WATERSHED REHABILITATION IN REDWOOD NATIONAL PARK AND OTHER PACIFIC COASTAL AREAS

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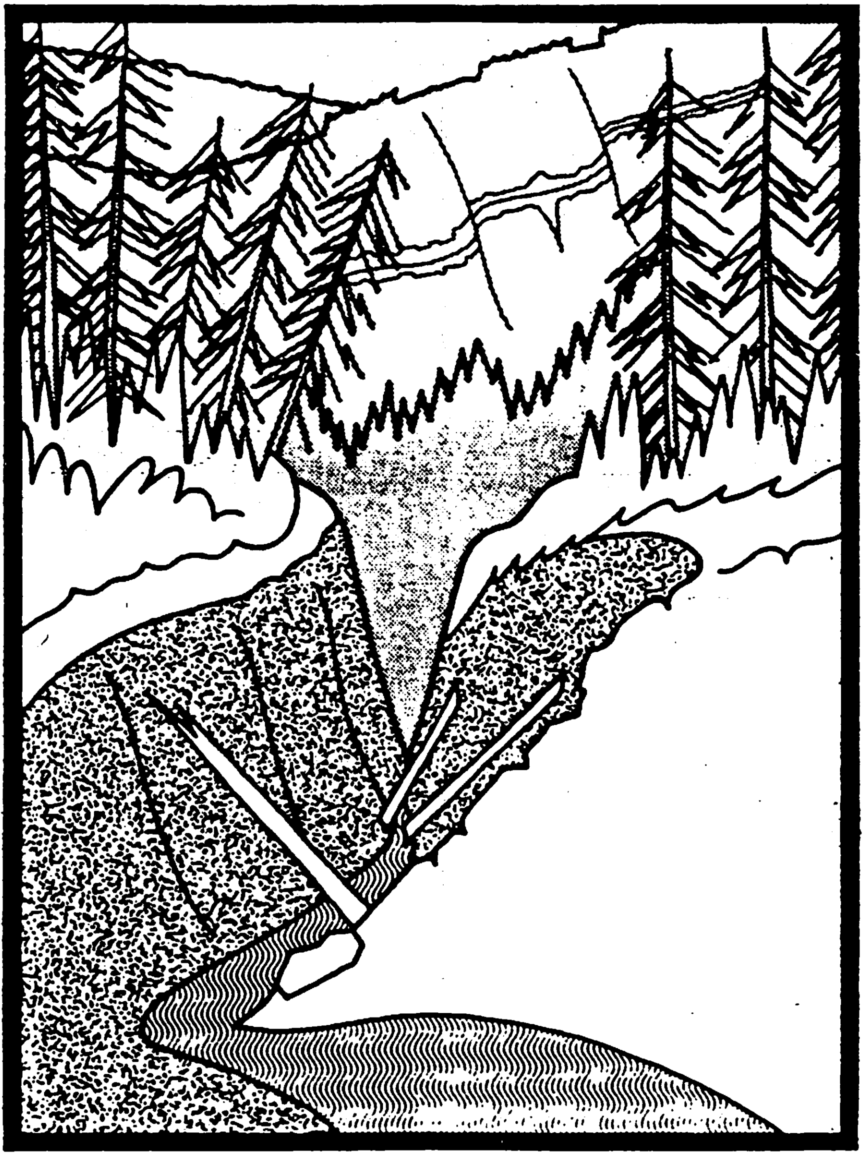

CENTER FOR NATURAL RESOURCE STUDIES OF JMI, Inc.
and NATIONAL PARK SERVICE

PROCEEDINGS OF A
SYMPOSIUM ON WATERSHED REHABILITATION
IN REDWOOD NATIONAL PARK
AND OTHER PACIFIC COASTAL AREAS

Edited by
Robert N. Coats

THE CENTER FOR NATURAL
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WATERSHED REHABILITATION: A PROCESS VIEW

Robert R. Ziemer [1]

ABSTRACT

The most effective control of erosion, in both physical and economic terms, is through prevention because once natural erosion is accelerated, corrective action is not only expensive but seldom entirely successful. To control erosion it is important to understand the forces that cause material to move or resist movement. Once the forces and processes of erosion are understood, proposed erosion control measures can be evaluated for anticipated effectiveness. The successful control of erosion is as much a philosphical and political problem as a technical one.

