. A diverse and motivated team of agency and contract personnel provided labor to complete the project over three days in November 2000. Additional buffer plantings were added in the spring of 2001. The project successfully stabilized and now appears integrated with adjacent stream **reaches**.

Figure 4-4. Before and after soil bioengineering stabilization with a vegetated reinforced soil stabilization (VRSS) system.

Trout Brook, Goodhue Co. Photos courtesy of Dakota County Soil and Water Conservation District, 2004.

Minnehaha Creek, Minneapolis
This soil bioengineered streambank stabilization project protects the most severely damaged banks of the 8-mile reach of the Minnehaha Creek, within the City of Minneapolis. The creek, which feeds the legendary Minnehaha Falls, is a completely urban stream where degradation symptoms include down cutting, channel straightening, as well as meander and channel width instability (Fig. 4-5).

Techniques included streambank gradient stabilization, pool and riffle recreation, meander and oxbow restoration, floodplain reconnection, **boulder toe** stabilization, **fiber rolls, live stakes, VRSS, fascines,** and **vegetated jute blankets** (Figs. 4-6 and 4-7). This project was funded by the federal Intermodal Surface Transportation Efficiency Act (ISTEA) trail grants, Minnehaha Creek Watershed District and Minneapolis Park and Recreation Board.

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Figure 4-5. Minnehaha Creek was severely eroded before soil

4.0 CASE STUDIES

Figure 4-6. Minnehaha Creek during soil bioengineering construction.

Figure 4-7. Minnehaha Creek two years after soil bioengineering installation.

Vermillion River, Dakota County
Many stream channel restoration projects have been completed along the Vermillion River since the late 1990's. The Girgen streambank project in the town of Vermillion is an excellent example of a major bank stabilization project. Staff from Dakota County, the Friends of the Mississippi River and other state agencies worked with student volunteers to stabilize 120' of streambank using willow and dogwood **live stakes** and **posts**, **fascines**, **rootwads**, and boulder **rock vanes** (Figs. 4-8 and 4-9). The project greatly improved trout habitat in the stream and reduced sedimentation from streambank erosion.

Figure 4-8. Planting soil bioengineering live stakes, in the dormant season, at the Vermillion River .
Photo courtesy of Dakota County Soil and Water Conservation District 2004.

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Figure 4-9. Live stake plantings along the Vermillion River, a state recognized trout stream, in rural Dakota County.
Photo courtesy of Dakota County Soil and Water Conservation District 2004.

4.0 CASE STUDIES

CHAPTER 5. SOIL BIOENGINEERING RESOURCES

5.1 PUBLIC AGENCY RESOURCES

Minnesota Board of Water and Soil Resources (BWSR)
One West Water Street, Suite 200
Saint Paul, MN 55107
Tel: (651) 296-3767; Fax (651) 297-5615; TTY (800) 627-3529
http://www.bwsr.state.mn.us

Minnesota Department of Natural Resources, Division of Waters
500 Lafayette Road
St. Paul, MN 55155-4040
Tel: (651) 296-4800
http://www.dnr.state.mn.us/waters/index.html

Minnesota Department of Transportation (MnDOT)
Transportation Building
395 John Ireland Boulevard
Saint Paul, MN 55155
http://www.dot.state.mn.us

Natural Resources Conservation Service (NRCS)
United States Department of Agriculture
375 Jackson Street, Suite 600
Saint Paul, Minnesota 55101
Tel: (651) 602-7900; Fax: (651) 602-7914
http://www.mn.nrcs.usda.gov

St. Anthony Falls Laboratory
#2 Third Ave. SE
Minneapolis, MN 55414
Tel: (612) 624-4363, Fax: (612) 624-4398
http://www.safl.umn.edu/index.html

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CHAPTER 6. GLOSSARY OF SOIL BIOENGINEERING TERMS

adventitious roots – roots that arise from a stem, rather than from a primary root.

bank full elevation – the stream elevation at which flood flows form the channel.

