Chapter Three - Streambank Bioengineering

BIOENGINEERING: ADVANTAGES AND DISADVANTAGES

Bioengineering can be defined as integrating living woody and herbaceous materials with organic and inorganic materials to increase the strength and structure of the soil. This is accomplished by a dense matrix of roots which hold the soil together. The above-ground vegetation increases the resistance to flow and reduces flow velocities by dissipating energy. The biomass also acts as a buffer against the abrasive effect of transported materials and allows sediment deposition due to low shear stress near the bank (Allen and Leech 1997).

In contrast, traditional engineered approaches to streambank stabilization include rip-rap, concrete revetments, bulkheads, concrete-lined channels, etc. These hard structures require some maintenance over the course of their usable lifespan. In addition, failure of a hard structure can be even more expensive to repair than the original construction costs. Bioengineering projects may be expensive initially, especially for labor, replanting, possible repairs, and monitoring. However, their maintenance costs will be significantly lower over time because of their resiliency and self-sustaining nature (Allen and Leech 1997).

Bioengineering techniques have a long history in central Europe where these practices have been used along small to large streams (Schiechtl and Stern 1994). In the United States, wattles and other bioengineering techniques were used in the 1930s (Kraebel 1936; Fry 1938). However, these techniques were largely ignored until recently and now are being applied in a variety of settings (Bentrup 1996; Gray and Sotir 1994; Hoag 1992; Rotar 1996).

Bioengineering projects do have some limitations (Gray and Leiser 1982; Schiechtl and Stern 1994): 1) sometimes the plants fail to grow, 2) plants and other components may be subject to scouring, 3) plants can be uprooted by freezing and thawing, ice flows, and debris loads, 4) livestock and wildlife often feed on the plants and may destroy them, and 5) the project may have to be maintained for a period of time, especially early in the project life.

Despite these limitations, a bioengineering approach offers several advantages over traditional approaches (Gray and Leiser 1982; Schiechtl and Stern 1994). Some of these advantages include:

Cost Effectiveness

As previously stated, typical bioengineering techniques are more cost-effective than hard engineered structures. Even when considering the occasional need to reinstall a bioengineered treatment (e.g. one which did not have time to establish roots before a flood), these techniques are usually less expensive in the long run. As a bioengineering project matures, little to no maintenance will be required.

Environmental Compatibility

Bioengineering techniques blend into the landscape, providing valuable fish and wildlife habitat. These methods improve water quality rather than diminish it like traditional approaches. These techniques will also evolve with the stream, adjusting naturally to flows and meandering.

Indigenous, Natural Material

Bioengineering techniques emphasize the use of natural, locally available materials: earth, vegetation, rock, and lumber in contrast to steel and concrete. This is a particularly important consideration in more remote areas where it is infeasible to bring in artificial materials.

Labor-Skill Requirements

A final but important consideration is that bioengineering techniques tend to be more labor-skill intensive than energy-capital intensive (Gray and Leiser 1982). These techniques depend more on easily trained labor than on high-cost manufactured materials. As a result, these methods can be installed with well-supervised volunteers. Acquiring volunteers for these types of projects is usually quite easy. Potential volunteers include high school groups, fish and game volunteers, NRCS Earth Team members, Boy and Girl Scouts, etc. In addition to the free labor, there is significant value in having people play a role in restoration. Stream restoration can instill a sense of ownership and care for the region's riparian areas (Lev 1995; Mcdonald 1995).

Characteristics of Bioengineering

<u>Vegetation Components</u>
Bioengineering techniques typically rely on woody plant materials because of their deep root system that reinforces the soil and their greater resistance to erosive flows. Herbaceous plant materials should also be used because they provide fine fibrous root systems. When herbaceous plants are used with woody vegetation, the combination will hold more soil and will buffer the force of the stream as it hits the streambank. Wetland herbaceous plant species also survive in areas of the streambank that have more water than the woody species can handle. Wetland plants can survive these conditions because of their aerenchyma cellular structures which move oxygen to the root systems and allow them to grow in anaerobic conditions.

Planning a Bioengineering Restoration Project

1. Analyze the watershed and determine the large scale reasons for degradation.
2. Work with the landowners to modify poor land management practices as necessary.
3. Enlist technical expertise and begin initial inventory of areas that may benefit from bioengineering. Begin to develop site-specific objectives.
4. Inventory and analyze prospective sites and determine causes of bank failure. Select a project site and refine objectives.
5. Design a site-specific bioengineering project to meet the objectives.
6. Gather input and permits as necessary from regulatory agencies.
7. Implement the project.
8. Monitor and maintain the project. Evaluate for future projects.

<u>Structural Components</u>
These techniques often use non-living material such as wood and steel stakes, wire, twine, etc. Sometimes these methods utilize specially manufactured products such as biodegradable coir fiberschines and erosion control fabric. Other non-biodegradable products such as plastic geogrid cells may be appropriate in certain applications.

BASIC PLANNING AND DESIGN PRINCIPLES

The above list illustrates the basic procedure for planning a bioengineering restoration project. **STEPS 1 and 2** were covered in Chapter Two.

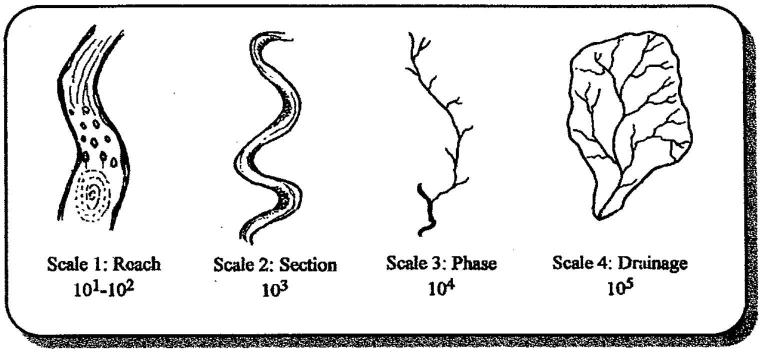


Fig. 3.1 *Multiple Scales of Inventory and Assessment. Numbers indicate approximate spatial extent in 10's of feet. (Modified from Stanley et al. 1997).*

STEP 3 PRELIMINARY INVENTORY

Enlist Technical Expertise

This step is essentially a review of the areas in a watershed which could benefit from having a bioengineering project. It is often worthwhile to enlist technical expertise at this point in the process to select sites that are suitable for bioengineering. An interdisciplinary team is always recommended. This team may consist of professionals like engineers, fluvial geomorphologists, grazing lands specialists, plant ecologists, fish and wildlife biologists, soil scientists, hydrologists, and landscape architects.

Also include local landowners and officials from regulatory agencies in the process. It is critical to involve individual landowners in the identification of any land management problems so that holistic solutions and support can be created. Including all of these people in the planning process will give them ownership in the project and will result in better restoration alternatives.

