

# Streambank Soil Bioengineering Approach to Erosion Control

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## 1. Introduction

Rivers in tropical regions have been submitted to strong environmental impacts through changes in the hydrologic and sedimentological regime, and also to the ongoing destruction of their riparian vegetation, despite the important role of riparian vegetation in riverbank protection through root systems and plant cover, which improve soil particle aggregation in a low cohesion situation, reducing runoff and resulting in a lower erosion rate and sedimentation of the river channel. Rivers are in effect often referred to as dynamic systems which means they are in a constant state of change.

Techniques of stream bank and bed stabilization are needed and can be accomplished in several ways, such as the use of rockfill, which, though efficient, is quite expensive, precluding its use extensively along the river banks. In an attempt to solve the problem, riverine populations have resorted to various empirical solutions that, in addition to not producing the desired effect, cause problems for riparian vegetation recovery besides degrading the landscape (Holanda et al., 2010). The function of riverbank protection is to avoid bank erosion, that could cause movement of the river channel, which can be of vertical and horizontal direction, arise meandering, braiding, or moving and changing the river's path.

As an alternative to the empirical practices of the riverines and to expensive bordering and rockfill techniques, the use of abundant raw material has been tested and used, providing a way of mitigating the problem that can be economically viable and with proven technical efficiency. This chapter intends to discuss soil bioengineering as a biotechnology that consists of the use of living materials or inert plant substances, biotextiles, associated or not with rocks, concrete, or metals that present themselves to be environmentally sustainable to riverbank erosion control at the various conditions of slope and soil texture along their water systems like reservoirs, irrigation canals, and rivers. Soil bioengineering can be applied in the mitigation of watershed disasters and protection and restoration of ecology. In soil bioengineering, plants assume an important ecological contribution (providing multiple ecological services), as well as an economic, and especially structural, contribution in contrast to other technologies in which plants are merely an aesthetic component of design. Also, a discussion will be developed on the vegetation component, which has a great importance in these biotechnologies, recognized not only for its landscaping qualities, but also for its beneficial hydromechanical effects and protection against soil erosion.

## 2. Basic concepts

### 2.1 Mechanisms of riverbank failure

The multiple demands for water resources show a typical picture of conflict for the use of waters required by the development's policies and ecologic services. Watersheds around the world have been subjected to the installation of hydroelectric dams along river channels and surface water withdrawal to ensure water for agricultural, industrial, and domestic purposes; for hydroelectricity; or for flood protection. Based on the Mediterranean rivers, Salinas & Casas (2007) listed nine observed main categories of impacts, which can be applied to most of the rivers worldwide, as follows: 1) canalization, 2) substrate excavations and/or leveling of the channel floor, 3) traffic along the channel, 4) grazing by mixed flocks of sheep and goats, 5) fires, 6) up-stream water extraction for irrigation, 7) cutting of woody vegetation, 8) organic or inorganic rubbish dumps, and 9) farming activities in the riparian corridor.

When hydroelectric power plants are constructed they cause an irreversible modification in the morphology of the natural environment; the possibility of flooding over adjacent areas increases; new local climatic conditions are created, and there is a loss in water and sediments that should be given back to the river downstream (Carone et al., 2006).

The operation of reservoirs, centralized for the generation of electricity and the supply of water for irrigation, generally considered the attending of ecologic priorities to be marginal (Holanda et al., 2009), leading to a strong environmental debt, such as with bank erosion, river channel sedimentation, the growth of a large quantity of aquatic vegetation, and the decrease of sediments which harm the reproduction and preservation of fish and navigation. In addition as a result of the construction of these dams, land adjacent to floodplain is currently flooded and river flow regime has been altered. According to DeWine & Cooper (2007), the response of stream channels and riparian vegetation to river regulation is influenced by several factors including pre- and post-dam river flow regimes, channel type, and the species involved.

Serious disturbances in the major extension of riparian ecosystems along river margins have led to riverbank destabilization, increasing erosion, stream lateral migration, and sedimentation, which are reflected directly in the number and position of sand bars. Stream bank erosion is in effect a natural process that over time has resulted in the formation of the productive floodplains and alluvial terraces, and paradoxically, even stable river systems have some eroding banks.

These hydrological alterations change ecosystem structures and processes in running waters and associated environments the world over. Aquatic ecosystems have been strongly degraded, and many fish and other aquatic organisms are now threatened or endangered, particularly because of river development projects and artificial patterns of flow regulation (Fausch et al., 2002), compromising the traditional economic activities (waterlogged land farming and local fishing) (Holanda et al., 2005). With the decline of the population of fish, the majority of fishing communities have become impoverished and left with few alternatives for generating income for the subsistence of their families (Gutberlet et al., 2007). Another common downstream effect of large dams is that the flood peak, and hence the frequency of overbank flooding, is reduced and sometimes displaced in time.

According to Nilsson & Berggren (2000), hydroelectric power dams also change geomorphologic processes such as sediment cycling. The water released from a reservoir tends to restore its original load of sediment and nutrients, resulting in increased erosion

downstream of the dam. This erosion leads to channel simplification and reduced geomorphologic activity in the river bed. Before the construction of a reservoir, bank erosion usually occurs in one local reach, while bank accretion also often happens in another local reach, which can maintain the dynamic balance of channel width. After the construction of a reservoir, the effects of the smoothing of flood peaks and decreasing of incoming sediment supply destroy the relative balance relationship between bank erosion and bank accretion, which often causes serious bank erosion (Xia et al., 2008).

The process of bank erosion is closely related to riverbank-soil composition and corresponding mechanical properties. Bank material may be cohesive or non-cohesive and may comprise numerous soil layers. Bank stability of cohesive riverbanks depends on numerous controlling variables such as soil properties and structure (Van Klaveren & McCool, 1998), soil moisture conditions (Simon et al., 2000), and complex electrochemical forces between cohesive particles and flow and vegetation (Pizzuto et al., 2010; Wynn & Mostaghimi, 2006).