boulder toe – placement of boulders at the toe of a slope to increase the stability of a slope or bank; often used in combination with live stakes or cuttings in highly erosion prone situations. Limestone and sandstone boulders should be avoided due to short life-span. Igneous rounded boulders are preferred. See Mn/DOT specifications for proper sizing.

brush bundle – consists of placing live branch cuttings in small trenches excavated into the slope with backfill on top of cuttings. The width of the trenches can range from 2 to 3 feet. The portions of the brush that protrude from the slope face assist in retarding surface runoff and reducing erosion.

brush fascine – see **fascine**

brush layering – see **brush bundle**

brush mattress – a mat or mattress from woven wire or single strands of wire and live, freshly cut branches from sprouting trees or shrubs placed in a slight depression on a bank. Branches up to 2.5" in diameter are cut 3' to 10' long and laid in criss-cross layers with the butts in alternating directions to create a uniform mattress with few voids. The mattress is covered with biodegradable **coir** twine or wire, and secured with wooden stakes up to 3' long. The mattress is then covered with soil and watered to fill voids with soil and facilitate sprouting; some branches should be left partially exposed on the surface (2 to 5 buds minimum). The structure may require protection from undercutting by a **boulder toe** or burial of the lower edge. Brush mattresses are generally resistant to waves and currents and provide protection from the digging out of plants by animals. Disadvantages are possible burial with sediment and difficulty in making later plantings through the mattress.

bud break – when **dormant** woody plants end dormancy in early spring and put forth their first leaves from buds; in Minnesota, typically from late March to early April, when daily high temperatures rise above 48º F.

concrete jacks – x-shaped, 6-spoked **hard armor** structures made out of concrete and installed on streambanks in an interlocking pattern to protect against erosion.

contour fascine – placing **fascines** parallel to a streambank, along a countour.

contour wattling – see **contour fascine**

coir – a natural fiber made from coconut husks that is used to make twine and fiber rolls used in soil bioengineering.

cut bank – streambank where erosion occurs along an outside turn of a meander; sediment is deposited downstream on **point bar**.

cutting – see **live cut branches**

dead stout stake – 36" long 2" x 4" studs of cedar, cypress, tamarack, fir, oak, elm, or hard maple sawed on the diagonal; a 1/8" deep notch shall encircle the stake within 1" of the top of the stake; with a sharp point on the end to secure erosion control fabric and soil bioengineering materials to the ground.

dormant – the time period from late fall to early spring in which woody plants stop growing and become dormant; the best time to harvest and install plants for soil bioengineering.

erosion control fabric – often made from jute or other biodegradeable material; used to cover ground surface to prevent erosion, especially during plant establishment period.

fascine – **dormant** cuttings bound together in sausage-like bundles. Long straight branches are used to form the 6"- 8" diameter bundles; placed in shallow trenches across the slope of the bank or on contours along the bank, and staked into place with live or dead stakes. The physical structure provides immediate bank support, prior to root growth. Adventitious root growth along the entire length of the cuttings stabilizes the soil more quickly than individual **live stakes**.

feet per second – (fps) velocity measure of water.

fish lunkers – a wooden or recycled plastic, box-like structure constructed and placed beneath an **undercut** streambank, preferably cut bank; used to protect the bank from erosion and also provide habitat to fish, especially trout.

hard armor – the use of hard, non-living materials such as: boulders, retaining walls, rip rap, used to stabilize a bank or slope; generally decreases the habitat or biological quality of a site while increasing slope stability.

head cutting – instability of stream bottom causes stream to seek hydraulic stability by cutting through stream bottom.

herbaceous plugs – small, container grown herbaceous plants. Nurseries specializing in native plants have a wide selection of aquatic and upland species. Plugs are an economical method of quickly establishing native plantings.

jute blanket – a type of erosion control fabric made out of biodegradable, natural jute fiber.

