Bio-structural" Erosion Control: Incorporating Vegetation in Engineering Designs to Protect Puget Sound Shorelines

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Abstract

The conventional engineering approach to slope stabilization and erosion control usually relies solely on structural components. Vegetation is rarely included in engineering designs, though occasionally it is treated as incidental landscaping. Though the benefits of vegetation's role in erosion control are poorly understood within the engineering community; the value of vegetation in controlling erosion and reducing shallow mass wasting is well documented.

While engineered structures provide immediate stabilization and erosion abatement, they become progressively weaker over time and do not adapt to changing site conditions. Vegetation, though ineffective when first established, becomes progressively more effective, adaptable, and self-perpetuating over time. Vegetation also improves water quality, reduces storm water run-off, enhances wildlife and fisheries habitat, improves aesthetics, and reduces noxious weed establishment.

A "Bio-Structural" approach to erosion and slope stability problems; i.e., incorporating planned vegetational elements in engineering designs, can be less expensive, more effective, and more adaptable than purely structural solutions. Vegetation should be used in conjunction with geo-textiles and engineered structures whenever appropriate and practical.

Vegetation selected for "Bio-structural" design elements should be native whenever possible. Plants chosen should also be appropriate to the site, have wide adaptability, favorable spread and reproductive capability, superior control value, roots of high tensile strength, and be available commercially.

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Introduction

Surface erosion and mass soil losses from landslides are of great concern to land managers. Accelerated erosion and slope instability can be caused or exacerbated by human activities. Increased erosion can cause adverse cumulative watershed problems by increasing sedimentation, degrading water supplies, reducing forest productivity, destroying anadromous fish habitat, and degrading other critical environmental functions. Mature structurally and floristically complex plant communities significantly reduce surface erosion and contribute greatly to maintaining slope stability.

The conventional engineering approach to slope stabilization and erosion control usually relies solely on structural components. Vegetation is rarely included in engineering designs, though occasionally it is treated as incidental landscaping. Though the benefits of vegetation's role in erosion control are poorly understood or appreciated within the engineering community, the value of vegetation in controlling erosion and reducing shallow mass wasting is well documented. The use of vegetation and biotechnical measures should be incorporated into engineering designs early in the planning and design phases of a project.

Role of Vegetation

"The loss or removal of slope vegetation can result in either increased rates of erosion or higher frequencies of slope failure. This cause-and-effect relationship can be demonstrated convincingly as a result of many field and laboratory studies reported in the technical literature." (Gray and Sotir, 1996). Vegetation also improves water quality, reduces storm water runoff, enhances wildlife and fisheries habitat, improves aesthetics, and reduces noxious weed establishment.

Benefits of vegetation in preventing surficial erosion

Protocols have been developed to describe the factors that are instrumental in vegetation's effectiveness in limiting surface erosion. Wischmeier (1975) identified three major subfactors: (I) canopy, (II) surface cover, and (III) below surface effects. Dissmeyer and Foster (1984) modified and made additions to the earlier work to adapt it to forest conditions. The basic forest sub-factors useful in applying the modified universal soil loss equation (USLE) include ground cover, canopy, soil reconsolidation, organic content, fine roots, residual binding effect, and on-site storage of water.

Gray and Leiser (1982) provide a summary of the major effects of herbaceous and woody vegetation in minimizing erosion of surficial soils. They include:

- Interception — foliage and plant residues absorb rainfall energy and prevent soil compaction.
- Restraint — root systems physically bind or restrain soil particles while above-ground residues filter sediment out of run-off.
- Retardation — above-ground residues increase surface roughness and slow run-off velocity.

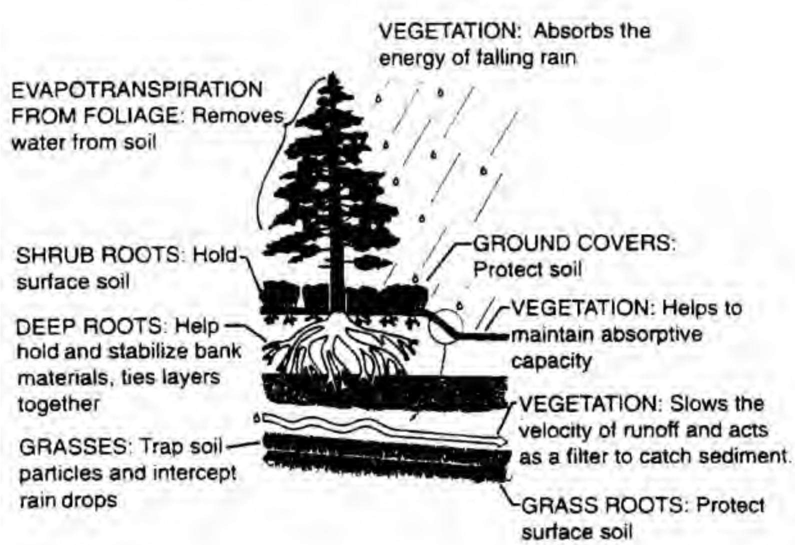

Figure 1.