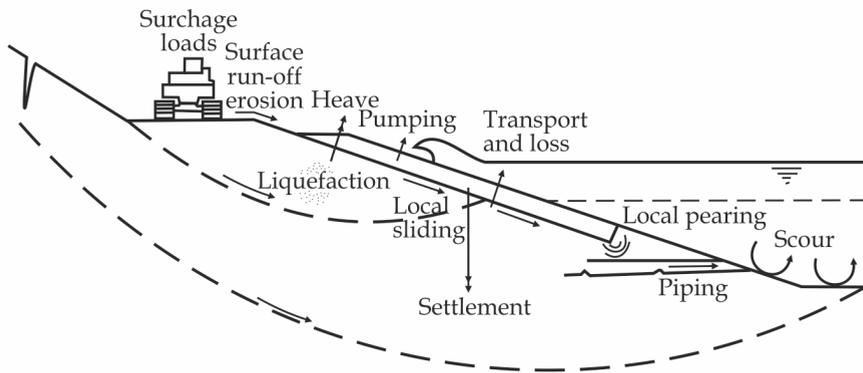


Fig. 1. Schematic representation of causes of geotechnical stability of riverbanks

A reasonable prediction of the bank ruptures can be provided by the qualitative evaluations of various elements influencing the river bank instability (Hunt, 1990). According to Queensland Government (2006) the various mechanisms of stream bank erosion generally fall into two main groups, bank scour and mass failure (Figure 1). In many cases of bank instability both will be evident, often with either scour or mass failure being dominant. Mass failure, which includes bank collapse and slumping, is where large chunks of bank material become unstable and topple into the stream or river in single events. Mass failure is often dominant in the lower reaches of large streams and often occurs in association with scouring of the lower banks. Landslides or mass failure occur when forces driving instability are greater than forces promoting slope stability (Conforth, 2005), that interact with river channel geometry and water flow, driving the sediment transport in the river. Bank scour is the direct removal of bank materials by the physical action of flowing water and the sediment that it carries. Piping is a subsurface form of erosion which involves the removal of subsurface soils in pipe-like erosional channels to a free or escape exit. As fluvial erosion at the bank toe takes place with the continuous removal of bank material, a change in the bank slope occurs with bank overdeepening and alteration of the bank angle (Bertrand 2010).

The likelihood of further mass movement will depend on the stability of the landslide itself and the surrounding soils. In addition, residual soils are likely to be unstable, subject to erosion and not readily colonized. Although many landslides occur naturally, humans are directly accelerating the frequency of landslides by land-use practices (e.g., roads, urbanization, agriculture, clear-cutting) and possibly through their indirect effects on weather patterns (e.g., increased storm frequencies) related to global climate change (Dale et al., 2000).

## **2.2 Fragmentation of riparian vegetation and restoration**

Riparian vegetation on the riverbank has been seriously and continuously deforested because of roads, hydroelectric power dam's construction, urban occupation, adjacent land use, irrigated agriculture, livestock grazing, and the extraction of wood and minerals. Riparian ecosystems occupy the ecotone between upland and aquatic realms and more precisely, the riparian ecosystem can be defined as the stream channel between the low- and high-water marks plus the terrestrial landscape above the high-water mark, where vegetation may be influenced by elevated water tables or extreme flooding and by the ability of the soil to hold water (Naiman et al., 2002).

Natural riparian ecosystems include a variety of community types, with deciduous trees and shrubs on heterogeneous substrates, deltas with distinct plant zonation, and well-developed forests having diverse animal communities. Vegetation interacts with hydrological processes from the earliest stages of plant succession and can have significant impacts on hydraulic processes, particularly during periods of low flow, as well as at the beginning or at the end of flood periods (Tabacchi et al., 2005). Therefore, assessment of deforestation impacts on stream biodiversity and appropriate management practices for its conservation are urgently needed. There are strong evidences that past slash-and-burn agriculture exerted a "press disturbance", which reduced community diversity over a long period in the tropical streams.

An emphasis on the importance of promoting management practices that protect the diverse stream communities from poorly regulated land use in tropical rain forests (Iwata et al., 2003) is needed. Considering every social-ecological problem in river basins with small or large flows, it is necessary to deal with the effects of the impacts on seasonal flow, discharge influence from dams, and traditional knowledge to reach management practices that build resilience.

Because of a river basin's vulnerability to erosion and the unsustainable activities conducted there, flora has been the natural resource most rapidly and easily threatened. The spatial distribution and the structure and dynamics of the riparian vegetation are strongly influenced by the hydrological and sedimentological regime and by associated geomorphological and soil factors, which determine a certain degree of instability and heterogeneity of ecological parameters (Campos & Souza, 2002).

Following river damming and diversion, downstream aquatic and riparian ecosystems have collapsed along many streams.

## **2.3 Streams restoration**

Many stream restoration efforts have targeted the reconstruction of small reaches through artificial measures such as boulder placement, vegetation planting, and fish stocking (Alpert et al., 1999). Live plants and other natural materials have been used for centuries to control erosion problems on slopes in different parts of the world.

According to Walker et al., (2009) once an initial vegetative cover is established on a landslide, many restoration projects end. The mechanism used includes the enhancement of soil shear strength using vegetation soil systems and limiting soil particle movements on slope via utilizing the effects of root systems on soil structure. In plant successional dynamics, great interest must be considered to explore further the influence of the engineering properties of the root system on slope stability and shallow landsliding. The complex interactions of physical and biological processes in riverine ecosystems can complicate restoration efforts. An alternate approach is to restore more naturalized instream flow patterns to allow recovery through natural recruitment and growth processes (Molles et al., 1998; Richter & Richter, 2000; Rood et al., 2003).