J-vane – use of hard armor boulders to construct a J-shaped structure in a stream that will provide grade control of stream bottom, stopping head cuts, and deflect current back to the middle of the stream and limit erosion of the banks; also provides habitat benefits to stream invertebrates and fish by creating stream structure, oxygenating water, and allowing fish passage.

live cut branches – any dormant, woody branch cutting which provides both dead and live structure to failing slopes, and is installed for the purpose of rooting and growing.

live branch cuttings – see **live cut branches**

live posts – large diameter **live stakes**, up to 6" in diameter.

live stake – live, rootable vegetative **cuttings** inserted into the ground; if correctly prepared and placed, the live stake will root and grow. A system of stakes creates a living root mat that stabilizes the soil by reinforcing and binding soil particles together and by extracting excess soil moisture; has a tensile strength greater than concrete and a much longer life span because it is a living, self-repairing system that strengthens with age. Most willows (*Salix spp*.) are ideal for live stakes because they grow adventitious roots along the inserted branch rapidly and begin to
dry out a slope soon after installation; is an appropriate technique for streambanks, small earth slips and slumps that frequently are wet. Other appropriate species are dogwoods and elderberries.

log revetment – a low wall made up of soft armor, hard armor, or a combination of engineering techniques.

point bar – sediment deposited downstream, and opposite of a **cut bank**, at an inside turn of a stream meander.

posts – see **live posts**

plugs – see **herbaceous plugs**

reach – see **stream reach**

rock vane – **hard armor** structure of boulders placed in a stream in a "U"-shape, with the closed end of the "U" pointing upstream; provides grade control for stream bottom – stopping **head cuts** and deflects current to the middle of the stream and limits erosion of the banks; provides habitat benefits to stream invertebrates and fish by oxygenating water and creating stream structure.

rooting hormone – added to **live branch cuttings** to stimulate growth of adventitious roots.

root wad – a **soft armor** streambank protection technique installed on **cut banks**, that provides immediate riverbank stabilization, protects the toe of slope and provides excellent fish habitat, especially for juveniles. Root wads are particularly well suited for higher velocity river systems and riverbanks which are severely eroded. They provide toe support for bank revegetation techniques and collect sediment and debris that will enhance bank structure over time. Because of their size, usually requires the use of heavy equipment for collection, transport and installation.

shredded hardwood mulch – shredded hardwood fibers which do not contain soil, manure, or compost.

soft armor – use of natural, living and self-repairing materials such as woody and herbaceous plants to protect slopes and banks from erosion and increase the aesthetic and habitat value of a site; as opposed to **hard armor**, which is non-living and has a limited life span. Examples of soft armor soil bioengineering are **brush fascines**, **brush mattressing**, **live stakes**, **VRSS**, and **wattles**.

soil bioengineering – a technique that uses live and dead vegetation alone or in combination with natural support material to stabilize eroding and failing slopes or banks.

soil mycorrhizae – naturally occurring fungal microbes found in intact soil ecosystems; have a symbiotic relationship with many species of plants; can be added as an amendment to increase the health and survival of new plant material. Mycorrhizae increase the capacity of roots to absorb water and nutrients up to 10 times. Most disturbed, excavated, filled soils do not have healthy mycorrhizae populations.

stream reach – length of channel which is uniform in its discharge depth, area, and slope; a relatively homogeneous length of stream having a similar sequence of characteristics.

super-absorbent polymer – a synthetic product which can be added as an amendment to potted live plants during installation, which absorbs and holds water near the roots during establishment.

thalweg – in a stream profile, the deepest part of the channel; may or may not be the horizontal center of the stream channel.

transpiration – the passage of water from plant roots in the ground, through leaves and into the air as water vapor.

undercut bank – erosion has cut into and removed soil from underneath a bank, upstream and opposite of a **point bar**.

vegetated geogrid – see **vegetated reinforced soil stabilization**

vegetated geotextile – natural or synthetic **erosion control fabric** is anchored to the ground with live plant material, such as a combination of **live stakes**, **fascines**, potted, and bare root shrubs; system is reinforced with **dead stout stakes** and **coir** twine; can be supplemented with live **herbaceous plants**.