> *Eventually, all things merge into one.*
> *And a river runs through it.*
>
> *Norman MacLean*

Multiple Scales of Inventory and Assessment

It is important to emphasize that restoration projects must incorporate several scales of inventory and assessment. Stanley and others (1997) provide a useful hierarchical framework for inventorying streams (Fig. 3.1).

In Step 3, the inventory should be focused at the watershed and phase scales. According to the framework by Stanley and others (1997), the spatial extent of the stream being inventoried at these scales would range from approximately 5 to 50 linear miles, although this will vary based on the context of the area. The main objective of the inventory at these scales is to highlight land management issues that may need to be addressed. In addition, this assessment should provide an understanding of the major problems and opportunities that exist in the watershed. Aerial photos that cover several decades may be extremely valuable tools for this process.

Potential sites identified during this step will be be more thoroughly inventoried and analyzed at a finer scale in Step 4. At the section and reach scales, the spatial extent of the inventory may range from approximately 10 feet up to 1 mile. Again, these ranges may vary depending on the situation. The main objective of this inventory is to gain insight into the site specific problems and opportunities.

Successful bioengineering projects are often dependent upon the careful integration of inventories and analysis conducted at multiple scales.

Initial Inventory: Geomorphic Valley Form

Fluvial geomorphology is the study of flowing water as it shapes the landscape. Riparian zones are the result of hydrologic and geomorphic conditions where water, energy, and materials from aquatic and upland ecosystems converge in a channel.

Bioengineering projects that fail usually lack an adequate multi-scale assessment of the fluvial geomorphic processes at work. It has been suggested that design teams should use geomorphic valley-forms for the Great Basin as described by Minshall and others (1989) as an initial guide in determining the feasibility of a bioengineering project (Carlson et al. 1995). Table 3.1 (pp. 20-21), based on the work by Carlson and others (1995) can be used as an initial guide.

The six classes of geomorphic valley-forms are glacial headwaters, glacial valleys, erosional fluvial canyons, depositional fluvial canyons, alluvial valleys, and lacustrine basins. The geomorphic valley forms can be correlated to the stream types described by Rosgen (1994), to vegetation community types described by Padgett and others (1989) and inferred from Brunsfeld and Johnson (1985). Under this correlation, alluvial valleys are subdivided into a mid- and low-elevation category, and braided stream channels are dealt with separately.

Developing Objectives

One the most important aspects of any restoration project is the development of specific objectives. By having firm objectives for the project, the chance of success increases dramatically. The entire project area should be considered and potential problems anticipated. At this stage in the process, preliminary objectives should be established and then refined in the next step as a specific site is selected. Hoag (1993) noted several factors that may be considered when developing objectives:

* If a decrease in water temperature and improvement of fish habitat are part of the project objectives, shade can be increased with tall and/or wide canopy species planted on the south side of the stream. A mixture of shrubs, short and tall trees may provide the most shade.

* If wildlife habitat is desired, determine the species of wildlife and their needs. Wildlife diversity is usually enhanced by having several vegetative layers; i.e. groundcover, mid-canopy and overstory. Habitat for food, shelter, nesting cover, brood habitat, and hiding cover should be determined and incorporated in the design.

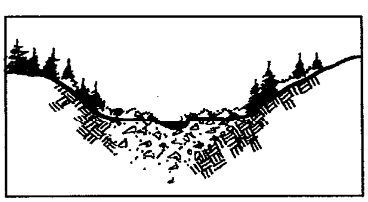
* Select plant species that have low palatability if the site is an area where grazing (livestock or wildlife) is not desired.

* If aesthetics are a part of the objectives, select species that flower in different months and that have colorful berries, fruits, and fall color.

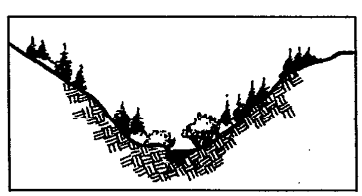
* If the revegetation site is an area where views are important, low growing shrubs might be more appropriate than taller shrubs and trees.

Table 3.1 Geomorphic Valley Forms

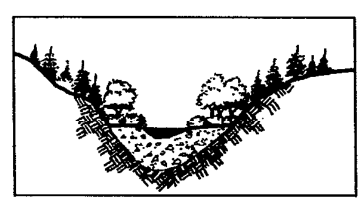
Valley Form	Stream Characteristics		
	Gradient and Flow	Rosgen Type	Additional Information
Glacial Headwaters and Valleys	Small, low gradient. Low order stream in U-shaped valleys.	C and E	Highly permeable substrate minimizes flooding during high precipitation events.
Erosional Fluvial Canyons	High gradient. Low to mid-order streams in V-shaped canyons.	A	Highly confined, may be downcutting.
Depositional Fluvial Canyons	Moderate to high gradient. Low to mid-order streams in V-shaped canyons where deposition has occurred.	B	Moderate to highly confined with restricted meandering. Flow regimes are widely fluctuating.
Braided Stream Channels	Moderate gradient. Often located where fluvial canyons empty into broad valleys and deposit coarse sediment.	D	These zones are naturally highly erodible.
Mid-elevation Confined Alluvial Valleys	Low gradient. Small to medium-sized low to mid-order streams.	C	Moderately confined. Usually at 5,000 to 7,000 feet elevation in north, higher moving south in the region.
Low-elevation Unconfined Alluvial Valleys	Low gradient and highly sinuous.	C	Slight to no confinement. Evaporation is high in Great Basin valleys.
Lacustrine Basins	Slow moving, low gradient. Often ephemeral streamflow.		May terminate in a saline lake, dry lake bed, or playa. Soil conditions often very saline.



Glacial Headwaters and Valleys



Erosional Fluvial Canyons

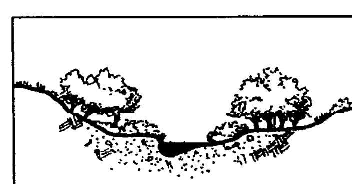


Depositional Fluvial Canyons

Vegetation	Revegetation Potential
Primarily herbaceous wetland species (*Juncus, Carex, Eleocharis*) with levees and hummocks supporting low-growing willows; planeleaf willow (*Salix planifolia*) and wolf willow (*S. wolfii*).	Moderate revegetation potential due to high elevation and short growing season.
Narrow band of riparian vegetation, primarily deep-rooted species: river alder (*Alnus incana*); water birch (*Betula occidentalis*); common shrubs include: dogwood (*Cornus spp*.) chokecherry (*Prunus virginiana*) geyer willow (*Salix geyeriana*) and booth willow (*S. boothii*).	Relatively low due to high flow velocities, erosion rates and/or rock. Rely on bioengineering methods that include adequate protection of plantings.
Stream terraces support river alder, water birch or cottonwoods: (*Populus trichocarpa, P. angustifolia, P. fremonti*); common shrubs include: dogwood, chokecherry, geyer and booth willow. Other willows include: whiplash willow (*S. lasiandra*), coyote willow (*S. exigua*) and drummond willow (*S. drummondiana*).	Relatively low due to high flow velocities, floodplain scouring and/or rock. Rely on bioengineering methods that include adequate protection of plantings.
Gravel bars and secondary channels may support cottonwood, coyote willow, and other species that establish on freshly deposited sediment.	Poor to fair; plantings are vulnerable to channel shifting; stream should be allowed to move as needed. Consider establishing and maintaining parent trees and shrubs as seed sources if large areas are denuded.
Booth and geyer willow dominate many communities on soils too waterlogged for deeper rooted alder, birch, and cottonwood, deeper rooted species may occur on small terraces.	High using booth and geyer willow as primary species for bioengineering treatments; river alder, water birch, and cottonwood may be planted where site conditions permit.
Black cottonwood (north and west), narrowleaf cottonwood (east), and Fremont cottonwood (south), are very common. Commonly associated with coyote willow and yellow willow (*S. lutea*).	High, using native cottonwood or willow; a typical planting along medium sized streams would include willows at the waterline and cottonwoods with understory shrubs on the upper banks and low terraces.
May include cottonwood and willow if in freshwater environment or salt-tolerant non-native, invasive species such as saltcedar (*Tamarix* spp.) or Russian olive (*Elaegnus angustifolia*).	High using native species where conditions are not excessively saline.

