VEGETATION AND EROSION: A LITERATURE SURVEY

Elliott Menashe
(360) 341-3433
c/o slincoln@whidbey.com
Greenbelt Consulting
P. O. Box 601
Clinton, WA. 98236
www.wa.gov/ecology/sea/pubs/93.31

Abstract

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 effects by increasing sedimentation, degrading water supplies, reducing forest productivity, destroying anadromous fish habitat, and degrading other crucial environmental values. Mature, structurally and floristically complex, plant communities, significantly reduce surface erosion and contribute greatly to maintaining slope stability. Vegetation management of forested, coastal, urban, agricultural, and riparian areas should conserve and maintain adequate plant cover to be effective. The relative effectiveness of vegetation in any specific locale will be a function of quality of vegetation, topography, slope, hydrology, geology, and soils.

Keywords

slope stability, non-native plants, shorelands, riparian, soil conservation, restoration, conservation biology

Introduction

Soil is the most basic resource; providing the medium for plant growth and water retention. Erosion and landslides are of great concern to land managers throughout the world. Reducing erosion and conserving the productive capacity of the land is a critical first step in maintaining the productivity of farmlands, fisheries resources, timberlands, and in reducing damage to developed areas. Maintaining and restoring vegetative cover is an effective means of reducing erosion.

Surface Erosion

Soil conservation has been a crucial land management objective for many years. In the 1930's, VanDersal (1938) stated "At no time has the need for conservation of our natural resources been more apparent as it is at present. We have seen the wasteful destruction of our most basic resource, the soil, take place at an ever-increasing rate within a comparatively short span of years." "Erosion is by no means a new phenomenon", writes John Burton Woods, "it is, in fact, a natural process which has its place in maintaining the balance of nature. … water erosion, wind erosion, glacial erosion, and other forms of mechanical and chemical weathering have all shared in the modeling of most of the present terrain. The effects of this natural or geological (surface) erosion are everywhere to be seen, but this natural erosion works slowly … Because it works so slowly, the effects of this type of erosion are hardly felt and present no serious problem. The real problem today is not natural erosion, but the intensification of this action, known as accelerated (surface) erosion. Unlike natural erosion, accelerated (surface) erosion is the result of human activities…", (Woods, 1938).

Surface erosion includes processes of rainsplash, sheetwash, rilling and gullying, and dry ravel. Extensive experiments by numerous researchers in the 1950's and 1960's produced the Universal Soil Loss Equation (USLE), which calculates agricultural surface erosion as a function of hillslope gradient, soil type, slope length, rainfall intensity and duration, management, and vegetation cover. (Wischmeier and Smith, 1978; Reid, 1993). The USLE was subsequently modified to better predict surface erosion on forest lands and the vegetation cover (C-Factor) function was expanded to reflect its complexity and importance. (Dissmeyer and Foster, 1981; 1984).

Mass Soil Processes

Though less frequent and more episodic than surface erosion; mass-soil wasting, or landslides, are of growing concern. "In the United States, losses from landslides, subsidence, and other ground failures exceed the losses from all other natural hazards combined" (Sangrey, et al, 1985). Mining, water impoundment, timber management, and roadbuilding, have increasingly occurred in both mountainous and coastal areas prone to mass-soil wasting. Concomitant with improved accessibility and utilization of previously remote resources; urbanization has increased.

Forested Slopes

While landslides occur naturally due to techtonic activity, intense seasonal precipitation and steep slopes; roadbuilding, timber harvesting, and site preparation practices can have significant impacts on slope stability in the Pacific Northwest. (Sidle, 1980). Undisturbed forested slopes in these areas are often significantly steeper than the angle of repose for their constituent bare soils. Rahn (1969) concluded that "the difference is attributed to the stabilizing influence of forest vegetation". Tubbs (1975) notes the probable anchoring role of plant roots in allowing accumulation of a greater thickness of regolith material than could be supported by the strength of the soil alone.

"Forest cover on mountain slopes in the Pacific Northwest is an important natural control of soil erosion and slope processes" (Fredriksen and Harr, 1981).