- Infiltration — roots and plant residues help maintain soil porosity and permeability.
- Transpiration — depletion of soil moisture by plants delays onset of saturation and run-off.

Greenway (1987) notes that "roots reinforce the soil, increasing sod shear strength", "roots bind soil particles at the ground surface, reducing their susceptibility to erosion," and "roots extract moisture from the soil..., leading to lower pore-water pressures." Several layers of vegetation cover, including herbaceous growth, shrubs, and trees, multiply the benefits discussed above.

Benefits of vegetation in slope stabilization

A substantial body of credible research concerned with vegetation and slope stability exists. Most of the literature supports the contention that, in the vast majority of cases, vegetation helps to stabilize a slope (Macdonald and Witek, 1994). As Gray and Leiser (1982) remark, "The neglect of the role of woody vegetation (and in some instances its outright dismissal) in stabilizing slopes and reinforcing soils is surprising." Their summary of beneficial influences of woody vegetation follows:

- Root Reinforcement — roots mechanically reinforce a sod by transfer of shear stresses in the soil to tensile resistance in the roots.
- Soil moisture modifications — evapotranspiration and interception in the foliage limit buildup of soil moisture stress. Vegetation also affects the rate of snowmelt, which in turn affects soil moisture regime.
- Buttressing and arching — anchored and embedded stems can act as buttress piles or arch abutments in a slope, counteracting shear stresses.

Greenway (1987) notes "that as vegetation is removed from a watershed, water yield increases and water table levels rise." Permanent loss of vegetation cover, or replacement by ineffective vegetation, increases soil saturation and surface water run-off. Vegetated watersheds exhibit lower peak flows, lower total discharge volumes, and increased lag-time between rainfall and run-off than do watersheds where effective vegetation has been removed (Figure 2).

Limitations of vegetation

While undisturbed mature native vegetation on slopes provides erosion control and slope stabilization benefits, disturbed or degraded sites undergo continual erosion, and may not establish an effective cover. Vegetation alone may be relatively ineffective where hydrologic influences, fluvial processes, or wave attack repeatedly interrupts natural plant succession and favors less effective species. Competition by invasive, exotic plants such as Himalayan blackberry can also retard or preclude natural establishment of effective vegetation. Hydro-seeded grasses are often ineffective in minimizing surface erosion subsequent to construction and additional expenditures are necessary to repair slopes damaged by rills and gullies. Grass provides virtually no slope stabilization benefits. Grassed slopes provide negligible storm water filtration ben-

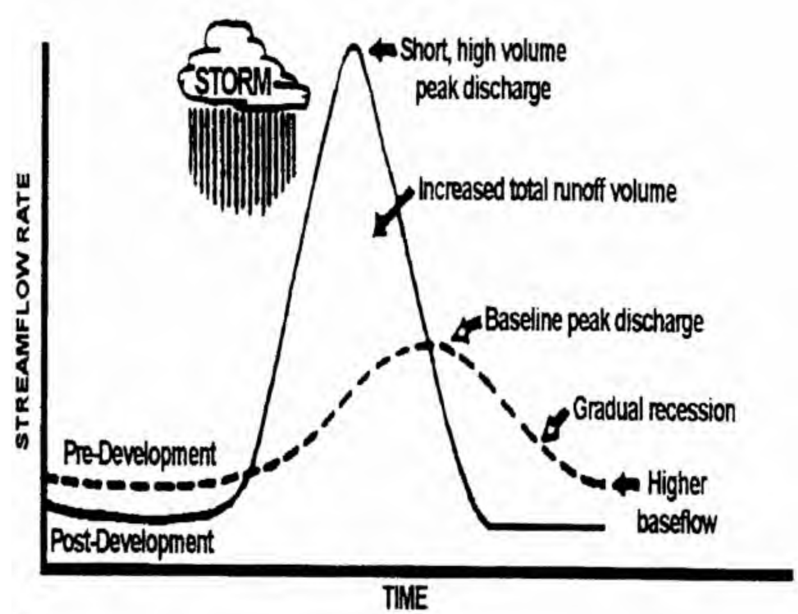

Figure 2.

efits compared to native ground covers. Grasses are ineffective in discouraging the establishment of undesirable invasive plants.

