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3. EVALUATION OF UNSTABLE LANDS FOR INTERAGENCY WATERSHED ANALYSIS

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Abstract

Although methods for evaluating landslide rates and distributions are well developed, much less attention has been paid to evaluating the biological and physical role of landsliding. New directions in land management on Federal lands of the Pacific Northwest now require such evaluations for designing Riparian Reserves. Traditional analysis methods are no longer sufficient, because: 1) the significance of instability is now partially defined on the basis of its ecological role; 2) Riparian Reserves are intended to serve terrestrial ecosystem needs as well as aquatic ones; 3) the level of effort justified in avoiding instability must be evaluated in the context of the economic and ecological impact of both the instability and its remedy; and 4) the existing distribution of ecosystem processes reflects the past history of instability; 5) rehabilitation plans must take into account the ecological role of instability; and 6) knowledge of such interactions is necessary to design monitoring plans. Landslide inventory is not a useful strategy for the types of analyses now required. Instead, watershed stratification and sub-sampling of landslides for evaluation will allow analysis of the factors influencing landslide distribution in different parts of a watershed, the types of ecological effects different types of landslides might have, and, indirectly, the likely distribution of unstable lands.

Introduction

There is a long history of landslide hazard evaluation on public lands, and the technology and skills for such analyses are well developed (e.g. Hall et al. 1994). Much of California, Oregon, and Washington has already been assessed at some scale for landslide or erosion hazard. Now, however, federal land management agencies have a new task: to interpret the implications of unstable lands for the resources, land uses, and ecosystem values present in different watersheds. This task will require a change in outlook if it is to be accomplished. We now must be able to analyze unstable lands from an interdisciplinary point of view.

The new approach to land management described by the Standards and Guidelines for Management of Habitat for LateSuccessional and OldGrowth Forest Related Species Within the Range of the Northern Spotted Owl (USDA and USDI 1994a; the combined Record of Decision and the Standards and Guidelines are here referred to as the "ROD") emphasizes the need to understand interactions between biological and physical processes before appropriate management activities can be planned. Unstable lands were originally included as areas for special protection under the PACFISH recommendations (Thomas et al. 1993, Appendix 5K) because of their role in supplying sediment and wood to streams and the consequent effect on aquatic habitat. Protection took the form of the inclusion of unstable and potentially unstable lands in the Riparian Reserve system. The later FEMAT recommendations (FEMAT 1993) expand the role of Riparian Reserves to address needs of all ecosystem components. New analysis methods are required to achieve the level of understanding needed to

design and manage reserves. It is no longer sufficient simply to understand what sites or land types are susceptible to what types of instability. Instead, it will take interdisciplinary work to determine what aspects of instability are relevant to the important management issues and how best to evaluate their influences.

Evaluation of the role of unstable lands is particularly important for delineating Riparian Reserves. Some criteria for reserve definition (e.g. a prescribed distance or the height of site potential trees) are easily determined, and others (e.g. the width of the 100-year floodplain, the extent of riparian vegetation, the extent of the inner gorge) are relatively objective measures. Only in the case of identifying unstable and potentially unstable lands is significant professional judgment required. Watershed analysis contributes to the recognition of unstable lands by identifying the type of instabilities present, their causes, the factors affecting their distribution, and their significance to ecosystem values.

The need for an interdisciplinary approach

But why bother? If future management is to be designed to minimize instability anyway, why can't geologists and soil scientists simply evaluate instability using the traditional approach? Isn't the basic problem simply to identify the unstable sites and protect them? If our goal is to maintain instability at natural levels, won't that automatically ensure that all the ecosystem and social values affected by instability will be protected? What do we get from the extra interdisciplinary effort?

An interdisciplinary approach is needed for several reasons. First, since all sloping land is potentially unstable, determining what level of instability is important requires subjective judgments. To make these decisions, we must assess the influence of unstable lands on the resources and values that instability is likely to affect. Second, Riparian Reserves are intended to serve terrestrial ecosystem needs as well as aquatic ones. If there are terrestrial habitat values associated with potential instabilities, these sites may be more important than their linkage to the aquatic system might suggest. Third, the environmental hazards posed by some types of instability can be avoided through extra effort in engineering and design. If the relative importance to ecosystem values of different types of instabilities can be assessed, the sites needing modification of operational guidelines can be identified and prioritized. Fourth, ecosystem patterns reflect the past history of instability, so these connections must be understood both to explain present patterns and to predict future patterns. An understanding of how the ecosystem reflects instability also helps in identifying potentially unstable lands.