INTRODUCTION

Earth scientists often look only at the physical processes of watershed rehabilitation. And yet, land management decisions are as much based on economic, social, and political processes as on physical processes. This paper provides a glimpse into how these diverse processes interact to influence erosion and subsequent rehabilitation efforts.

Rehabilitation is the restoration to a former state or capacity. Implicit in the term is the assumption of a degraded condition. In wildlands, the greater the degradation, the greater the public visibility and, therefore, the greater the pressure for restoration or rehabilitation. Unfortunately, the greater the perceived "need" for rehabilitation, the lower the probability that rehabilitation efforts will be successful. Thus, this dilemma: The greater the public outcry that "something be done," the smaller the opportunity to actually succeed.

The public perceived that portions of Redwood National Park and surrounding areas had reached an advanced state of degradation. Accordingly, Congress, through P.L. 95-250, directed the Secretary of the Interior to undertake "the rehabilitation of areas within and upstream from the park contributing significant sedimentation because of past logging disturbances and road conditions ... [and to] undertake and publish studies on erosion and sedimentation originating within the hydrographic basin of Redwood Creek with particular effort to identify sources and causes, including differentiation between natural and man-aggravated conditions, and shall adapt his general management plan to benefit from the results of such studies" (Public Law 95-250, Sec. 101[a][6]).

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Generalizations about the control of erosion are both difficult and risky to make. It is usually possible to find as many examples in which a generalized erosion control measure is ineffective as in which it is effective. To control erosion it is important to understand the forces that cause material to move or resist movement. Once the forces and processes of erosion are understood, proposed erosion control measures can be evaluated for anticipated effectiveness.

The most effective control of erosion is through prevention because once natural erosion is accelerated, corrective action is not only expensive but seldom entirely successful. In Redwood National Park, the opportunities for prevention of erosion may be limited, but not entirely lacking. In most of the Pacific coastal region, however, active prevention rather than rehabilitation is the most effective means to control accelerated erosion.

Much of the concern over erosion from forested coastal areas is directed more to the degradation of stream resources by the eroded material than to the loss of soil and nutrients from hillslopes. Consequently, erosion management is often deemed successful if eroded material does not enter a stream. Furthermore, it is often commonly assumed that ground disturbance and erosion are closely correlated, and that soil detachment and movement increase the likelihood that sediment will be transported to and by a stream. Such assumptions are usually weak links in understanding and controlling erosion.

Rehabilitation of areas eroded by simple processes is likely to succeed, but a similar effort aimed at complex erosional processes is likely to fail. Consequently, managers tend to concentrate rehabilitation efforts on the simple processes and ignore the complex processes that require detailed on-site geophysical study. Unfortunately, successful control of the simple process may represent only a minor and insignificant portion of the total erosion within a steepland watershed.

This paper discusses how some interactions of climate, soil, geology, topography, and vegetation can affect erosion processes, and describes three types of erosion: surface, channel, and mass erosion. Each type can occur singly, but more commonly erosion of Pacific coastal areas is a composite of the three.

TYPES OF EROSION

Surface Erosion

Surface erosion is characterized by the lack of permanent channels. Sheet and rill erosion are forms of surface erosion in which individual soil particles are moved by raindrops, thin film flow, and concentrated surface runoff. In undisturbed coastal forests, surface erosion is generally insignificant because infiltration rates usually exceed rainfall intensities and the soil surface is protected by forest litter. Disturbance by logging, road construction, wildfires, or mass erosion, however, exposes mineral soil where the naturally high porosity of forest soils may be severely reduced by raindrop impact and compaction by heavy equipment. Fire can also produce water repellency in soils (DeBano 1981). If the flow of water over bare areas is not controlled, surface erosion may progress from sheet to rill and then to channel erosion as gullies are formed.

The best known method for predicting surface erosion is the Universal Soil Loss Equation developed for agricultural lands in the Midwest by the Soil Conservation Service, U.S. Department of Agriculture (Foster 1977). Attempts to apply it to steepland forest areas generally have been unsuccessful--mainly because of inappropriate basic assumptions (Wischmeier 1976). Most erosion from forests is not the result of sheet overland flow.