Vegetation alone is ineffective in the presence of deep-seated instability and active mass wasting. A disturbed or modified site must be stable enough to allow establishment and development of an effective plant community, often for as long as JO years.

Engineered Measures Provide Stabilization, but at a Cost

Where accelerated erosion, slope destabilization, and landslides have occurred, engineered measures suited to the geomorphologic conditions are often necessary to stabilize the site. Engineering solutions aim to both reduce the influences of destabilizing forces and physically arrest slope failure and surface erosion. There are four basic methods used to improve slope stability:

- Unloading the head of the slope
- Ground and surface water regime modification
- Buttressing the toe of the slope
- Shifting the position of the potential failure surface

The specific measure or combination of measures employed is dependent upon a wide variety of complex factors, including geomorphology, hydrology, slope, climate, failure type, and topography. Macdonald (1994) provides an excellent written and photographic description of commonly employed conventional structures and hydrologic control measures in the Puget Sound region. Most engineered solutions result in significant incidental slope modification and environmental impacts. Toe stabilization on marine and riparian shorelines, such as riprap, are disruptive to nearshore habitat and affect coastal processes. Slope stabilizing measures, such as stepped crib walls, change slope geometry. Drainage measures, such as horizontal drain piping, alter both slope and down-gradient hydrology.

While engineered solutions effectively provide immediate stabilization and erosion abatement, they also cause environmental impacts to public resources. Removal of vegetation is common during construction of structures. Loss of vegetative cover often initiates soil degradation causing the site to become less productive. Conventional erosion control and revegetation efforts subsequent to construction are often ineffective and fail to adequately protect bare soil from incidental surface erosion and adjacent slope impacts. Products such as "jute" mats are ineffective in reducing surface erosion or encouraging the establishment of effective vegetation.

Engineering measures deteriorate over ti me, becoming progressively less effective or failing entirely. Adjacent slope movement can involve structures and impair their effectiveness. Where revegetation efforts consist merely of hydro-seeding or sod, ineffective vegetation is likely to become established, providing few of the benefits discussed above. If desirable effective vegetation is not deliberately incorporated into engineered measures, slope problems may become recurrent over the long term.

Bio-Structural Approach

A Bio-Structural approach to erosion and slope stability problems (i.e., incorporating planned woody vegetational elements in engineering designs) can be less expensive, more effective, and more adaptable over the long term than purely structural solutions. Revegetation and biotechnical measures should be used in conjunction with geotextiles and engineered structures whenever appropriate.

Bio-structural erosion control and slope stabilization includes the measures known as soil bioengineering and biotechnical slope protection. As Gray and Leiser (1982) state, "both biological and mechanical elements must function together in an integrated and complementary manner.

The following is a very brief summary of important factors to consider when incorporating planting and biotechnical measures in engineering designs.

Define objectives

What do you hope to achieve by incorporating vegetation in an engineering design? Some common objectives and goals include the following:

- Erosion control (rilling and gullying)
- Slope stabilization (marine, riparian, terrestrial)
- Restoration of pre-project vegetative cover
- Creation of wildlife and fisheries habitat (cover, food, and shade)
- Stormwater management (reduction of run-off and sedimentation)
- Aesthetic enhancement (landscape restoration)
- Regulatory mitigation (buffer enhancement)
- Reducing invasive plant establishment

Suitability of the site

What are the physical environmental, and social characteristics of the site? Is revegetation possible and desirable? Each site is different and unique. Failure to consider pertinent factors often results in failure of biotechnical and planting efforts.

General Physical Characteristics:

- Topography
- Soils
- Slope
- Hydrology
- Aspect
- Geomorphology
- Climate

General environmental characteristics:

- Wind
- Salt (spray, tidal)
- Soil moisture and productivity
- Sun/shade conditions
- Precipitation (rain, snow, fog)
- Presence of invasive exotic plants
- Flooding and/or inundation
- Potential animal impacts

Social considerations:

- Offsite influences (drainage, invasive plants)
- Land use regulations
- View constraints
- Conflicting objectives (view vs. erosion control)

Project design

It is imperative that planting and biotechnical measures be incorporated into the design from the project's inception. Vegetation should be considered integral to design rather than incidental. A team approach from first reconnaissance and feasibility through final construction will assure a successful project. Vegetational and engineering measures need to be coordinated to be effective. Common components of such projects may include structural, geotextile, biotechnical, and planting measures. Communication between project team members will minimize disruption to construction schedules and prevent other potential problems. Installation of vegetational measures often needs to be coordinated with mechanical structures and groundwork efforts. This is especially important where riprap or other slope-face stabilization measures are planned.