Braided Stream Channels

Mid-elevation Confined Alluvial Valleys



Low-elevation Unconfined Alluvial Valleys and Lacustrine Basin

STEP 4 DETAILED INVENTORY AND ANALYSIS.

In this step, the areas should be inventoried and analyzed and a site with the most potential for improvement should be selected. The interdisciplinary team should consider factors such as topography, soils, climate, hydrology, vegetation, fluvial geomorphology, and geotechnical considerations as well as other factors deemed necessary by the design team. The following is a brief discussion of the type of data the team should collect and record on a base map (Fig. 3.2). A base map can be created by enlarging the project area from an U.S.G.S. 7.5 minute quadrangle map.

Topography

1. Determine degree of streambank slope in stable and unstable areas to assess a suitable angle of repose. Generally, final slopes should not exceed a 3H:1V slope.

2. Determine site-accessibility to stage materials such as brush and rock for revetment techniques.

Soils

1. Analyze soil type and depth for revegetation activities. Take soil cores to see what type of layers are present. It is difficult to get successful rooting in thick clay layers.

2. Other soil factors to consider include compaction, crusting, pH, fertility, organic matter, and special limiting conditions such as sodic, acidic, calcic, or saline soils.

Infertile, inorganic, and poorly drained subsoils can make the establishment of vegetation very difficult. Compacted soils are often saturated with high levels of carbon dioxide and may be deficient in oxygen, thus making plant establishment difficult.

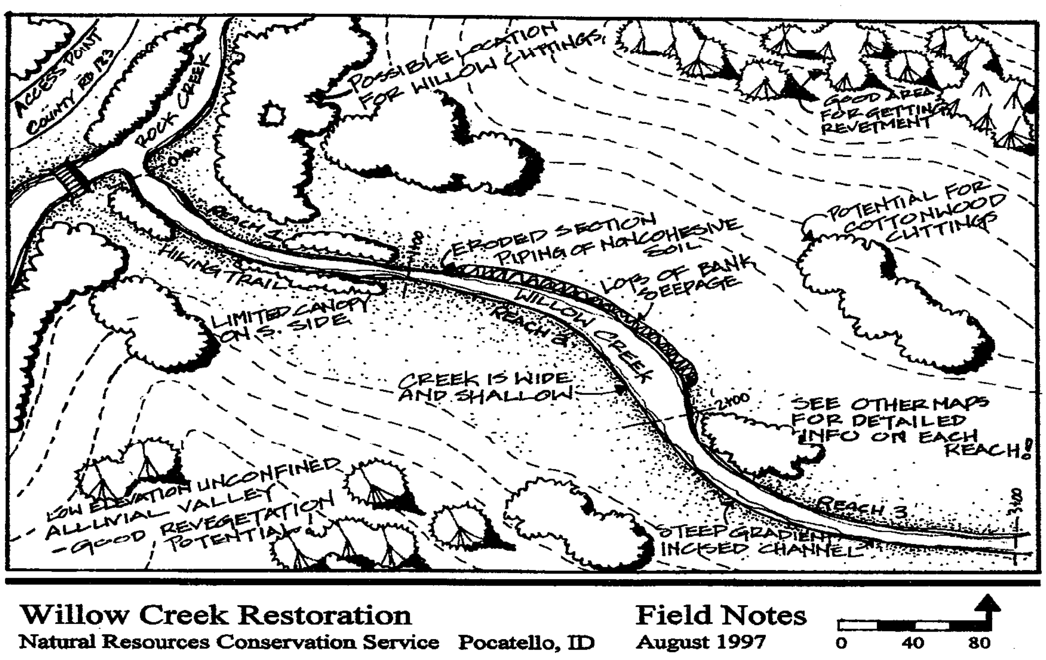


Fig. 3.2 *Base Map with Field Notes*

Soil pH, either high or low, causes many problems with nutrient deficiency or toxicity (Munshower 1993). Limiting conditions such as sodic, acidic, calcic, and saline conditions are detrimental to root and shoot growth. Few plants are tolerant of these conditions. Plantings in these types of soils are rarely successful when conditions are extreme and only moderately successful if care is taken to use plants tolerant to these limitations.

Climate

1. Regional climate data should be collected and assessed for impacts on the proposed project, particularly in regards to planting. The USDA Plant Hardiness Zone Map (USDA Agricultural Research Service 1990) delineates zones in which day length, radiation, temperature, frost, heat, and rainfall are described.

2. It is critical to inventory microclimates at the project scale, because these can be very different from average regional climates. Microclimates are the result of local physical and biological factors in relation to climatic factors. For example, a south facing streambank receives more solar radiation than a north facing slope which will influence soil moisture conditions.

Hydrology

1. If the stream has a gauging station, the flow data should be analyzed for peak flows up to the 100-year flow frequency and late summer low flows.

2. If there is no gauging data, qualitative information can be collected from local residents and field indicators along the channel. Field indicators include old flotsam lines, water level markings on rocks and changes in the vegetation community.