In addition, the ROD mandate does not end at designing Riparian Reserves. Restoration of hillslopes and channels will be an important part of future land management. The design of effective restoration works requires understanding both the reason for degraded conditions and the potential sideeffects of restoration. For example, many resource specialists have relied on emplacement of logs in streams and on other instream works to restore fish habitat, irrespective of the cause of habitat decline. However, if the degradation occurred because of accelerated landsliding upstream, the added logs will not provide a longterm "fix" for the problem and are likely to disappear with the next flood. In addition, inappropriate emplacement of woody debris can severely impact other beneficial uses: increased mobile debris loads can damage bridges and structures on banks, and logs provide an extreme hazard to whitewater recreationists and swimmers. Interdisciplinary evaluations of unstable lands will provide much of the information required to design appropriate restoration programs by assessing the role of biological and physical hillslope processes in modifying onsite and downstream ecosystem values.

Information on the interdisciplinary implications of unstable lands is also needed to design the monitoring strategies called for by FEMAT. Not only would it be difficult to interpret monitoring and inventory data if these relations are not understood, but relationships also can be used to identify appropriate monitoring and inventory sites and time frames. In addition, large natural instability events cannot be prevented by altering land use. It is therefore important to understand the ecological effects of these events if resilient management plans are to be designed. This issue is also important for interpreting results of land management experiments in Adaptive Management Areas (AMAs). Successful AMA experiments will be applied to other sites, so we must know enough about temporal patterns of instability to develop adequate criteria for judging success. An experimental management plan cannot be considered successful until it can be shown to respond benignly to large storms and other expected natural disturbances. Simply demonstrating that the plan has generated no landslides after 5 years

of observation is not sufficient if most landslides in an area occur during storms with recurrence intervals of 20 years or greater.

Definition of unstable lands

The ROD states that unstable and potentially unstable lands are to be included in the Riparian Reserves whether or not watershed analysis is required (ROD, p. C30), but it does not define unstable land. For a definition, we must look to the Final Supplemental Environmental Impact Statement (USDA and USDI 1994b, Glossary p. 18): "The unstable land component of the RRs includes lands which are prone to mass failure under natural conditions..., and where human activities...are likely to increase landslide distribution in time and space...The following types of land are included: 1) active landslides and those which exhibit sound evidence of movement in the past 400 years; 2) inner gorges; 3) those lands identified as unstable by geologic investigations... Highly erodible lands (i.e. lands prone to sheet and rill erosion) are not included in this definition." Most geomorphologists would include areas susceptible to rapid channel extension by gullying as potentially unstable, since the process is often associated with landsliding. These areas might include steep, unchannelled swales that may incise rapidly with hydrologic change, and unchannelled meadows where similar meadows have undergone entrenchment.

Riparian Reserves are intended to provide special protection to areas where changes likely to occur in the absence of that protection would significantly affect onsite or downstream aquatic and riparian values. This criterion can be used to decide what lands should be considered unstable in a particular setting. Discrete or catastrophic instabilities are generally considered more important than smaller, chronic ones because they provide fewer options for restoration. Landslides and gullies form quickly and rehabilitation begins only after much of the damage has been done, while sheet erosion can be effectively treated even after it has begun.

The 400year "window" for instability was selected for convenience: most unlogged forests contain some trees older than 400 years that can be used to date old landslide scars. However, widespread debris flow deposits associated with a 500yearold fire might suggest that future deforestation could trigger a similar response, even though the area has remained stable for more than 400 years.

It should be noted that some types of landslide scars represent areas that are now stable, because previously unstable materials have been rearranged into a stable configuration. The least stable sites often are those that have not yet failed. Therefore, landslide maps do not directly indicate the unstable and potentially unstable land, although they can help to recognize the types of sites likely to fail in the future. In addition, past landslide frequencies associated with certain types of disturbance may not be a useful guide to future slope failure if those disturbances are no longer likely. For example, roadrelated landslides often decrease in frequency with the age of a road, so landsliding rates may decrease as fewer new roads are built. We thus must understand the causes for instability before we can assess the stability of a landscape. Landslide maps alone are not sufficient for providing this information, but they are useful for identifying the distribution patterns that can allow cause to be inferred. Landslide maps quickly become outdated, but decadesold maps can be as useful for identifying patterns and causes as maps made only a season ago.