Vegetation component of design

Every effort should be made to understand the specific constraints and opportunities of the site and project. Reference sites adjacent to the project should be surveyed to identify desirable species and plant communities for erosion control, slope stabilization, and wildlife and fisheries habitat value. If bioengineering measures are to be used; survey local areas for suitable plant materials for cuttings. Note any significant disease or insect problems. Determine if undesirable plant seeds will be a problem if existing project topsoil is to be used. Mulch or geotextile may be needed to reduce plant competition with new plantings. There are no "cookbook" plant lists or generic solutions. An inappropriate plant or biotechnical measure in the wrong place will compromise the project's effectiveness and waste money. Micro-site factors may need to be considered on project sites with varying slope, aspect, hydrology, and soils. All the factors listed previously regarding physical, environmental, and social characteristics should be specifically considered in plant and biotechnical measure selection.

Species selected should have the following attributes:

- Native to the area
- Appropriate to the site (e.g. salt tolerant, drought hardy)
- Have a wide biologic amplitude of adaptability
- Favorable spread and reproductive capability

- Superior erosion control value
- Excellent root spread and strength
- Be commercially available in adequate numbers or able to be contract-grown (1-2 year lead time).

Plant materials are available in a variety of stock types. Use of cuttings, bare-root stock, planting tubes, containers, or other types are all common. The type of plant stock selected will be dependent on various project-specific factors. These include planting season, site characteristics, plant availability, and soil type. Seeding of native woody vegetation is seldom practical or effective.

Additional planning issues

Site preparation is a crucial element in planting or biotechnical projects. Eradication of undesirable species from the planting site and topsoil seed bank is critical. On sites with harsh exposures or droughty sites, irrigation may be required. The use of geotextile fabric may provide multiple benefits, including immediate erosion control, control of competing vegetation, and conservation of soil moisture. Animal damage protection for new plantings is often necessary to reduce losses.

Monitoring, maintenance, and replacement

Many planting and biotechnical projects fail from neglect. Vegetative measures require care during the establishment period, from one to three years after installation. Contingency plans, and funds to implement them, should be part of project specifications. Vegetation measures are weak, ineffective, and vulnerable when first installed, but become progressively stronger, more effective, more adaptable, and self-perpetuating over time. If proper establishment, monitoring, and maintenance measures are undertaken subsequent to installation, the site should be self-sufficient after the third year.

Some monitoring elements to assess include:

- Mortality (replace dead plants)
- Damage (animal, insects, disease, vandalism)
- Wilting (check soil moisture regime)
- Trampling (human, animal)
- Adequate growth (to achieve coverage and effectiveness)
- Competing vegetation (control or eradication indicated)
- Erosion or hydrologic damage

Important maintenance efforts include:

- Replant as necessary to maintain stocking
- Irrigate as necessary
- Remove undesirable competing vegetation
- Protect plants from animal damage (browsing, trampling, etc.)

Conclusion

Extensive clearing, grading, and slope modification are concomitant impacts of conventional erosion control and slope stabilization projects. Revegetation measures are often only an incidental component and are inadequate or ineffective, leading to the establishment of undesirable, invasive exotic plants subsequent to construction. Sedimentation of drainage facilities and adverse impacts to water quality, as well as degradation of fish habitat, are often unintended consequences. Existing mechanical best management practices and engineered hydrologic controls can be ineffective in mitigating increased and cumulative storm water impacts.

The recent listing of several salmonid species under the Endangered Species Act has focused attention on the importance of maintaining effective, native vegetation cover and minimizing impervious surfaces.

If native, woody vegetation planting and successful establishment becomes a routine objective of engineering plans and projects, then many of the adverse impacts and effects noted above will be significantly reduced.

Potential applications include slope stabilization, road and right-of-way, marine shore protection, and stream projects. Restoring the most valuable and effective plant communities on construction sites would also reduce future maintenance costs, reduce long-term erosion and landslide rates, improve wildlife and fish habitat, improve water quality, and help to maintain the aesthetic features synonymous with our region. While individual projects may have a relatively small benefit, the cumulative beneficial impacts are potentially enormous.

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