According to Li & Eddleman (2002), traditional engineering methods for streambank stabilization that were once thought successful in the past are being re-evaluated in context of impacts resulting from excessive and rapid urbanization, and from the public awareness of these new environmental issues. These restoration strategies are very costly, may require perpetual effort, and often fail. Schiechl (1985) mentioned that the stabilization of slopes through vegetation and soil treatment measures may be particularly appropriate in situations where an abundance of vegetative materials is present, and where manual labor, rather than machinery for installation, can be easily found.

The interest in natural techniques as biotechnical engineering has been raised, and the benefits and advantages of biotechnical engineering or ecological engineering have been gradually re-examined (Riley, 1998). It is necessary to understand the responses toward environmental changes for the management and sustainable use of resources, biological diversity, and ecosystems.

### 3. Defining soil bioengineering

In the last few decades, the seeking for ecologically correct technologies for environmental restoration has become very important. The new paradigm of economic development was built in order to create improvements in the livelihood of future generations, which incorporates a concept of agriculture production, and consequently less pollutants, associated to environmental techniques applied to restore natural systems and degraded agroecosystems. Researchers all around us have been pointing out signs that indicate that a paradigm shift is taking place both within and outside the engineering profession to accommodate ecological approaches to what was formerly done through rigid engineering and a general avoidance of any reliance on nature. Mitsch & Jørgensen (2003) brought the concept of ecological engineering that involves creating and restoring sustainable ecosystems that have value to both humans and nature. According to the authors, Ecological Engineering combines basic and applied science for the restoration, design, and construction of aquatic and terrestrial ecosystems.

Mitsch et al. (2002) provided example of ecological engineering techniques as a new field that has gained more and more importance, incorporating concepts that make it an increasingly attractive alternative to traditional engineering approaches, which are often much more expensive to construct and sustain. The merits of ecological engineering methods lie in the emphasis on comprehensive consideration of all aspects for soil and water conservation tasks (Wu & Feng, 2006). In addition to what has been said Mitsch & Jørgensen (2003) make prominent that Ecological engineering requires a more holistic viewpoint than in many ecosystem management strategies, with a strong emphasis, as does

ecological modeling for systems ecologists, in the need to consider the entire ecosystem, not just species by species.

In this direction Pahl-Wostl (1995) argues that there are two ways that systems can be organized by rigid top-down control or external influence (imposed organization) or by self-organization (Table 1). Imposed organization, such as done in many conventional engineering approaches, results in rigid structures and little potential for adapting to change and desirable for engineering design where predictability of safe and reliable structures are necessary. Self-organization, like ecological engineering, develops flexible networks with a much higher potential for adaptation to new situations.

Characteristic	Imposed organization	Self-organization
Control	Externally imposed; centralized control	Endogenously imposed; distributed control
Rigidity	Rigid networks	Flexible networks
Potential for adaptation	Little potential	High potential
Application	Conventional engineering Machine	Ecological engineering Organism
Examples	Fascist or Socialist society Agriculture	Democratic society Natural ecosystem

Table 1. Systems categorized by types of organization (Pahl-Wostl, 1995).

Although practitioners have coined the terms ground (soil) bio and eco-engineering, confusion still exists as to the exact definition of each. It appears that the term bioengineering was first used as the translation from the German word 'Ingenieurbiologie', created in 1951 by V. Kruegener when referring to projects using both the physical laws of "hard" engineering and the biological attributes of living vegetation, which described the work that encompassed both engineering and biology (Schluter 1984; Stokes et al., 2010) that was considered in an "ecological engineering" context. In 1981, after many discussions with Dr. Schiechl and other European practitioners, R. Sotir developed the new terminology 'soil bioengineering' for North America (Schiechl, 1980). The differences between soil bioengineering and eco-engineering are largely due to their effectiveness over time and space. In soil bioengineering, from the first moment of installation no erosion should occur, as this would be considered part of the original criteria and may be alleviated by the angular arrangement and density of the installed measures. Still, Stokes et al. (2010) call to attention that in eco-engineering, civil engineering techniques are not used, although local organic material at the site, e.g. logs and stumps, may be positioned to prevent soil runoff.

Soil bioengineering, or biotechnical slope protection, has been defined variously as 'the use of mechanical elements (or structures) in combination with biological elements (or plants) to arrest and prevent slope failures and erosion' (Gray & Leiser, 1982), 'the use of living vegetation, either alone or in conjunction with non-living plant material and civil engineering structures, to stabilize slopes and/or reduce erosion', and 'the use of any form of vegetation, whether a single plant or collection of plants, as an engineering material (i.e. one that has quantifiable characteristics and behavior)' (Campbell et al., 2008). The biological and ecological concepts are to build based on the increase of the resistance of slopes to

surface erosion by providing limited mechanical support to the soil, thereby reducing the potential for further surface erosion, gully formation, shallow failures, surface debris movement, and debris entrainment.

Soil bioengineering, in the context of upland slope protection and erosion reduction, combines mechanical, biological, and ecological concepts to arrest and prevent shallow slope failures and erosion (Gray & Sotir, 1992). Gray & Sotir (1996) describe soil bioengineering as a specific term that refers to 'the use of live plants and plant parts, in which live cuttings and stems are placed in the ground, or in earthen structures, where they provide additional mechanical support to soil, and act as hydraulic drains, barriers to earth movement, and hydraulic pumps or wicks'. Soil bioengineering systems commonly incorporate inert materials such as rock and wood, or geo-synthetics, geo-composites, and other manufactured products. Simplifying the concept, Sotir (2001) stated that soil bioengineering is the combined application of engineering practices and ecological principles to design and build systems that contain living plant materials. Thereby, bioengineering has as strategy to provide a sustainable ecosystem that benefits both human society and the natural environment (Zhai et al., 2010).