Coastal Areas

Coastal areas within the region are subject to both shoreline erosion and landsliding. Marine shoreline erosion is of concern to coastal property owners and those who use and manage coastal public resources. (Macdonald and Witek, 1994). Though shorelines are subject to many erosive influences, vegetation can play an important role in maintaining stability and reducing erosion (Menashe, 1993).

Riparian Areas

Riparian areas run like threads, tying the mountains to coastal areas. Erosion and slope processes can profoundly impact these fragile yet crucial linkages. "The most productive habitats for salmonids are small streams associated with mature and old-growth coniferous forests where large organic debris and fallen trees greatly influence the physical and biological characteristics of such streams." (Maser, et al. 1988). Riparian vegetation influences stream and floodplain geomorphology by trapping sediments, stabilizing streambanks, and sustaining natural flows (Connin, 1991). Vegetation maintained immediately adjacent to drainage channels and throughout the watershed protects the aquatic habitat (Marchent and Sherlock, 1984).

Role of Vegetation

"Vegetation affects both the surficial and mass stability of slopes in significant and important ways. The stabilizing or protective benefits of vegetation depend both on the type of vegetation and type of slope degradation process. In the case of mass stability, the protective benefits of woody vegetation range from mechanical reinforcement and restraint by the roots and stems to modification of slope hydrology as a result of soil moisture extraction via evapotranspiration." (Gray and Sotir, 1996).

"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).

Benefits of Vegetation in Preventing Surficial Erosion

Protocols have been developed to describe the factors instrumental in vegetation's effectiveness in limiting surface erosion. Wischmeier (1975) identified three major sub-factors: (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 discussed in the introduction 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 to a lesser extent woody vegetation in minimizing erosion of surficial soils. They include:

1. Interception – foliage and plant residues absorb rain fall energy and prevent soil compaction.
2. Restraint – root systems physically bind or restrain soil particles while above-ground residues filter sediment out of run-off.
3. Retardation – above-ground residues increase surface roughness and slows run-off velocity.
4. Infiltration – roots and plant residues help maintain soil porosity and permeability.
5. Transpiration – depletion of soil moisture by plants delays onset of saturation and run-off.

Greenway (1987) notes that "roots reinforce the soil, increasing soil shear strength", "roots binds soil particles at the ground surface, reducing their susceptibility to erosion," and "roots extract moisture from the soil …, leading to lower pore-water pressures." Wilford (1982) observed that large organic debris in old growth forests provide important sediment storage elements, especially on slopes. Several layers of vegetation cover, including herbaceous growth, shrubs, and trees, multiply the benefits discussed above. (Menashe, 1993).

Limitations of Vegetation in Preventing Surficial Erosion

While natural, mature vegetation is usually effective in preventing surface erosion, on disturbed or degraded sites undergoing continual erosion, conditions may preclude the establishment of an effective vegetation cover. Removal of the original vegetation, for whatever reason, often initiates a process of soil degradation, causing the site to become less productive. (Marchent and Sherlock, 1984). Vegetation may be relatively ineffective in the presence of slope modifications, hydrological influences, fluvial or shoreline processes, and where invasive, non-native species have become established.

Benefits of Vegetation in Slope Stabilization

An enormous body of 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) remarked, "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 soil 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. Gray and Sotir (1996) added a fourth beneficial effect. (The earlier work listed it as potentially negative).

Surcharge – weight of vegetation can, in certain instances, increase stability via increased confining (normal) stress on the failure surface.

Greenway (1987) concurred with the work above and notes that as vegetation is removed from a watershed, the water yield increases and water table levels rise in response to logging. These occurrences would tend to increase soil saturation and run-off.

Zeimer (1981) states that "root decay after timber cutting can lead to slope failure. *In situ* measurements of soil with tree roots showed that soil strength increased linearly as root biomass increased."

Zeimer and Swanston (1977) found that "roots add strength to the soil by vertically anchoring through the soil mass into failures in the bedrock and by laterally tying the slope together across zones of weakness or instability". Sidle (1985) also comments on the importance of tree roots and cites numerous corroborating studies.