Environmental issues concerning unstable lands

The tasks required of watershed analysis in the evaluation of unstable lands are several: to understand what controls the distribution and occurrence of instability and to understand the likely effects of instability on onsite and downstream values. In the past, the concern over unstable lands has focused on their role in destroying infrastructure, altering water quality, and causing changes in channel form. There is an emerging appreciation of the natural role of instability in sustaining ecosystems, and of what components of the ecosystem are affected by unstable ground. Management has generally been based on the assumptions that 1) the fewer landslides, the better; 2) landslide scars should be "repaired" as soon as possible; and 3) the worst landslides are those that contribute materials to channels. To evaluate these assumptions, we need to examine the relation of unstable features to a variety of ecosystem needs. We also must address the attributes of unstable lands that may have little to do with their potential future instability (Table 3-1). It may become necessary to identify particular types

of instability not because of their downstream impacts or risk of failure, but because they are special habitat features of value to the ecosystem in a watershed.

Table 3-1. Attributes of unstable lands that may need assessment for particular concerns

Attribute	herpto- fauna	wildlife	aquatic biota	fire	vegetation	social
Type of instability	x	x	x	x	x	x
Natural background rates	x	x	x	x	x	
Rates of instability under management	x	x	x	x	x	
Distribution in watershed		x	x	x	x	x
Connection of feature with channel	x		x			
Proximity to ridgetop		x				
Time required for recovery	x	x		x	x	x
Size of feature		x		x	x	x
Type of surrounding vegetation	x	x		x	x	
Timing of sediment input	x		x			
Amount, size, location of woody debris on slope	x	x		x	x	
Amount, size, location of wood in channel	x	x	x			x
Effect of instability on soil moisture	x			x	x	
Effect of instability on surface flow	x	x	x			
Substrate in scar	x	x			x	
Sediment delivery to	x		x			x

channel						
Grain size delivered to channel	x		x			x
Routing of sediment downstream	x	x	x		x	x
Effect on temperature of air and humidity	x	x		x	x	
Effect on vegetation cover	x	x		x	x	

Herpetofauna and other wildlife

Reptiles and amphibians are strongly influenced by landslides and gullying because these processes create and destroy onsite and downstream habitat. The effects depend on the type of instability, and their importance differs for different species. Influences can be evaluated by examining their effects on particular environmental needs of these species.

Most amphibians require open water during some phase of their life cycle, and landslides and gullies often influence the distribution of open water. Large slumps may form ponds at their heads, and debris flows may create perennial streams by exposing flow that previously percolated through channel fill. Landslides can also interrupt perennial flow by depositing porous gravels in channels. What species are present in a stream is influenced by the water velocity, which can be modified by landsliding and gullying. Debris flows can remove logs and boulders that slow flow in small channels, while landslide debris can pond flow and decrease velocities. For example, cumulative aggradation from slides in the South Fork Trinity basin has created abundant habitat for foothill yellowlegged frogs (*Rana boylei*, a class 2 candidate for listing as a threatened or endangered species) (Amy Lind, USDA Pacific Southwest Research Station, personal communication). Soil moisture is also important to many species. Earthflows are often characterized by high soil moisture, while gullies tend to dry out adjacent soils. Landslides and gullies also influence food resources and microclimatic characteristics important to both amphibians and reptiles.

Particular species are associated with particular substrates. Del Norte salamanders (*Plethodon elongatus*, a class 2 candidate for listing) and several lizard species often inhabit rock piles such as those associated with rockfalls and recovering landslide scars. Torrent salamanders (*Rhyacotriton ?sp.*, a class 2 candidate for listing) are found in mossy rock accumulations along streams, and such sites often form in recovering debrisflow tracks. Larvae of many amphibians are aquatic and require large channel gravels for places to hide. Large gravels tend to be buried where high rates of landsliding and gullying aggrade channels. Other species are closely associated with woody debris. Terrestrial salamanders are often found under logs, while Pacific pond turtles (*Clemmys marmorata*, a class 2 candidate for listing) frequent instream logs. Landslides are an important source of woody debris in both terrestrial and aquatic environments.