Many techniques have been developed to control surface erosion, including contour terracing, grass seeding, and mulching. These methods are intended to reduce both raindrop impact and the energy of surface sheet wash, and to create a root network to hold individual soil particles in place. Water bars on roads or skidtrails serve as a form of contour terracing used to reduce the concentration of surface runoff and to prevent surface erosion from becoming channel erosion. More effort has been devoted to reducing man-induced surface erosion in forested steeplands than to any other form of erosion because it is the most easily controlled. But surface erosion is the least important of the erosion types found in Pacific coastal forests (Kelsey, et al. 1981).

Channel Erosion

Channel erosion is the detachment and movement of material from a gully or stream channel. The material may be individual particles derived from the channel skin, or it may be material previously deposited in the channel by surface or mass erosion. The amount of erosion may be directly related to the amount and size of material being transported within the channel. This condition is evident particularly in channels where energy available to transport material and the supply of that material are at an equilibrium. If the supply is decreased below the transport capability, the channel bed tends to erode. If the supply of particles to a stream is increased, the transport capability may be exceeded, and net channel bed erosion ceases while the channel aggrades. As channel beds aggrade, bank erosion may be accelerated if the stream is directed against vulnerable banks by the aggraded bed. In forested steeplands, however, there is commonly an energy excess and a supply deficiency--at least for the smaller grain sizes (Rice, et al. 1979). Channel erosion in forested steeplands is related more to the resistance of the bed material to erosion than to the availability of energy to transport that material.

Some steepland channels become unstable only when an energy threshold is exceeded. Erosion resistance may be provided by a bed composed of relatively large particles, commonly called an armor layer, and by the incorporation of large organic debris into the channel. Organic debris reduces the local channel gradient and creates a stepped channel where energy is spent as turbulence when water cascades over successive logs into pools. Upstream of these logs is a flat reach containing readily transportable material. If the large particles or logs are moved, as by the process of high discharge or by decay of the organic debris, erosion can proceed rapidly until new bed resistance is encountered (Beschta 1979, Bryant 1980).

Finally, some steepland channels may be rapidly eroded at a rate dependent upon the energy supply. An example of such channels are newly forming and transient gullies in mass erosion terrain.

Land management activities influence channel erosion principally by the following: placing readily erodible material in existing channels; introducing large organic debris into small channels; increasing surface runoff from bare and compacted soils; modifying the surface microdrainage network by roads, tractor trails, and ditches; and converting subsurface drainage to surface runoff (i.e., by intersecting subsurface flow with road cuts). When the existing drainage network is modified, some channels may receive less water while others receive more. Erosion would be expected to decrease in the channel with reduced flow and increase in the channel receiving the additional water. If water is routed from an actively eroding channel to a resistant one, however, net channel erosion could be reduced.

A common control measure to reduce channel erosion is to increase the particle-size of the material in the bed and channel margins sufficiently so that the stream can no longer transport the material. To be successful, particles must be large enough to withstand the energy of large stormflows and be sufficiently extensive to prevent undercutting. If either condition is not met, this effort to control channel erosion will be unsuccessful.

Stepped erosion-resistant channels have successfully been created by using artificial check dams to control channel erosion. In steep channels, this practice is an expensive measure because the dams must be closely spaced to prevent accelerated erosion between dams and subsequent failure of the dam by undercutting.

Mass Erosion

Mass erosion is the downslope movement, *en masse*, of soil or rock, in response to gravitational stress. In steeplands, mass erosion includes a large variety of processes that range from slow and subtle deformation of the soil mantle (creep) to rapid, discrete failure of hillsides (debris avalanche) and stream channels (debris torrent). In undisturbed forested steeplands, mass erosion is the dominant mechanism by which soil is transported from hillslopes to stream channels. Land management activities can dramatically increase the probability of certain types of mass erosion, but influence other types only slightly (Swanston 1976).

Creep is the slow downslope movement of the soil mantle where the long-term gravitational shear stress is large enough to produce permanent deformation but too small to cause discrete failure. Creep is the most common and widespread mass erosion process in steeplands, but is the least understood and documented. It occurs at varying rates and depths in all sloping cohesive soils. Changes in the rate of creep of a given slope seem to be correlated with changes in the piezometric level in the slope. Measurements of borehole deformation in a variety of geologic materials in Pacific coastal forested areas suggest annual creep rates of less than 10 mm/yr. These rates vary widely with climatic stress even within the same geologic material (Swanson and Swanston 1977). Measurements in the Redwood Creek basin show a definite seasonality in the rate of creep. The deformation rate of some boreholes is highly correlated with the amount of winter precipitation, while the deformation of other boreholes seems independent of precipitation. Consequently, the effect of land management on creep rates is poorly documented.