3. Determine bankfull discharge also known as the channel forming flow. Bankfull discharge is the flow event where the flow is at the top of the point bar and ready to enter the floodplain and typically occurs every 1.5 years (Leopold 1994). In many incised streams, the flows may not be able to leave the channel due to entrenchment. In this case, it is still advisable to know where the

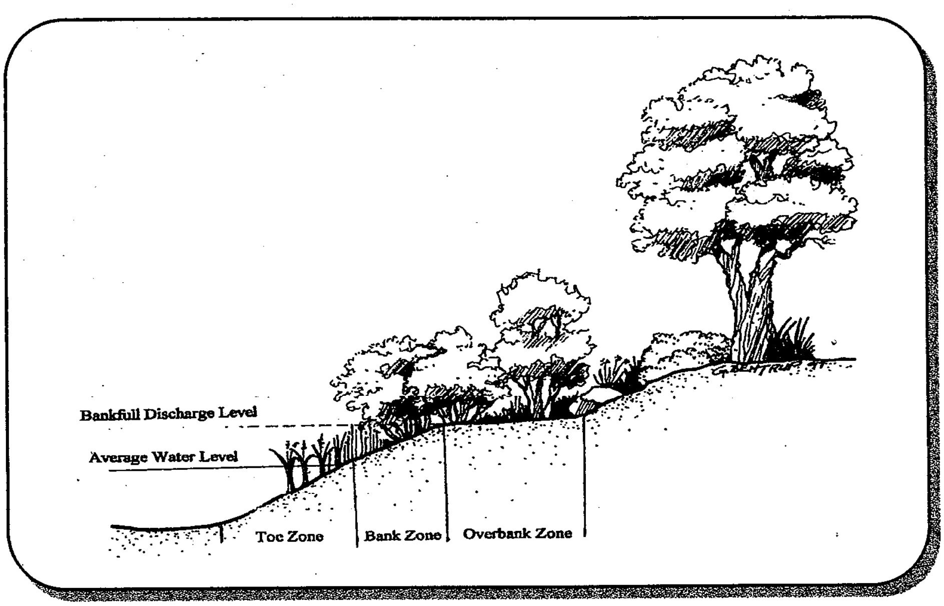


Fig. 3.3 *Streambank Zones and Bankfull Discharge*

top of the flow is for a 1.5 to 2 year event for design purposes (Fig. 3.3). The video, *A Guide to Field Identification of Bankfull Stage in the Western U.S,* may be a useful tool for this task and is referenced in the Resource section.

4. Determine discharges and flow velocities of peak flow events. Often 2-, 5-, 10-, and 100-year return intervals are evaluated to determine design parameters associated with these events.

5. Determine late summer or permanent water-table levels for vegetation planting. Piezometers or shallow groundwater wells constructed of perforated PVC pipe may be used to monitor groundwater levels (Briggs 1996) (Fig. 3.4).

Vegetation

1. Inventory the vegetation in the area to determine suitable species for the restoration project. In degraded areas, historical data and professional judgment will be required to create a planting list.

2. Locate healthy vegetation communities in the area where cuttings may be harvested for the bioengineering techniques.

3. Determine where the different species occur in relationship to the stream channel and water table (Refer to Fig. 3.8 and Fig. 3.9). Use this as a biological benchmark for the restoration plan.

Fluvial Geomorphology and Geotechnical Factors

<u>Streambank Zones</u>

Johnson and Stypula (1993) provide a useful classification of streambank zones: the toe, bank, and overbank zones (Fig. 3.3).

Toe Zone. The toe zone is the portion of bank that is between the average high water level and the bottom of the channel at the toe of the bank. This zone is the most susceptible to erosion since it is inundated most of the year and experiences strong flows, wet-dry cycles, ice jams, and debris flows. Most of the bioengineering projects that fail inadequately address the erosive forces in the toe zone (Allen, pers. com.).

Bank Zone. The bank zone is that area between the average water level and the bankfull discharge level. This area will experience periodic erosive flows. In entrenched stream systems, the historic bankfull discharge volume may no longer reach the top of the bank due to downcutting.

Overbank Zone. The overbank area is situated above the bank zone and is traditionally considered the floodplain. This area only receives erosive flows during flooding events and commonly experiences dry periods.

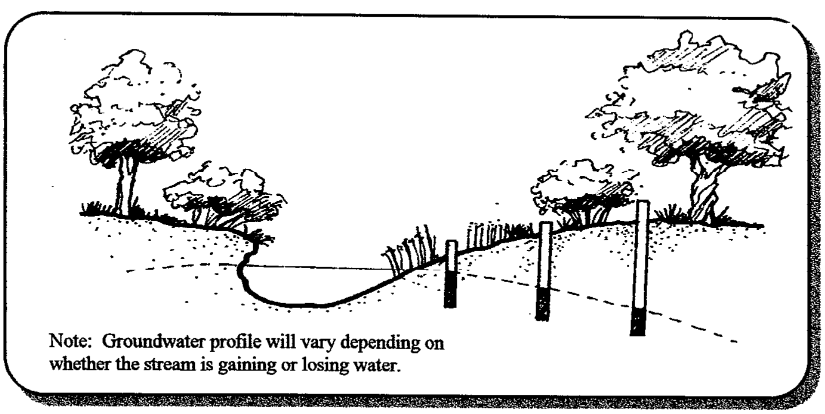


Fig. 3.4 *Groundwater Monitoring Wells*

<u>Streambank Composition</u>

Streambank failure is closely related to the composition of the streambank material. Although these materials can be highly variable, they can be broadly divided into four categories. Johnson and Stypula (1993: pp 3-2) describe each as follows:

Bedrock. Outcrops of bedrock are generally quite stable; however, they can cause erosion in the opposite bank if it is softer material.

Cohesionless Banks. Cohesionless soils are heterogeneous mixtures of silts, sands, and gravels. These soils have no electrical or chemical bonding between particles and are eroded particle by particle. Erosion of cohesionless soils is determined by gravitational forces, bank moisture, and particle characteristics. Factors influencing erosion also include seepage forces, piping, and fluctuations in shear stress.

Cohesive Banks. These banks generally contain large quantities of clay particles which create a higher level of bonding between the particles. Consequently, cohesive soils are more resistant to surface erosion because they are less permeable. This reduces the effects of seepage, piping, and frost heaving. However, because of low permeability, these soils are more susceptible to failure during rapid drawdown of water levels due to the increase in soil pore water pressures.

Stratified or Interbedded Banks. These banks are generally the most common bank type in fluvial systems because of the natural layering process. These soils consist of layers of materials of various textures, permeability, and cohesion. When cohesionless layers are interbedded with cohesive soils, the erosion potential is determined by the characteristics of the cohesionless soil. When the cohesionless soil is at the toe of the bank, it will generally control the erosion rate of the overlaying cohesive layer (Fig. 3.5). When a cohesive soil is at the toe of the slope, it will generally protect any cohesionless layers above (although these layers will still be subject to surface erosion).