#### **4. Bioengineering applications**

The emphasis on ecosystem management, on improving fisheries, and on healthy watersheds has renewed interest in erosion control in the form of soil bioengineering. In these cases, what is focused on primarily is the erosion control that will start with a planted vegetation, and then establishment of a natural recovery by a "succession". According to Normaniza & Barakbah (2011), an understanding of these plant successional processes and pioneer vegetation will allow the development of effective strategies for revegetation of the slopes. Systems largely structured by a broad-scale physical process, such as riparian ecosystems worldwide, may be the most difficult to restore if the process is muted or extinct (Didham et al., 2005; Fremier & Talley, 2009). Managing plant communities that were created and maintained under extinct historic conditions, while not taking advantage of the impacted process (i.e., within site approaches), will lead to unexpected and often undesirable outcomes (Zedler, 2005). There are many biotechniques available to be applied in order to reduce bank erosion along rivers, pounds, and another water bodies.

As observed by Salix Applied Earthcare (2004), each one needs to focus on some elementary information about the site that will receive the bioengineering technique. Streambank soil bioengineering works are often useful on sensitive or steep sites, in areas with limited access, or where working space for heavy machinery is not feasible and its application involves the installation of woody plant materials, securely embedded in the ground and placed in specific planned configurations to create effective erosion control measures. They are intended to have an immediate effect and also to provide a foundation that will encourage colonization by the surrounding plants, thus ensuring long-term remediation and protection of slopes scarred by erosion, experiencing active soil erosion, and affected by shallow slope failures (Nilsson & Berggren, 2000). In addition, soil bioengineering measures are intended to both encourage and accelerate the processes of natural re-vegetation, thus enhancing natural diversity and sustaining the natural hillside ecosystems.

According to Stiles (1988), one of the benefits of these biotechniques compared to traditional engineering is their capacity to increase resistance over time. It is possible due to the strength increase that the plants provided the structures (as stakes, layering, etc.) as they

grow and spread over the soil that they are holding. As we know, one of the main principles of soil bioengineering design for riverbank recovery is to provide support to forestation, especially to the native vegetation. Sometimes it is necessary to manage the vegetation so that it remains at the shrubby bush stage, without a main trunk, to reduce the risk of erosion. In fact, the development of trees is also to be avoided in order to maintain access for towing and other riverbank activities (Evette et al., 2009).

Soil bioengineering techniques to stabilize streambanks and shorelines are as effective, and sometimes more effective, than traditional engineering treatments (Li & Eddleman, 2002). Techniques to stabilize streambanks work by either reducing the force of the flowing water, by increasing the resistance of the bank to erosional forces, or by a combination of the two. They are generally appropriate for immediate protection of slopes against surface erosion, shallow mass wasting, cut and fill slope stabilization, earth embankment protection, and small gully repair treatment, also including dune stabilization, wetland buffers, reservoir drawdown areas where plants can be submerged for extended periods, and areas with highly toxic soils (Evette et al., 2009). Soil bioengineering for erosion control is not a method that imposes manmade structures on the site at the expense of existing native plant materials. Control of bank erosion can be accomplished in several ways, such as the use of rock-fill, which, though efficient, is quite expensive, precluding its use extensively along river banks.

In the Nineteenth Century, Defontaine (apud Evette et al., 2009) had suggested that traditional practices of engineering could be supplemented by soil bioengineering using stone and rock pavements (rip-rap) as shown in Figure 2.

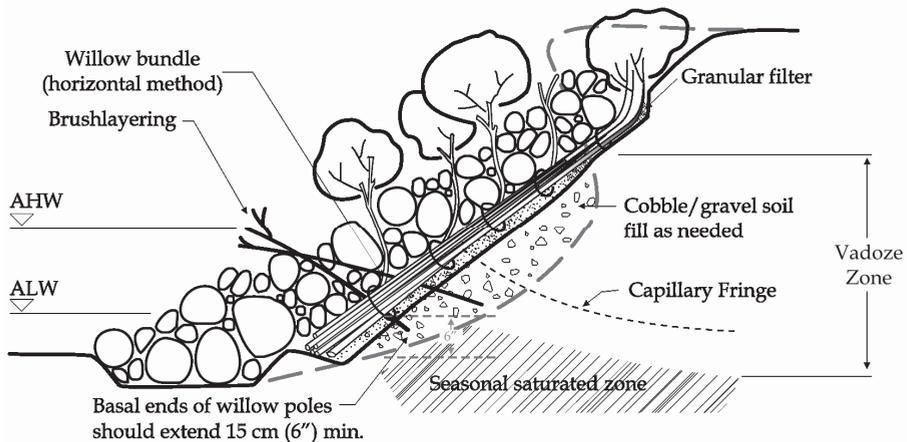


Fig. 2. Vegetated Riprap or Joint Planting composed live stakes, brushlayering and willow bundle, considering the average high or low water level. Adapted from Salix Applied Earthcare (2004).

Joint planting or Vegetated Riprap, in effect, involves tamping live cuttings of rootable plant material into soil between the joints or open spaces in rocks that have previously been placed on a slope (USDA-NRCS, 2007).

Petrone & Preti (2010) demonstrate that soil bioengineering for bank stabilization interventions regarding erosion occurrence is the most appropriate, because it is in

accordance with the main concept of sustainable development, and also that soil bioengineering transfer provides users with an instrument that guarantees stability. This is essential to clearly demonstrate the objectives, risks, and reproducibility of the technology to local communities, certainly leading to a range of other innovative and sustainable technologies and a stimulating research environment. Like ecological engineering, soil bioengineering to provide riverbank restoration based on erosion control requires a more holistic viewpoint than what is common in many ecosystem management strategies; it considers all components of the riverine system simultaneously.