Zeimer (1981) reports that live brush roots were twice as strong as conifer roots of the same size. Woods (1938), Marchent and Sherlock (1984), VanDersal (1938), Menashe (1993), Meyers (1993), and Gray and Sotir (1996) provide information on the effectiveness and use of herbaceous and woody vegetation in slope stabilization.

Limitations of Vegetation in Slope Stabilization

Gray and Leiser (1982), Greenway (1987), and Gray and Sotir (1996) report destabilizing influences of woody vegetation. Those applicable to Pacific Northwest conditions are summarized as follows: "The primary detrimental influence on mass stability associated with woody vegetation appears to be the concern about external loading and the danger of overturning or uprooting in high winds or currents." (Gray and Sotir, 1996). (Gray and Leiser (1982) notes that windthrow can adversely affect stability.) Greenway (1987) concludes that though trees exposed to wind can transmit dynamic forces into the slope, it is unlikely that shear stress, due to wind alone, would be sufficient to weaken a slope to the point of failure.

Gray and Leiser (1982) mention that the weight of woody vegetation on a slope may exert a de-stabilizing stress to a slope while Cundy (1988) concludes that the weight of a tree is negligible if the regolith is greater than 2 feet deep.

Vegetation is relatively ineffective in the presence of seismic activity, deep-seated instability, severe fluvial and shore processes, active mass soil wasting, modified slopes, or hydrological influences.

The establishment of desirable vegetation on disturbed sites is often complicated by invasive plant competition, degraded substrates, and harsh environmental conditions. A site must be stable enough to allow establishment and development of an effective plant community, often as long as 15 years.

Conclusions

"Vegetation improves the resistance of slopes to both surficial erosion and mass wasting. Conversely, the removal of slope vegetation tends to accelerate or increase slope failures." Gray and Sotir (1996). "Large-scale removal or clear-cutting of trees on slopes exacerbates stability problems. A preponderance of evidence from studies all around the world supports this conclusion …". (Gray and Leiser, 1982). "Vegetation, once established, provides a self-perpetuating and increasingly effective permanent (erosion) control." (Kittredge, 1948). "As every soil conservationist knows, there is a very definite relationship between the density of the plant cover on the soil, the amount of soil lost through erosion, and the productivity of that soil." (VanDersal, 1938).

Literature Cited

Connin, S. 1991. Characteristics of Successful Riparian Restoration

Projects in the Pacific Northwest. EPA-910/9-91-033. Water Division, Environment Protection Agency, Region 10, Seattle, Washington.

Cundy, T. 1988. Mechanics of Mass Soil Movement. Program from Slope Stability and Forest Management Conference, Center for Streamside Studies, University of Seattle, Washington.

Dissmeyer, G. E., and G. R. Foster. 1981. Estimating the Cover – Management (C) in the Universal Soil Loss Equation for Forest Conditions. Journal of Soil and Water Conservation. 36(4):235-240.

Dissmeyer, G. E., and G. R. Foster. 1984. A Guide for Predicting Sheet and Rill Erosion on Forest Land. U.S.D.A. Forest Service, Southern Region, Atlanta, Georgia.

Fredricksen, R. L., and R. D. Harr. 1981. Soil, vegetation and watershed management. In Forest Soils of the Douglas Fir Region. P. E. Heilman, H. W. Anderson, D. M. Baumgartner (editors) Washington State University Co-op Extension Service.

Gray, D. H., and A. T. Leiser. 1982. Biotechnical Slope Protection and Erosion Control. Van Nostrand Reinhold Company. New York.

Gray, D. H., and R. B. Sotir. 1996. Biotechnical and Soil Bioengineering Slope Stabilization: A Practical Guide for Erosion Control. John Wiley and Sons.

Greenway, D. R. 1987. Vegetation and Slope Stability. In Slope Stability, edited by M. F. Anderson and K. S. Richards. Wiley and Sons, New York.