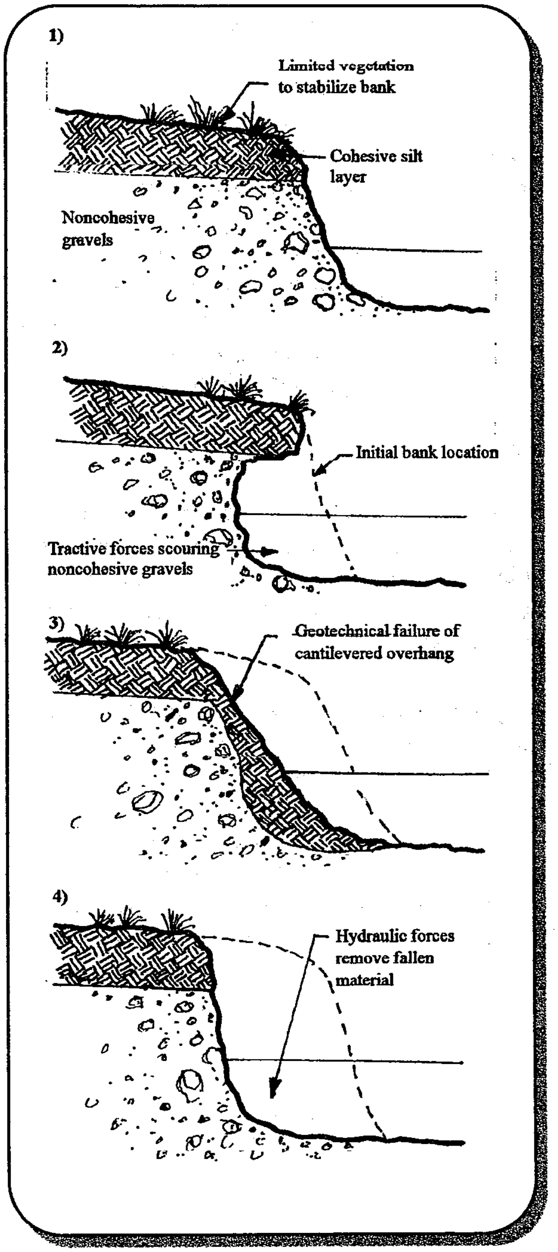


Fig. 3.5 *Stratified Streambanks and Combination Failures (Adapted from Johnson and Stypula 1993)*

Streambank Failure Mechanisms

Bank failures in fluvial systems generally occur in one of three ways (Fischenich 1989): hydraulic forces remove erodible bed or bank material, geotechnical instabilities result in bank failures, or a combination of hydraulic and geotechnical forces cause failure. Fischenich (1989: pp 103) describes each failure mechanism and its characteristics as follows:

Hydraulic Failures. Bank erosion occurs when flowing water exerts a tractive force that exceeds the critical shear stress for that particular streambank material. Hydraulic failure is generally characterized by a lack of vegetation, high boundary velocities, and no mass soil wasting at the toe of the slope.

Geotechnical Failures. Geotechnical failures that are unrelated to hydraulic failures are usually a result of bank moisture problems. Moisture can affect the ability of the bank material to withstand stresses. Failures are often the result of the shear strength of the bank material being exceeded. Characteristics of geotechnical failures can vary, although mass wasting of soil at the toe of the bank is often one indicator.

Combination. The most common failure is due to a combination of hydraulic and geotechnical forces (refer to Fig. 3.5). For example, bed degradation due to hydraulic forces can lead to an oversteepening of the banks which can result in a geotechnical failure of mass wasting.

Cause of Failures

Although bank failures result from three different mechanisms, the actual causes of erosion are complex and varied (Fischenich 1989). Successful bioengineering projects need to address the causes of failure.

Erosion from hydraulic forces is usually connected to flow velocities and/or its direction (Fischenich 1989). Human actions are often responsible. Channelization and constrictions caused by bridges are examples that will change velocities. Changes in flow direction often result from an obstruction along or in the channel. Any unnatural destruction of bank vegetation promotes erosion by hydraulic forces.

Geotechnical failures are usually the result of moisture conditions in the streambank which create forces that exceed bank resistance. Common examples of the causes include (Hagerty 1991; USACE 1981):

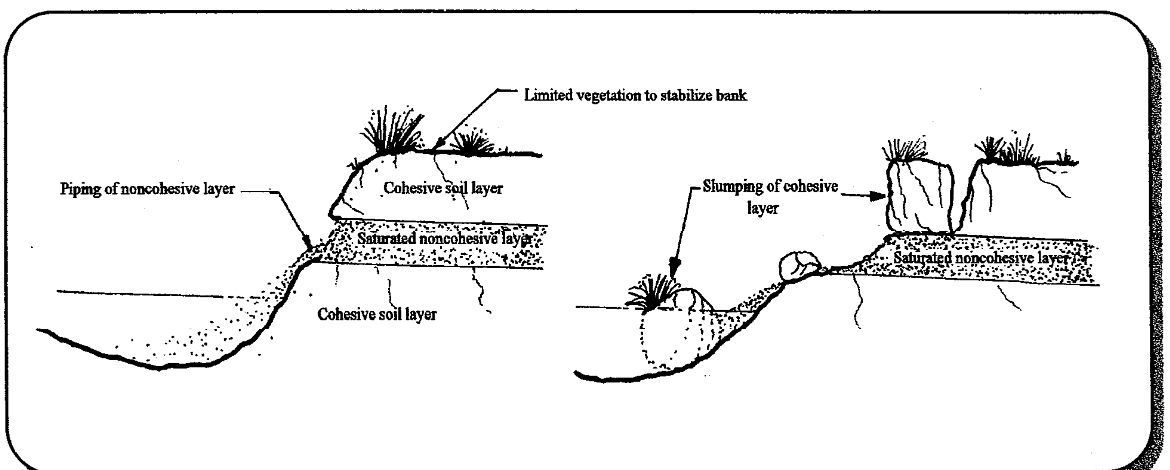


Fig. 3.6 *Bank Erosion Due to Piping (Adapted from Hagerty 1991).*

* Banks are destabilized by the piping of cohesionless soil from lenses (Fig. 3.6).

* Capillary action temporarily decreases the angle of repose of the bank material to less than the existing bank slope.

* Liquefaction of fine-grained material causes fluid-like failures of the bank from pore pressure increase during rapid drawdown.

* Shrinking and swelling of clay soils during wetting and drying cycles causes tension cracks.

* Freezing and thawing of soil which weakens the shear strength.

* Subsurface moisture changes weaken the internal shear strength of the soil mass at the interface of different soil types.

Since the most common mode of failure is a combination of hydraulic and geotechnical forces, a interdisciplinary team is crucial in identifying the causes of failure. Some of the steps to assist in determining streambank failure mechanisms and causes include the following:

1. Determine streambank composition and stratification. Assess possible streambank failure mechanisms by observing the site over a period of time.

2. Several cross sections should be taken to graphically show the channel in relation to the floodplain. This information will help reveal the type of degradation (i.e., lateral erosion or downcutting) and will provide baseline data for future monitoring. If a channel is actively downcutting, these sites are significantly more difficult to stabilize and should generally be avoided unless instream structural measures are planned. If the streambank is cutting laterally, appropriate bioengineering methods may be more successful.

3. A survey should be completed of the longitudinal profile of the channel thalweg (the deepest point along a stream). This will illustrate any unusual characteristics of the stream slope which might indicate areas that may be more unstable.

4. Type of bed material and distribution should be determined. This will provide clues to the resistance of the material to erosive flows. Particle size distributions can be calculated by collecting and screening samples, or for the surface layer only, a pebble count of exposed particles can be sampled (Leopold 1994).

STEP 5 DESIGN PROCESS

The next step is to design a site specific bioengineering project. Appendix A covers a selection of bioengineering techniques (Fig. 3.7). Many of these techniques should be combined with others to provide a method that will be most suitable for the project.