Although management-induced changes in creep rate may be nearly impossible to measure, the quantity of material delivered by creep to the numerous stream channels in the area can be large. For example, if timber cutting increased the average creep rate in a catchment from 3 to 10 mm/yr, the change would probably not be noticed--even by detailed hillslope observation. But the quantity of soil added to stream channels would be trebled, and the change in sediment transport may be easily detected. In ephemeral streams, soil may be delivered continuously to channels throughout the year but is transported from the channels only during large storms as episodic pulses.

Earthflow can be considered accelerated creep where shear stress exceeds the strength of the soil mantle and results in discrete failures. These failures may range from less than a hectare in area and a meter in depth to several square kilometers in area and tens of meters in depth. The rate of movement of earthflows, as of creep, may be imperceptibly slow, but can exceed a meter per day (Kelsey 1980). Movement may be continuous, seasonal, or episodic. Like creep, deep-seated earthflows may be affected little by timber cutting or road building unless the distribution of mass or water within the slide is changed substantially. The distribution of mass can be changed by excavations that undercut the toe of the earthflow, removing downslope support. Road fill can add mass to the head of an earthflow, adding to the gravitational forces contributing to slope failure. Roads can also modify the water relations within the earthflow. Road cuts can intercept subsurface flow. If this water or surface road drainage is diverted away from the earthflow, the slide below the road may become more stable. If water is diverted onto the slide, dormant earthflows may be reactivated. Timber cutting can also modify the internal water relations of the earthflow.

Evapotranspiration by forests may deplete 50 to 75 cm of soil moisture per year (Ziemer 1981). In a Mediterranean-type climate having warm, dry summers, a substantial soil moisture deficit can reduce both piezometric head and the slide mass. Vegetated dormant landslides may be reactivated if the forest cover is removed. This step effectively adds water normally removed from the slope by evapotranspiration. The more active earthflows are often moving too rapidly for trees or other deep-rooted perennial vegetation to become established.

The potential effect of land use manipulation on earthflows is correlated with the scale of both the earthflow feature and the activity. A small tractor trail crossing a massive earthflow would have less effect than a large road undercutting a small, shallow potential failure surface.

There are interactions and feedback mechanisms between erosion types. In some cases, channel incision undercuts the toes of earthflows, upsetting the balance of forces on the hillslope. In other cases, aggradation with accompanied increases in bank erosion undercuts the toes of earthflows. In small, steep streams, incision is more common than aggradation, while in large, low-gradient streams, the reverse is true. Accelerated earthflow erosion, in turn, can modify other types of erosion.

Debris avalanches are rapid, shallow hillslope failures generally found in shallow noncohesive soils on steep slopes where subsurface water concentrates. Plant roots can reduce the frequency of these shallow failures. Roots can anchor through the soil mass into fractures in bedrock. They can also develop lateral support by crossing zones of weakness to more stable soil as well as providing long fibrous binders within a weak soil mass. In deeper soils, root-anchoring to bedrock becomes negligible, but the lateral support by roots remains. In marginally stable areas, debris avalanche frequency may increase after trees are cut, as their root systems progressively decay (Ziemer 1981). Depletion of soil water by evapotranspiration requires additional rainfall to saturate the slope. Debris avalanches occur primarily during periods of rapid snow melt or high rainfall when piezometric levels are high (Swanston 1970). Once soil moisture deficits are satisfied and the soil is saturated, the influence of winter evapotranspiration on soil water becomes negligible. In unaltered forest soils, subsurface water often quickly flows through interconnected root channels and other macropores. But if forest soils are disturbed, these subsurface conduits can collapse or become plugged, delaying drainage, increasing piezometric levels, and resulting in slope failure.

Although many studies have documented debris avalanche erosion after logging, road building appears to increase the frequency of debris avalanches much more than does timber cutting. In addition to profoundly affecting the soil water regime, road cuts can intersect and undercut the shallow failure surface. And road fills can add a substantial mass surcharge to the slope. These effects become relatively less important as the depth to the failure surface increases.