Kittredge, J. 1948/1973. Forest Influences: The Effects of Woody Vegetation on Climate, Water, and Soil, With Applications to the Conservation of Water and the Control of Floods and Erosion. (1973) Dover Publications, New York.

Macdonald, K. B., and B. Witek. 1994. Management Options for Unstable Bluffs in Puget Sound, Washington. Coastal Erosion Management Studies. Volume 8. Shorelands and Water Resources Program. Washington Department of Ecology, Olympia, Washington.

Marchent, C., and J. Sherlock. 1984. A Guide to Selection and Propagation of Some Native Woody Species for Land Rehabilitation in British Columbia. Research Report RR84007-HW. British Columbia Ministry of Forests, Victoria, B.C.

Maser, C., et al. 1988. From the Forest to the Sea: A Story of Fallen Trees. Gen. Tech. Tep. PNW-GTR-229- U.S.D.A. Forest Service, PNW Research Station, Portland, Oregon

Menashe, E. 1993. Vegetation Management: A Guide for Puget Sound Bluff Property Owners. Shorelands and Coastal Zone Management Program, Washington Department of Ecology, Olympia, Washington.

Meyers, R. D. 1993. Slope Stabilization and Erosion Control Using Vegetation: A Manual of Practice for Coastal Property Owners. Shorelands and Coastal Zone Management Program, Washington Department of Ecology, Olympia. Pub. No. 93-30.

Rahn, P. H. 1969. The Relationship Between Natural Forested Slopes and Angles of Repose for Sand and Gravel. Geol. Soc. Am. Bull. 80(10):2123-2128.

Reid, L. M. 1993. Research and Cumulative Watershed Effects. G.T.R. PSW-GTE-141. P.S.W. Research Station, U.S.D.A. Forest Service, Albany, California.

Sangrey, D. A., et al. 1985. Reducing Losses from Landsliding in the United States. Committee on Ground Failure Hazards. Commission on Engineering and Technical Systems. National Research Council. National Academy Press, Washington, D. C.

Sidle, R. C. 1980. Slope Stability on Forest Land. PNW 209. Pacific Northwest Extension. United States Department of Agriculture, Forest Service.

Sidle, R. C. 1985. Factors Affecting the Stability of Slopes. In: Proceedings of a Workshop on Slope Stability: Problems and Solutions in Forest Management, U.S.D.A. Forest Service, PNW Research Station, Portland, Oregon.

Tubbs, D. W. 1975. Causes, Mechanisms, and Prediction of Landslides in Seattle. PhD Thesis, University of Washington. Seattle, Washington.

VanDersal, W. R. 1938. Native Woody Plants of the United States: Their Erosion-Control and Wildlife Values. Misc. publication No.

303. United States Department of Agriculture. Government Printing Office, Washington, D. C.

Wilford, D. J. 1982. The Sediment Storage Function of Large Organic Debris at the Base of Unstable Slopes. Paper presented at old-growth symposium, Juneau, Alaska.

Wischmeier, W. H. 1975. Estimating the Soil Loss Equation's Cover and Management Factor for Undisturbed Areas. In: Proceedings, Sediment Yield Workshop, Oxford, Miss-ARS-40. New Orleans, LA: U.S.D.A., Agricultural Research Service, Southern Region. Pg. 118-124.

Wischmeier, W. H., and D. D. Smith. 1978. Predicting Rainfall Erosion Losses – A Guide to Conservation Planning. Agriculture Handbook. No. 537. U.S. Department of Agriculture, Washington, D. C.

Woods, J. B. 1938. Ligneous Plants for Erosion Control. M. F. Thesis, College of Forestry, University of Washington, Seattle, Washington.

Zeimer, R. R. 1981. Roots and The Stability of Forested Slopes. International Association of Hydrogeological Sciences. Publication No. 132. pp. 343-361.

Zeimer, R. R. and D. N. Swanston. 1977. Root Strength Changes After Logging in Southeast Alaska. U.S.D.A. Forest Service, PNW Research Station, Portland, Oregon.