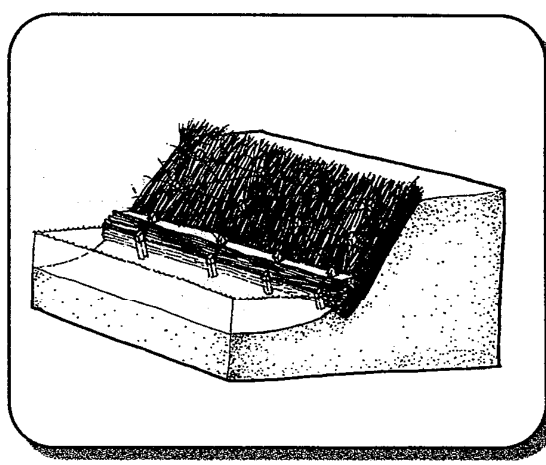


Fig. 3.7 *Willow Brush Mattress Technique*

DESIGN GUIDELINES

The following are some important factors to consider during the design process. This discussion of factors is not complete but rather a starting point for a collaborative process between members of the design team.

Hydrology

Hydrology is one of the most important factors to consider in a bioengineering design. It is common for streams to have widely fluctuating flows from spring runoff to late summer flows. Bioengineering in the Great Basin and Intermountain region is a balancing act. In addition to providing protection during high flows, the vegetation must also have access to the late summer water table in order to survive.

Groundwater well data can provide insight on the fluctuations of the water table. Calculating the magnitude of discharge (Q) for different flow events can also provide valuable information. Discharge is based on:

$$Q = V * A$$

where
Q = discharge (ft^3/sec)
V = velocity (ft/sec)
A = cross-sectional area (ft^2)

while velocity is based on Manning's equation:

$$V = \frac{1.49 * R^{2/3} * S^{1/2}}{n}$$

where
R = hydraulic radius (ft^2/ft)
S = slope (ft/ft)
n = coefficient of roughness

(Dunne and Leopold 1978)

Using these equations, a hydrologist can construct a characterization of the hydrological parameters at the site. For example, different theoretical flood events can be used with cross-sectional data to estimate the water elevations at the proposed restoration site. Duration of flooding can also be estimated to determine if the plant species selected can handle the period of inundation.

In particular, bankfull discharge ($Q_{1.5}$), which typically has a recurrence interval of approximately 1.5 years, is an important benchmark because it is a dominant channel shaping flow (Leopold 1994). It is also crucial because it will provide some guidance for locating vegetation that may receive moisture from this frequent flooding activity.

<u>Streamflow Velocity</u>

Very little research is available on the relationship of the stability of woody streambank vegetation to flow velocity (Carlson et al. 1995). Parsons (1963) evaluated streambank willow plantings in the northeastern United States and equated a fully developed stand of densely stemmed purple-osier willow (*S. purpurea*) to a blanket of 6-inch angular rip-rap. Other research has focused primarily on grassed waterways and may not be directly transferable to the region's cobble bed streams (Temple et al. 1987).

Instead, tractive force guidelines provided in the following section may be a better indicator of stability. In high velocity situations, a combination of bioengineering techniques and hard structures may be necessary. Hard structures will significantly reduce erosion in a much shorter period of time than bioengineering structures, however, by incorporating bioengineering into the plans, a much better design will be obtained.

Hydraulic Considerations

Tractive Forces

One of the most important hydraulic design criteria for bioengineering projects is the erosive forces on the bed and banks usually referred to as tractive force or shear stress (Miller 1996). The average tractive force on a bank is equal to:

$$T = ydS$$

where y = unit weight of water; 62.4 lb./ft^2
d = depth of flow for a particular discharge event in feet (ft); and
S = channel gradient in ft/ft

(Chen and Cotton 1988)

Schiechtl and Stern (1994) offer some guidelines for maximum tractive forces in lbs/ft^2 for structures immediately after completion and after 3 to 4 years of root development (Table 3.2). Again, it should be remembered that some bank erosion is part of the natural process.

Depth of Scour

Another important design criteria is depth of scour. During high flow events, bed materials become mobile (Leopold 1994). For a given discharge, there is an average depth at which the bed will begin to move, referred to as the depth of scour. Excessive scour can undermine the bioengineering treatment and cause failure. The estimated scour depth can be used to identify the depth at which toe stabilization will need to be placed in order to remain stable during a particular discharge event (Miller 1996). There are different equations that can be used to estimate the depth of scour (Chang 1992).

Endpoint Protection

Another area that is subject to failure in a bioengineering project is the upstream and downstream ends of the installation. These endpoints must be protected so that the streamflow does not get behind the structure. If flows do get behind the structure, soil can be scoured out, stakes and wire can be dislodged, and the integrity of the structure can be weakened or destroyed. Sometimes the endpoints can be keyed into existing features such as boulders, large trees, etc. (Fig. 3.8). In other cases, the endpoints will need to be protected by keying in the treatment ends using rock and other types of revetment. Remember to always start and extend the treatment beyond the obvious eroded areas.

Table 3.2 *Maximum tractive forces for bioengineering*

Technique	Force (lbs/ft^2) immediately after completion	Force (lbs/ft^2) after 3-4 seasons
Reed plantings (herbaceous)	10	70
Deciduous trees plantings	50	290
Willow Wattle	145	190
Brush Layer	50	340
Brush Mattress	120	725
Rip-rap with live cuttings	480	725

Adapted from Schiechtl and Stern (1994).

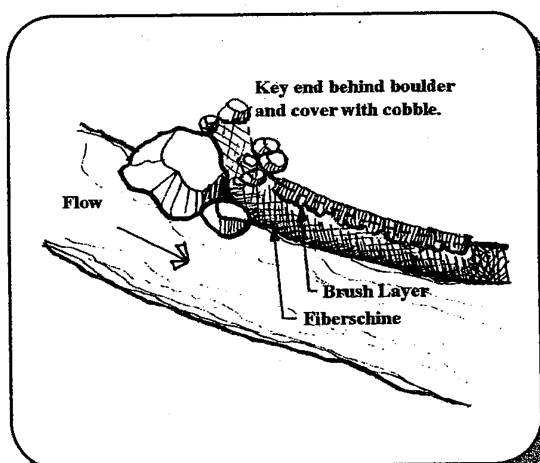


Fig. 3.8 *Endpoint Protection*

Fluvial Geomorphology

Fluvial geomorphic parameters should be used in the design phase of the bioengineering project to assess how the treatment might affect the stream channel and flows. For example, it is important that the appropriate channel width, depth, and hydraulic radius are maintained to carry the bankfull discharge (Miller 1996; Dunne and Leopold 1978).

One tool that may be used to gain an understanding of fluvial geomorphology, at least in the West, is the Rosgen Stream Classification System (Rosgen 1994). It should be noted that the system is based on natural streams and may not be easily transferable to a degraded system.