Another application for this technique is found to improve environmental factors. Its set can help protect environments that are still preserved and provide better conditions for the development of local fauna and flora. This has been widely used in public recreation areas, national parks, creeks, inlets, among others (Salix Applied Earth Care, 2004; Wu & Feng, 2006).

## 5. Planning of stream mitigation using soil bioengineering

Design and construction of specific soil bioengineering measures, selection of appropriate plant species, the maintenance requirements during the establishment period of the measures, and the subsequent monitoring and evaluation procedures are the procedures that guarantee the success of this technique (Campbell et al., 2008). Nevertheless, considering that soil bioengineering has unique attributes, and it is not appropriate for all sites and situations a list of factors and causes known to influence slope stability was chosen by Mickovski & Van Beek (2006) as part of a decision support system to implement eco-engineering practices, as shown in Table 2.

Once the decision is made the installation of the biotechniques plays a major structural role immediately or may become the major structural component over time. The effective installation of soil bioengineering measures requires careful planning and design, based upon the specific characteristics of each site. These include factors such as the site geology, soils, slope angle, slope aspect, hydrology, existing vegetation cover, etc., which should all be assessed before appropriate measures can be prescribed (Campbell et al., 2008).

Implementing projects in harmony with natural landscapes include the following considerations: careful selection of suitable construction machinery and tools matched to terrain characteristics; stable and correctly shaped banks; avoidance of steep gradients; use local building materials, e.g. stone, gravel, sand, soil, wood; use of local building materials that do not naturally occur at the construction site, e.g. rocks and boulders in fine grained alluvials, are best avoided; avoidance of artificial building materials, e.g. steel, concrete, plastics for surface cladding of grouting of river or stream beds; preferential use of live building materials; obtaining woody plants capable of vegetative propagation from the construction site, its environs or from similar nearby habitats; preservation of vegetation on the fringes of the construction or regulation area by the considerate use of moving machinery and equipment; removal, temporary storage and re-establishment (transplantation) of vegetation; restricted or, at best, total avoidance of cutting traces, fragmentation or clearing of alluvial woodland (Schiechl & Stern, 1997).

Basic principles of soil bioengineering necessary for good planning are summarized as follows in Table 3.

Site characteristics	Slopes with high hazard of slope instability
<i>Morphology</i>	
Gradient	Moderately steep for landslides (>10_) to extremely steep for falls (>35_). Some flows can maintain momentum even on very gentle slopes.
Shape	Convergent or irregular in profile.
Height	Short steep slopes for rotational slides, long slopes for translational slides.
<i>Material</i>	
Slope material	Plastic soils, material sensitive to physical or chemical weathering or heavily fractured or jointed rock.
Stratigraphy	Alternation of weaker and stronger beds, of different permeability.
Hydrology	Signs of ponding and springs, presence of gleyic horizons indicating stagnating water in the soil.
Drainage	Heavily dissected by ephemeral or permanent streams with signs of undercutting at the base of the slope or signs of disrupted drainage.
Climate	Periods of intense or prolonged rainfall or rapid snowmelt; Strong diurnal and seasonal variations in temperature, e.g. freeze-thaw.
Seismicity	Evidence of moderately strong to strong earthquakes.
Past activity	Signs of previous slope movements (creep, sliding) and/or surface wash.
Vegetation	Irregular stands and/or deformed or underdeveloped vegetation; Exposure of roots in cracks or at the surface.
Human activity	Evidence of poor site management (leakage of sewer systems, blocked drains etc.) or extensive changes to the shape or composition of a slope. On a marginally stable slope, human intervention can easily upset the critical balance.

Table 2. Site characteristics and slopes with high hazard of slope instability.

In order to correctly plan and install a soil bioengineering project it must be considered that sites typically require some earthwork prior to the installation of soil bioengineering systems. A steep undercut or slumping bank, for example, requires grading to flatten the slope for stability.

1) The degree of flattening depends on the soil type, hydrologic conditions, geology, and other site factors; 2) Scheduling and timing planning and coordination are needed to achieve optimal timing and scheduling; 3) Vegetative damage to inert structures does not generally occur from roots. Plant roots tend to avoid porous, open-faced retaining structures because of excessive sunlight, moisture deficiencies, and the lack of a growing medium. 4) Moisture

1. Establishment of the cause of the damage if repair work is needed.
2. Establishment of the objective and final appearance of the project.
3. Evaluation of the hydro-engineering aspects of the project details.
4. Evaluation of the legal position (ownership, use, liability, etc).
5. Final selection of the bioengineering technique to be implemented.
6. Fit the soil bioengineering system to the site, which means that it has to consider information on site topography, geology, soils, vegetation, and hydrology. At a minimum, collect information on:
  - i. Topography and exposure, related to the degree of slope in stable and unstable areas;
  - ii. Geology and soils, related to geologic history and types of deposits (colluvium, glacial, alluvium, other), soil type and depth;
  - iii. Hydrology, drainage area and the annual precipitation, and calculation of peak flows or mean discharge through the project area;
  - iv. Site visit, alignment route, longitudinal and cross-section, (hydrological information);
  - v. Evaluation of the soil analysis results of the bed material and watercourse bank stability;
  - vi. Evaluation of the vegetation survey of the project area and its environment;
  - vii. Evaluation of all available information on the hydro-ecology of the area;

In order to reach this information:

Obtain topographical maps, aerial photos, orthophotos and construction plans.