Debris torrents are the failure and rapid movement of water-saturated soil, rock, and organic debris in small, steep stream channels. Debris torrents might be considered a transitional link between mass erosion caused by a debris avalanche, and channel erosion. They typically occur during periods of high precipitation and streamflow. They may be started by a debris avalanche that enters the channel, or they may result from an initial failure of accumulated debris within the channel. Typically, as debris from the initial failure moves downslope, it entrains large quantities of additional material obtained from the channel banks and bed. The resulting channel may be scoured to bedrock for a great distance until the channel gradient lessens and deposition occurs (Costa and Jarrett 1981).

Debris torrents may start in channel reaches where fluvial channel erosion is typically small. In these reaches, water may flow through the interstices of accumulated organic material and coarse noncohesive rock and soil. As the volume of subsurface flow increases, the piezometric level within the accumulated debris rises, ultimately leading to failure at some critical piezometric head. Debris torrents appear to be episodic. They recur whenever there is enough noncohesive debris accumulated in the steep channel and water to mobilize that debris (Takahashi 1978).

Land management activities may increase the frequency of debris torrents by increasing the quantity of water delivered to a channel or by increasing the quantity of debris in a channel, or both. Channel flow can be dramatically changed by roads intercepting subsurface flow, rerouting of microdrainage networks, and the concentrating of surface runoff from compacted road or tractor trails. Material from accelerated hillslope erosion can increase the amount of debris accumulated in channels. Road fills at stream crossings place a large mass of rock and soil in channels. Road culverts in small steep stream channels are commonly plugged with soil and organic debris, resulting in saturation and failure of the road fill. Failure of road crossings is a principal cause of accelerated channel erosion and debris torrents in many forested steepland areas.

DISCUSSION

Where and how land is managed are primary considerations in efforts to reduce steepland erosion. The "how" is often thought to be completed with planning. Although sound planning is a major and necessary step in minimizing erosion, its implementation is all too often underplayed. The on-the-ground operator is the key to success or failure of a plan. Commonly, little effort is expended to include operators in the planning process. In general, their skills have been developed through personal experience of what seems to work. Unfortunately, what works best for dragging a log or constructing a stream crossing may not be best for reducing erosion. An important part of reducing steepland erosion is successful interactions between planners and operators. Success is often based as much on personalities as on their technical abilities.

The cumulative impact of management activities on erosion is a matter of concern. A common assumption is that if a small proportion of the area is logged, the rest will buffer the effect of the logging on downstream values. The proportion of a catchment that can be logged without undue degradation of the stream resource is, however, a matter of conjecture. This sort of assessment is appealing in its simplicity, but assumes erosion sources are uniformly distributed and that there is an equal probability of erosion occurring at any given location. Most steepland erosion occurs in a few areas, and most of the remaining area produces only a small amount of erosion. To effectively minimize erosion in steeplands, it is more important to specify where land is to be treated than to be concerned with how much land is to be treated. A small amount of activity conducted in the wrong place can result in a great deal more erosion than a large amount of activity conducted in locations which are erosion resistant.

The key to successful management of erosion is the ability to 1) identify potentially erodible sites, 2) correctly assess appropriate activities on those sites, and 3) have a political or regulatory system that fosters the appropriate action. In some cases, the only appropriate action is to do nothing. The cost required to correct management-induced erosion is often far beyond the benefits obtained from the land management activity or the costs required to follow a more sensitive alternative.

The time must be lengthened for which costs are evaluated relative to benefits. In general, the current period of concern of land management-related erosion is short--several years at most. This is perhaps acceptable for surface erosion, but channel erosion and mass erosion may follow land treatment by many years or even decades.

The effectiveness of erosion control, if evaluated, is often on the basis of the "typical" meteorological event. But channel erosion and mass erosion, which produce the erosional features that are generally considered to be "unacceptable," are usually associated with rare meteorological events.

Efforts to control erosion from the typical runoff event could lead to more erosion during the large storm. For example, small log check dams may effectively trap sediment and curtail erosion during average-size storms, but may provide a large source of material if these small dams fail during a major event. Such an erosion control effort may not reduce the amount of material transported during the long term, but simply change the time-related distribution of sediment yield. In some cases, the transport of a large quantity of material within a short period may be more destructive than the same quantity being transported over a long period. Large sediment pulses may produce pronounced deposition downstream. Channel aggradation may then lead to secondary erosion from deflected flow, which undercuts and oversteepens stream banks. Accumulation of material behind small check dams in a steep channel may also predispose the channel to mass failure as a debris torrent, which may be many times more destructive to downstream values than would continued transport of eroded materials.