This system should not be used as a recipe book for determining restoration techniques and specific channel geometry. Each project should be approached as an unique situation (Kondolf 1996). Beschta and Platts (1986) note that channel morphology is related to a large number of interacting variables such that the "expected" width or depth of a particular stream reach cannot be calculated or predicted. However, with caution, the Rosgen classification system may provide some guidance for width, depth, and sinuosity of similar natural streams.

Geotechnical Considerations

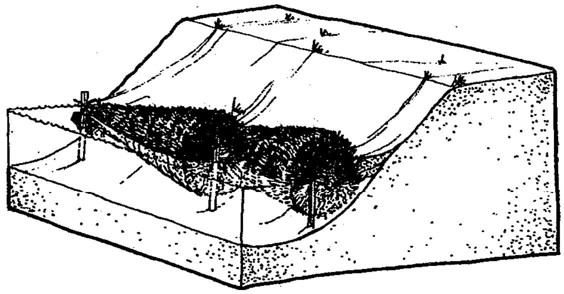
As Fischenich (1989) stated, erosional problems along streams often result from a combination of hydraulic and geotechnical mechanisms. The detailed inventory should reveal all geotechnical failures occurring at the project site. Once these factors are identified, the design should incorporate measures to address these problems. In general, most geotechnical deficiencies require an increase in soil shear strength (Fischenich 1989). This is usually accomplished with roots in the vegetative component of the bioengineering project (Gray and Leiser 1982). In addition to the tensile strength provided by the roots, they will also moderate saturated soil conditions and minimize effects of piping and liquefaction (Gray and Leiser 1982).

In some cases, supplementary drainage measures may be required when rapid drawdown of flood waters causes streambanks to fail due to increased soil water pressure (Miller 1996). Methods allowing internal drainage may be necessary such as sloped gravel drains and weep pipes (Miller 1996; Fischenich 1989).

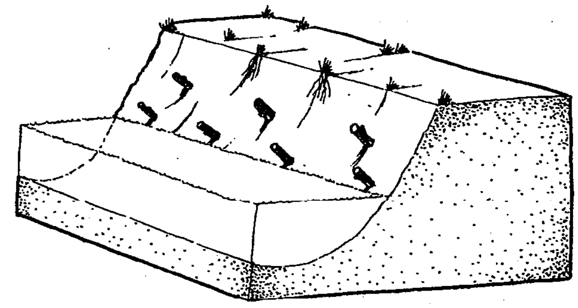
Another geotechnical design consideration is determining a stable angle of repose or slope. Different theoretical analyses can be used to estimate a suitable angle of repose (Gray and Leiser 1982). Existing, stable slopes in the area can be used as a benchmark for design purposes. Be sure to select slopes that occupy similar channel positions compared to the treatment area; i.e. a concave bend may have a steeper slope than other areas. It should be pointed out that a natural stabilized slope can occur at a steeper angle than a newly vegetated slope unless additional protection measures such as erosion control fabric are incorporated in the design.

Putting It All Together

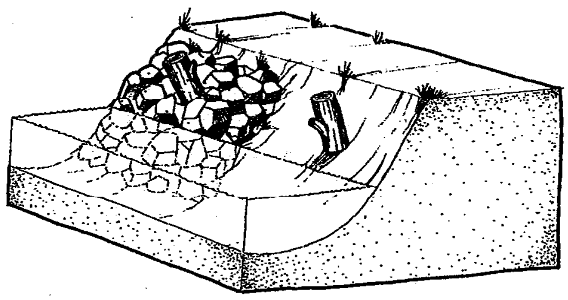
The following pages illustrate the different techniques found in Appendix A (Fig. 3.9a-b). Each treatment is described in separate technique sheets to clarify and highlight that specific technique. During the design process, these various techniques will usually be combined into one treatment that will address the problems identified during the inventory and analysis phase. These technique sheets may be photocopied individually and handed out to landowners contemplating bioengineering work on their property. Additional technique sheets may be added in the future.