7. Selection of the construction method and type.
8. Selection of the live and dead vegetative material to be used.
9. Retain existing vegetation whenever possible - Limit removal of vegetation by the removal and storage of existing woody vegetation that may be used later in the project.
10. Stockpile and protect topsoil, related to the topsoil removal during clearing and grading operations that can be reused during planting operations.
11. Protect areas exposed during construction.
12. Divert, drain, or store excess water.

Table 3. Checklist for the planning of water bioengineering construction. Adapted from USDA-NRCS (1992) and Schiechl & Stern (1997).

requirements and effects must consider that the backfill behind a stable retaining structure has certain specified mechanical and hydraulic properties. Ideally, the fill is coarse-grained, free-draining, granular material. Free drainage is essential to the mechanical integrity of an earth-retaining structure and also important to vegetation.

Soil bioengineering applications work directly with plants and live structures, so we must not forget that their basic science is ecology. Ecological knowledge is the fundamental scientific basis to planting and managing sustainable systems, and since holism and systems theory open up new perspectives and provide broader visions for planning, then it is highly desirable to have on staff people that are specialized in it. According to Leitão & Ahern (2002) sustainable planning represents a promising challenge for motivating and inspiring trans-disciplinary collaboration. Then, biologists, agronomists, engineers, geologists are part of the professionals necessary to develop plain environmentally and economically correct projects.

### 5.1 Suitable plant materials

The role of vegetation on slopes is increasingly being recognized and slope greening has become more important, as reflected in the number of landscaped slopes, government policies and business opportunities (Chong & Chu, 2007).

Although traditional erosion control practices have often focused on structures made from stone and other nonliving materials, interest in the use of plant materials, alone and in combination with nonliving materials (“soil bioengineering”) for a range of applications, is increasing (Li et al., 2006). Some of the ecotechnological methods are not new and, in fact, some have been practiced for centuries, particularly in China (Stokes et al., 2010).

Vegetation helps to prevent erosion on slopes by: 1) Binding and restraining soil particles in place; 2) Reducing sediment transport; 3) Intercepting raindrops; 4) Retarding velocity of runoff; 5) Enhancing and maintaining infiltration capacity; 6) Minimizing freeze-thaw cycles of soils susceptible to frost Gray & Sotir (1992).

The selection of suitable plant species and species combinations in soil bioengineering measures must be based on careful vegetation surveys. The plants must tolerate thin, well-drained soils, steep slopes, and exposed sites. Native species, mainly shrubs, are preferred, once they are compatible with local ecosystems and are relatively inexpensive, because they can be harvested from areas adjacent to the site. Also, they are well suited to the local climate, soil, and moisture conditions. Exotic species may be considered in certain circumstances, to stabilize riverbanks generally has shown very good results, although native species are more suitable reducing the likelihood of erosion by mass failure due to reinforcement of riverbank soils by tree roots and this reduced likelihood of mass failure (Hubble et al., 2010). Despite that in some cases these techniques cannot resist in environments where the river’s flow is continuous with high sediment transport. Live staking, live fascines, brush layers, and branchpacking have been current listed as soil bioengineering techniques that use stems or branch parts of living plants as initial and primary soil reinforcing and stabilizing material. Based in Li & Eddleman, (2002) and USDA-NRCS (2007), we listed some of the most important biotechnical streambank stabilization techniques in Table 4.

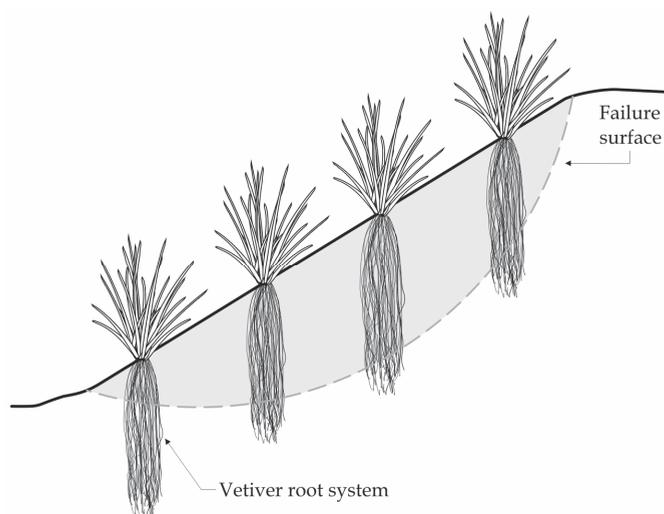
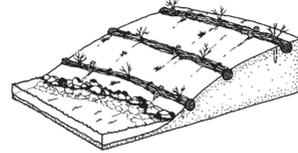


Fig. 3. Soil reinforcement by vetiver grass roots minimizing erosion risks.

Polser & Bio (2002) mentioned other biotechniques typically applied to small streambanks or creeks such as wattle fences, live palisades, live gravel bar staking and live shade.

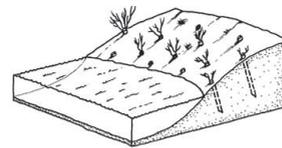
### Live Fascine

Is a long bundle of live cuttings bound together into a rope or sausage-like bundles and their structure provides immediate protection for the toe. Since this is a surface treatment, it is important to avoid sites that will be too wet or too dry. The live cuttings eventually root and provide permanent reinforcement.



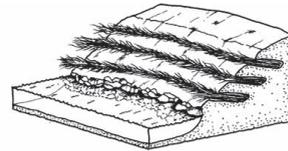
### Live Stakes

Live pole cuttings are dormant stems, branches, or trunks of live, woody plant material inserted into the ground with the purpose of getting them to grow. Live stakes are generally shorter material that are also used as stakes to secure other soil bioengineering treatments such as fascines, brush mattresses, erosion control fabric, and coir fascines.