A potentially useful system for managing erosion would be an Erosion Danger Rating--conceptually similar to the Fire Danger Rating used for forest fire planning. The Erosion Danger Rating would encompass a number of variables that predict the probability of erosion, including weather forecasts. Requirements for personnel and equipment would be based on predicted erosion damage. For example, if a large storm is forecast, certain measures might be taken to reduce erosion related to road plumbing: vulnerable culverts could be inspected and cleared in advance of the storm, critical road-side drainage ditches could be cleaned, and road berms could be repaired. During the storm, additional workers could be hired to patrol roads to prevent minor plumbing problems from developing into major failures. This sort of approach has been used successfully on the Siuslaw and Mendocino National Forests, where the frequency of road-related erosion has been dramatically reduced.

One method to minimize road-related debris torrents is to install "oversize" culverts or to bridge the water-course. This method is often rejected because of its high initial expense. Construction costs are frequently viewed in the short term and fail to include maintenance and replacement, let alone long term social costs. If the accounting system included the total costs required during the life of the project, many current construction practices would probably be changed.

Many innovative techniques have been successful in reducing the failure rate of stream crossings. By identifying channels which have a high debris torrent potential, road crossings have been designed so that water and debris will easily pass over the road and down a resistant concrete- or rock-faced fill. Another effective technique to reduce road failures has been to color-code road posts at culverts to indicate the potential of plugging, for example, red for high, yellow for moderate, and green for low. Employees are instructed that whenever they cross a red culvert during the rainy season, they must stop and assure that it is free of debris. Yellow culverts are to be routinely checked after storms. Green culverts are only checked on a normal maintenance schedule.

Management activities can modify the stability of debris within the channel. The local gradient of a steepland channel, as well as its stability, is often controlled by bedrock. However, large woody debris, a natural component of forested steepland channels, can also control channel gradient. The residence time of large decay-resistant logs, such as redwood, in a channel may approach a geologic time scale--up to 500 years. Large logs of Douglas-fir may remain in a channel up to 200 years. When this organic debris decays, accumulated material is subject to channel erosion and, further, is available for rapid mobilization into a debris torrent.

Land management activities can influence both short- and long-term stability of debris deposits within channels. Mechanical removal of naturally accumulated large organic debris can release stored sediment within a short time, whereas decay allows intermittent releases over a longer time while new deposits simultaneously form behind recently fallen trees. Logging residue can greatly add to the organic loading of a channel, thus providing additional opportunities for debris deposits. These additional deposits can increase the risk of debris torrents in steep channels or predispose channels to increased erosion many years after logging as organic components eventually decay and release accumulated deposits. If channel stability is controlled by the long-term supply of large organic debris, and large trees adjacent to channels are eliminated by continued forest management, active channel erosion may follow the decay of existing logs because new large logs are no longer available for replacement. In intermittent channels, live roots from surrounding trees provide substantial strength and reinforcement to the channel bed. If these trees are cut, the strength of the debris composing the bed will progressively weaken as the roots decay. This condition may result in accelerated channel erosion or increased risk of a debris torrent.

To manage steepland erosion successfully, it is important to define the erosional concern. If the principal concern is the loss of soil productivity, then on-site erosion control is perhaps appropriate. If the concern is reservoir aggradation, perhaps on-site soil loss is not important as long as eroded soil is deposited on the slope or in a stream before entering the reservoir.

Traditional land management decisions rely on cost-benefit ratios limited to short-term economic factors of monetary outlay and income. Social costs and benefits are often not considered. The costs of erosion are often considered only when road maintenance or other direct costs are affected. Indirect costs such as loss of fish habitat, soil productivity, and long-term slope instability are difficult to quantify, either physically or economically. Nonetheless, indirect costs must be assessed.

Considering these uncertainties, sensitive land stewardship should identify the values at risk and direct erosion control activities toward processes most likely to affect those values. Steepland erosion is controlled most effectively, in both physical and economic terms, by preventive land-use practices rather than corrective action. Management of steepland erosion is merely the appropriate application of varying levels of care and caution when dealing with terrain of varying erosional sensitivity.

We tend to fix our mistakes. The public often demands that we attend to actively eroding sites--whether management-induced or natural. However, unless more effort is devoted to prevention rather than to correction, we will continually be playing a game of catch-up.

The successful management of erosion is as much a philosophical and political problem as a technical one.

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