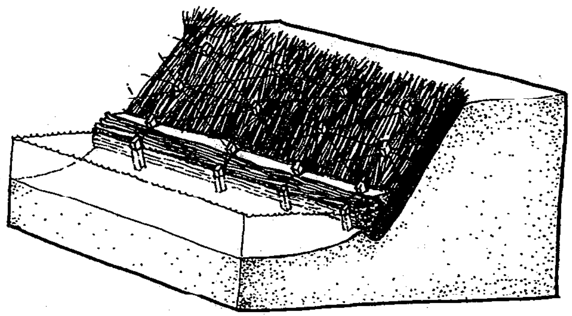
Brush Revetment



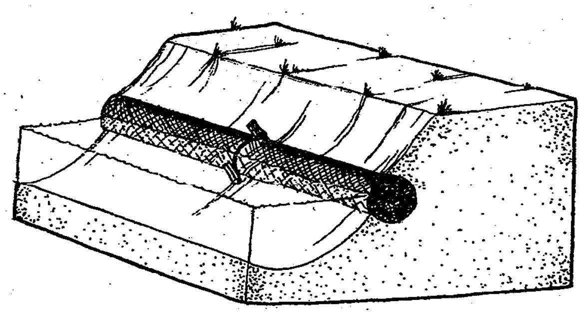
Pole Plantings



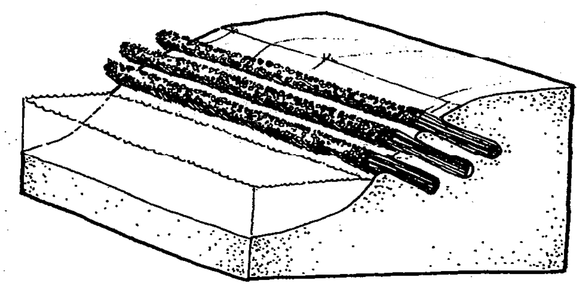
Post Plantings



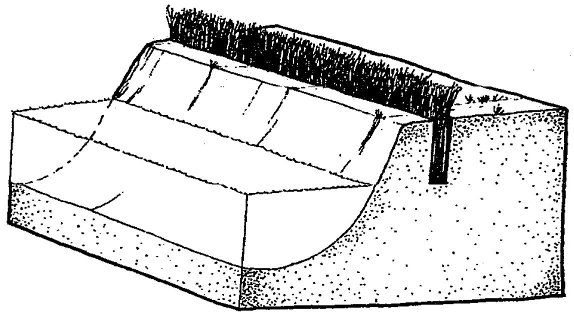
Brush Mattress



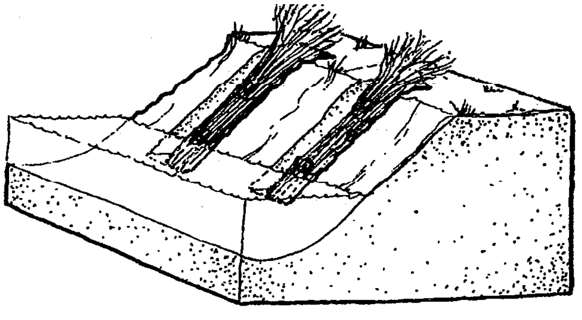
Fiberschines



Brush Layer

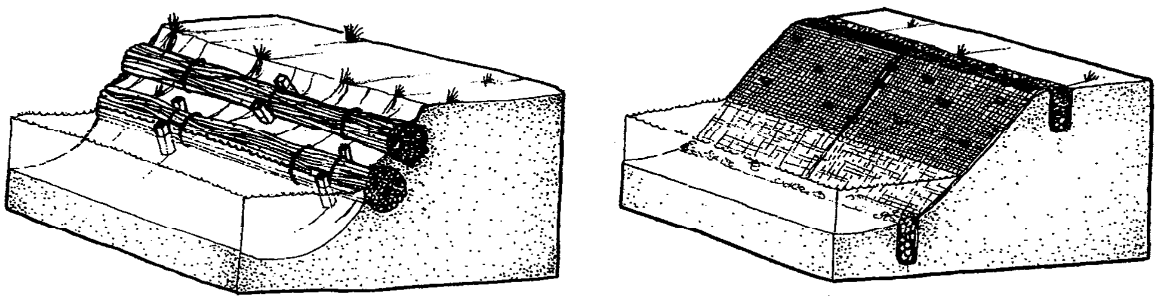


Brush Trench



Vertical Bundles

Fig. 3.9a



Willow Wattles **Fig. 3.9b** *Erosion Control Fabric*

Many other bioengineering techniques are applicable for riparian areas. Some resources include Allen and Leech (1997), Schiechtl and Stern (1994) and Gray and Leiser (1982).

Fig. 3.10 demonstrates a theoretical application of the use of a combination of techniques. Although this is a simplified example, it illustrates how the different hydrologic, hydraulic, geotechnical, and vegetation considerations can be addressed.

STEP 6 PERMIT PROCESS

After a conceptual design has been completed, it is important to check with the Army Corps of Engineers, the state agency in charge of regulatory stream permits, and any local agencies that might have jurisdiction to determine the necessary permits. In some cases, it may be worthwhile to bring the regulatory agencies on site so they can fully understand the project's objectives and design.

If the proposed project requires the placement of fill material in any waters of the United States, it will be necessary to obtain a Section 404 Permit from the U.S. Army Corps of Engineers. Most stream work falls under the Nationwide permitting (NWP) process which includes over 30 types of NWP. The most commonly used NWP for stream stabilization projects is the NWP 13-Bank Stabilization.

NWP 13 allows bank stabilization measures for erosion prevention based on the following analysis:

* amount of material placed in the waters of the U.S.;

* length of the bank stabilization project;

* will material be placed in any special aquatic site;

* is the activity part of a single and complete project.

In some instances, a Letter of Permission may be all that is required to install a bioengineering project if fill is not being added to the stream channel. However, the regulatory agencies should **always** be contacted in order to prevent any surprises.

STEP 7 IMPLEMENTATION

Timing of bioengineering projects is critical. The most optimum time to install projects is usually in the spring. Periods of high flows should be avoided for safety reasons. Spring time projects allow the use of dormant cuttings which have the highest success rate. Implementation should also take into consideration wildlife and fisheries concerns. Critical spawning periods should be avoided.

Scheduling the sequence of work is also important. Dormant cuttings should be soaked for 5-7 days (see Chapter Four). Thus, harvesting and soaking of cuttings needs to be scheduled and completed a few days before construction. If the project incorporates nonliving material, such as brush revetment, it may be installed while the cuttings are soaking. Non-living components such as brush revetment may be constructed the season before the installation of the plantings.

Projects should always avoid or minimize impacts to wetlands and other sensitive areas. Never disturb the site unnecessarily. Remember the goal is to stabilize a site. The less it is disturbed, the easier it will be to restore.

STEP 8 MAINTENANCE AND MONITORING.

Maintenance and monitoring are probably the most important things that you can do to ensure the success of a bioengineering project. Many times, planned maintenance can make the difference between success and failure. Monitoring will help you to determine what has worked and what hasn't. Remember that bioengineering is not exact science, but rather it is an art that must be designed from many different factors that are not always easy to determine. Some of the techniques will work well in one situation, but not in others. The secret is to learn over time and many different projects.

Maintenance and monitoring will be covered in detail in Chapter Five.

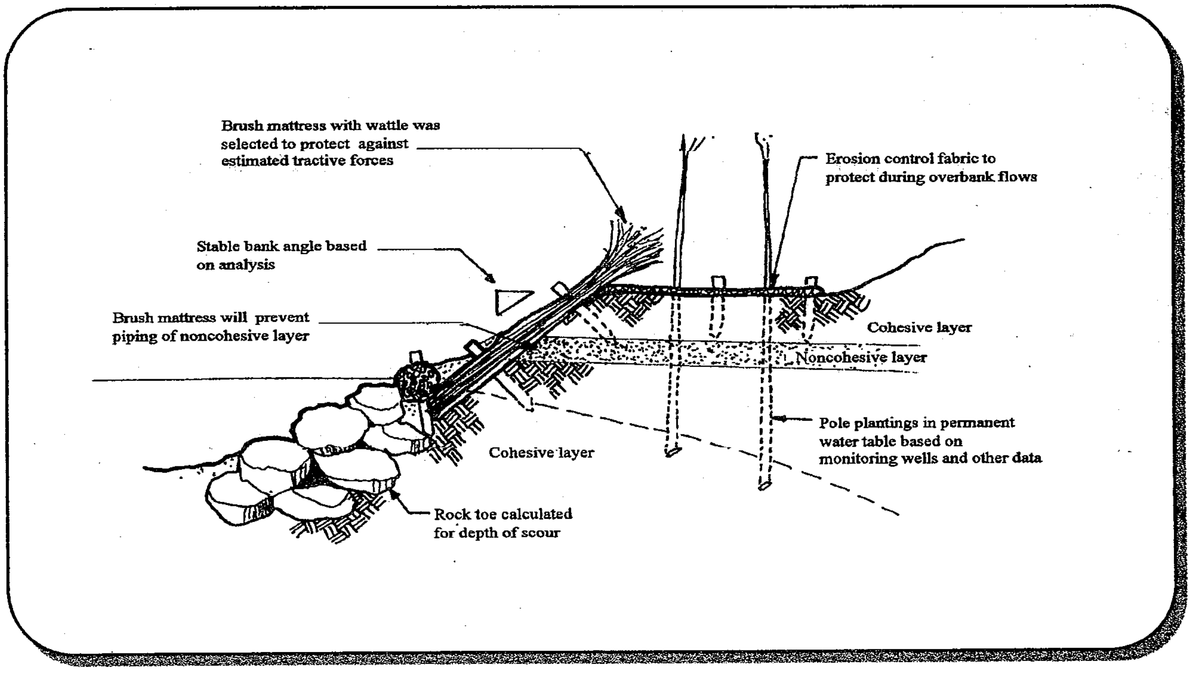


Fig. 3.10 *Theoretical Example of Combining Techniques*