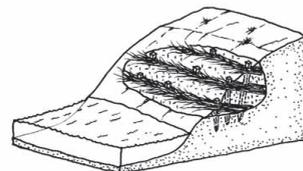
### Brushlayering

Consists of alternating layers of live cuttings and soil. The cuttings protrude beyond the face of the slope approximately 6 to 18 inches. The installed live cuttings provide immediate frictional resistance to shallow slides, similar to conventional geotextile/geogrid reinforcement.



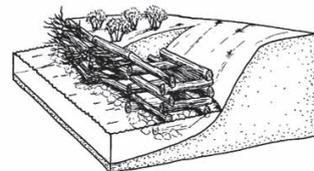
### Branchpacking

Consists of alternating layers of live cuttings and soil to repair small slumps and holes in streambanks. The live cuttings reinforce the soil similar to conventional geotextile/geogrid reinforcements. The stems provide immediate frictional resistance to shallow slides.



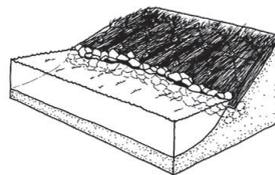
### Live Cribwall

Is a hollow, boxlike structure of interlocking logs or timbers filled with rock, soil, and live cuttings, or rooted plants, that are intended to develop roots and top growth and take over some or all of the structural functions of the logs.

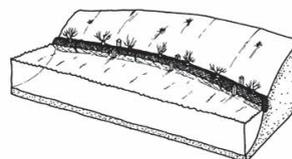


**Brushmattress**

Is a layer of live cuttings placed flat against the sloped face of the bank. Dead stout stakes and string are used to anchor the cutting material to the bank. This measure is often constructed using a fascine, joint planting, or riprap at the toe, with live cuttings in the upper mattress area.

**Coconut Fiber Rolls**

Coconut fiber rolls or Coir fascines consist of coconut husk fibers bound together in a cylindrical bundle by natural or synthetic netting and are manufactured in a variety of standard lengths, diameters, and fill densities for different energy environments. They are flexible and can be fitted to the existing curvature of a streambank.

**Erosion Control Blanket**

They are produced from natural and synthetic materials such as straw, wood excelsior, woven coir, or combinations of these and turf reinforcement mats produced from nondegradable, synthetic, three-dimensional fibers. Jute mesh and coir mesh are the most used.

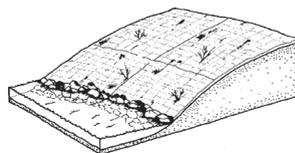


Table 4. Some biotechnical streambank stabilization techniques (Li & Eddleman, 2002; USDA–NRCS, 2007).

There is a certain influence of the root tensile strength on the increase in soil shear strength. The progress made during the past few years on the contribution of the root system in reinforcing mass-stability of slopes is an eye-opener. Soil cover with grass or herbaceous vegetation provides an efficient protection against surface erosion by reducing the impact of rainfall on bare soil (Davide et al., 2000), besides increased percolation of water, soil cohesion, and resistance on the banks, which are provided by the root systems (Burylo et al., 2009). Cazzuffi et al. (2006) mentioned that vetiver grass (*Vetiveria zizanioides* L. Nash) among other species is characterized by very resistant roots and confirms how they, could be successfully used with stabilizing effects on phenomena like shallow instability (Figure 3).

Vetiver grass have been used in practices of erosion control and slope stabilization (Mickovski & Van Beek, 2009; Mickovski et al., 2005; Truong, 2002), promoting a reduction by 50% and 70% of surface runoff and eroded soil (Phien & Tam, 2007). Being a very easy crop to grow, at various levels and fertility types of land, which very well resists both drought and immersion in water, Vetiver grass tolerates conditions of root asphyxia; it is easy to cultivate, almost without maintenance, and likes to be exposed to full sun; it is a long-lived crop, living more than 10 years, and for land conservation does not yield seed, and rhizomes or stolons (roots which can yield new crop), does not expand wildly outside

the planned area, and consequently will not become an intruder upon other plants (Budinetro, 2004).



Fig. 4. Stages of installation of the biotechniques in Paramopama Creek in northeastern Brazil. a) Degraded river channel and riparian zone; b) Gabion at the toe and at the river bed, plus jute matting at the streambank; c) Development of the grass cover; d) Vegetation development six months after installation, composed by legume-shrubs mixture. Adapted from Holanda et al., (2009).

Other species are widely used in bank recovering projects, especially in the Northern Hemisphere. The genus *Salix*, also recognized as willow (*Salix* L.), has around 400 species between trees and shrubs, and the most used, generally, is found in soils with high moisture in temperate and arctic zones, but also can occur in subtropical and tropical zones; that is why it is highly desirable in this type of design. Among the range of agronomical, physiological and ecological characteristics of the genus *Salix* that are pertinent to ecological engineering, erosion control in order to protect slopes, streambanks and shorelines against water erosion, is very remarkable (Kuzovkina & Volk, 2009; Kuzovkina & Quigley, 2005; Wilkinson, 1999; Pezeshki et al., 2007; van Splunder et al., 1994; Shields Junior et al., 1995), and if they are established successfully they alter the microclimate, improving soil conditions, control invasive species, and re-establish natural ecological complexity. Beside this, it became most useful due its fast growth rate allied to a dense root system that can rapidly stabilize the streambank and promote the secondary establishment of other vegetation (Figure 2). Willow (*Salix* spp) are analogous to annual or short-lived perennial grasses in a seed mixture (nurse or companion crop), and they provide a quick pioneer plant cover for soil protection. Their longevity depends on the region of the country and specific site conditions. In all cases, they prefer damp soils (USDA-NRCS, 2007).