vegetated reinforced soil stabilization (VRSS) – a system made from living, **live cut branches**, bare root, and container plant stock in combination with rock, geosynthetics, geogrids, and/or geocomposite textiles; also known as "vegetated geogrid". The system provides immediate structural stabilization that increases as the plant material roots and matures.

wattle – from Old English "watel," which means a "hurdle," or to weave branches of wood into structures such as low fences for holding livestock. The term now is used to describe several different soil bioengineering techniques, which also involve the weaving together of branch cuttings, either live or dead. Because it is a non-specific term with several different, often interchangeable meanings, we avoid the use of the term *wattle* in this handbook as applied to specific techniques. Sometimes the term *wattle* is used to mean the same thing as **fascine** and **brush mattress**, which are actually very different soil bioengineering techniques.

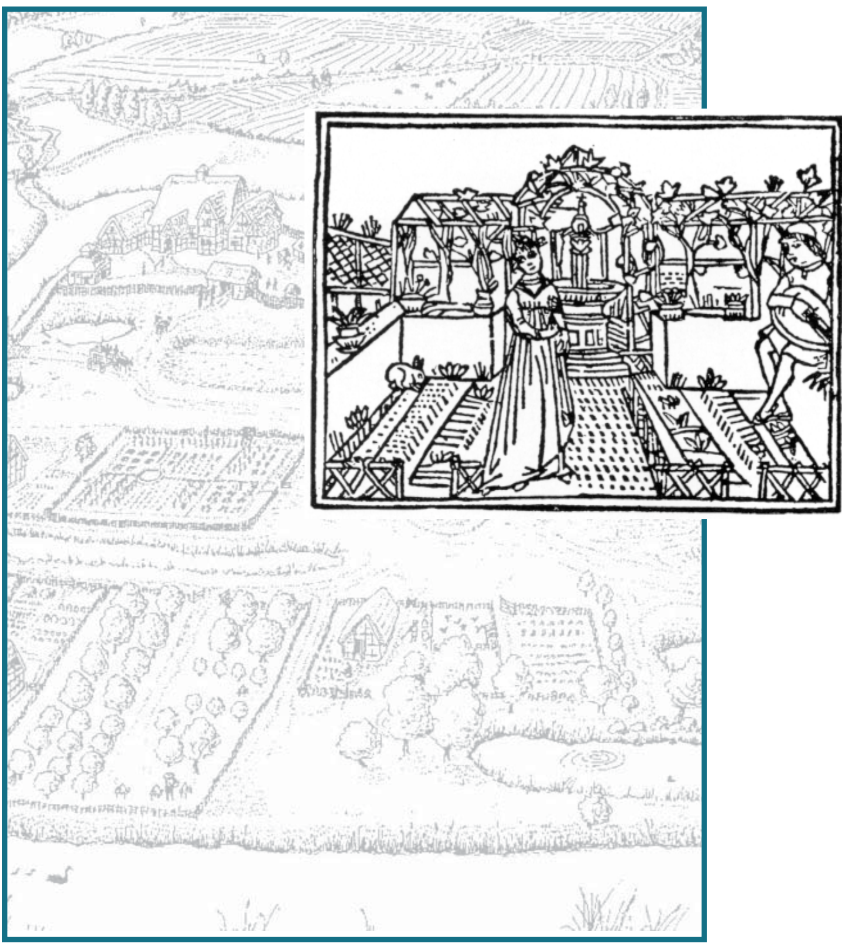

Figure 6-1. Wattles and hedgerows, early forms of soil bioengineering, were used by farmers and gardeners across Medieval Europe as living enclosures. Image sources: Heritage Trust of Lincolnshire, http://www.lincsheritage.org/htl and Medieval Renaissance Gardens, http://www.lehigh.edu/~jahb/herbs/medievalgardens.htm.

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