Among the versatile leguminous trees, *Leucaena leucocephala* has been determined as a potential slope plant. Being a multipurpose tree that profusely produces propagules (beans) and has been used as an erosion control plant, Normaniza, et al (2008) identified a very important contribution of this species in terms of slope stability enhancement, showing that it plays a major mechanical role, as well as a hydrological role, in stabilizing slopes and protecting against soil erosion. It is suggested that the high capacity of root reinforcement and water absorption of *L. leucocephala* rank it as an outstanding future slope remedy for preventing slope failure.

## 5.2 Structural components

Structures can be built from natural or manufactured materials. Natural materials, such as earth, rock, stone, and timber, usually cost less, are environmentally more compatible, and are better suited to vegetative treatment or slight modifications than are manufactured materials. Natural materials may also be available onsite at no cost (USDA-NRCS, 1992). Live cribwalls, vegetated rock gabions, vegetated rock walls, and joint plantings are soil bioengineering techniques that use porous structures with openings through which vegetative cuttings are inserted and established (Figure 4). The inert structural elements provide immediate resistance to sliding, erosion, and washout, and as vegetation becomes established, roots invade and permeate the slope, binding it together into a unified, coherent mass.

## 6. Advantages and limitations of soil bioengineering practices

Several potential environmental benefits can be achieved by using soil bioengineering measures as opposed to conventional engineering methods. Notably, they generally require only minimal access provisions for equipment, materials and workers, and typically create only minor disturbances to the site during installation. In environmentally sensitive locations, where preservation of scenery or wildlife habitats may be critical, soil bioengineering measures can usually offer more environmentally compatible solutions. More importantly, for sensitive or remote sites, these measures do not require long-term maintenance, thereby creating fewer disturbances.

According to Schiechl (1985) the use of natural building material requires spaces and it would be to attempt the implementing of vegetative methods in the construction of protection measures. Soil bioengineering systems generally require minimal access for equipment and workers and cause relatively minor site disturbance during installation, and cannot be installed where the site is in bedrock, on deep-seated failures with high back scars, or on steep slopes (over about 35-50°).

Soil bioengineering measures that combine mechanical, biological, and ecological principles and practices to protect and enhance slopes, repair erosion gullies, and remediate shallow mass movement scars are generally considered to be cost-effective techniques with desirable environmental and visual characteristics.

## 7. Site maintenance and monitoring

Designs for application of soil bioengineering techniques should also consider the periodic access of people, tools, supplies, and machinery (in some cases) to the site in order to guarantee the efficiency of the conjunct of elements involved in each situation. Commonly, when the site requires some kind of repair, this simple step in the planning can avoid unfortunate and expensive costs of material movement and replacement. The situation can be aggravated if the site was designed for experimental studies.

Recently, few techniques for evaluating streambank stability and the real ground geotechnical behavior are available, providing low-resolution monitoring and, in most cases, restricting visual comparison by photographic registries or invasive measurements in field, like topographic surveys. Nowadays, with an increasing need for high-resolution data in many areas involved with riverbank erosion (i.e. fluvial geomorphology and geotechnical engineering), the advance of remote technology, and the increment of electronic sensors, monitoring soil bioengineering sites has been becoming more accurate and trustful. For Lawler (2005), it also allows for collecting directly and routinely in the field, at event time scales, real-time high-resolution data.

Thus, it is possible to advance in knowledge and acquire data on the mechanism of riverbank erosion using high-resolution techniques, in addition to the meteorological and fluvial data that are already widely available.

Other tools have reached a great importance in erosion monitoring or in the effectiveness of the techniques toward its control, as they provide automated and continuous real-time bank erosion data. This information is of great importance to the field of geomorphology, as well as to numerical models such as the computer model Streambank Erosion CONCEPTS (Langendoen & Alonso, 2008), which simulates channel width adjustment by incorporating the two fundamental physical processes responsible for bank retreat: fluvial erosion or entrainment of bank-material particles by flow, and bank mass failure due to gravity.

Bertrand (2010), also studying erosion monitoring concluded that the Photo-Electric Erosion Pin, or PEEP, provided real-time monitoring of erosion events in terms of magnitude and frequency, which is not possible with manual instruments where only net changes from previous measurements are known. This real-time monitoring coupled with the automated nature of the instrument makes it ideal for certain sites that are not easy to access on a continuous basis.

## 8. Conclusions

There is a strong and urgent need to restoration the riparian zone with native or exotic plant species that have a fast vegetative development, in order to reduce riverbank erosion. Nevertheless, the preservation of riparian remnants is vital because they produce source of plant seeds, provide home for pollinators and dispersal agents, and contribute enormously to the recovery of the riparian zone. In the tropical region the riverine populations have tried their own solutions in order to control the riverbank's erosion through the use of local low cost materials. At the same time public policies have focused on the Streambanks recovering mostly with the use of riprap to absorb the strong impact of rivers discharge regularization and its consequences. The use of soil bioengineering techniques have been motivated by practitioner's to promote immediate soil protection against erosion, by fast revegetation. It seems that it will take time and the participation of the public authorities, users and communities until these biotechniques will be recognized with its remarkable technical and environmental importance on the streambanks degraded recovery.

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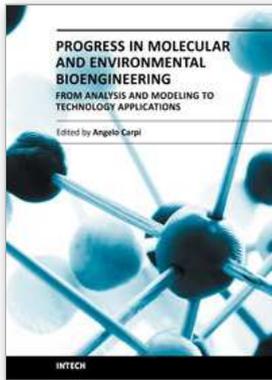
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This book provides an example of the successful and rapid expansion of bioengineering within the world of the science. It includes a core of studies on bioengineering technology applications so important that their progress is expected to improve both human health and ecosystem. These studies provide an important update on technology and achievements in molecular and cellular engineering as well as in the relatively new field of environmental bioengineering. The book will hopefully attract the interest of not only the bioengineers, researchers or professionals, but also of everyone who appreciates life and environmental sciences.

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