Several types of information are thus needed to evaluate the importance of a potentially unstable feature to herpetofauna. First, we need to understand its influence on the seasonality and extent of surface water, the hydraulics of channel flow, and the soil moisture regime. Similarly, the effects on the woody debris regime should be noted, along with the influence on hillslope and channel substrates. Third, the "connectedness" of the disturbance with other habitats should be noted. An isolated landslide surrounded by tracts of unbroken forest will be colonized in a very different way than a similar slide adjacent to a channel. Finally, it is important to note the persistence of a disturbance. Habitat qualities change as a disturbance recovers, so some uses may be quite

transient at sites that recover quickly. On the other hand, large, ancient slumps may have a persisting complex of soil moisture characteristics, seeps, and vegetation types that enhances their significance for centuries.

Unstable lands affect other wildlife primarily by altering vegetation and hydrology, although their influence on woody debris and substrate is also important for some species. Edges of communities are often particularly important habitat elements because they allow easy access to a wider variety of resources, and large landslides and linear disturbances provide lengthy edges. Wildlife use closely reflects the habitat changes that occur as a disturbance recovers.

Unstable lands are an integral part of the natural habitat mosaic for herpetofauna and other wildlife, so the natural instability regime must be maintained if the natural variety and viability of the biota are to be sustained. In addition, large old features that may no longer be important from a stability standpoint can remain significant as habitat elements. Because of the association of herpetofauna with unstable lands, a description of the natural instability regime may make it easier to estimate the natural distribution and relative abundance of species in the past.

Aquatic ecosystems

The link between instability and aquatic ecosystems is widely recognized, and unstable lands originally were included in PACFISH reserves because of their impact on downstream fish habitat. Aquatic biota are affected by landslides and gullies in much the same way as aquatic herpetofauna: they also need open water, a particular velocity distribution, certain substrate characteristics, temperatures, and food supplies. In this case, too, instability both enhances and destroys habitats for different components of the ecosystem.

Altered substrates are especially important to salmonids, which require a specific grainsize distribution for spawning, and to benthic species, many of which are found only on organic debris or on sediment of a particular size. Fish are particularly affected by changes in the continuity of flow. The formation of a sliderelated debris jam or waterfall may prevent migration of anadromous fish, as can aggradation that widens and shallows flow. Abnormally shallow flows may force migrating stocks to remain in estuaries or downstream reaches for longer than usual and thus sustain higher predation losses.

On the other hand, the areas of highest primary productivity in the Elk River basin of coastal Oregon are associated with ancient landslides. Channel gradients are low at these sites, there is abundant wood, riparian canopy covers are sparse, and water temperatures are high. High productivity at these sites contributes nutrients downstream, increasing the habitat value of downstream reaches (Glen Chen, USDA Forest Service, Logan, Utah, personal communication). In other areas, landslides may be important as sources of spawning gravel, and landslide blockages may isolate and protect upstream aquatic communities from the influx of downstream species.

Aquatic biota evolved in a particular environmental setting that included a natural distribution of landslides and gullies. These features are a necessary part of the system that creates aquatic habitat. Unstable land becomes a problem only when the disturbance pattern is altered from natural, or when other changes, such as loss of refuge habitat, defeat the species' strategies for coping with disturbance. If there is a shift from the natural input rates, size distribution, or composition of woody debris and sediment, the pattern of aquatic communities and the community compositions will change. Some parts of the aquatic system are more sensitive to change than others. Thus, productivity for anadromous fish is often highest in lowgradient reaches where organic material can accumulate, but these are also the sites most susceptible to accelerated aggradation.

Social considerations

Because landslides and gullies are obvious features that often affect roads and structures, most people are aware of their negative impacts. To many, landslides represent the major symptom of poor landuse practices. The success of a management strategy thus is likely to be judged in part by its success in avoiding landslides. If a significant landslide occurs despite the most conscientious management efforts, the credibility and competence of the managing agency are likely to be challenged. This level of mistrust occasionally results in the public

blaming management activities even when landslides occur far from the site of any past or present activity. It thus is particularly important to plan landuse activities to avoid destabilizing slopes, quite apart from the physical and biological impacts that instability provokes.

Issues of particular concern to the general public are damage to roads and bridges either at the site of instability or downstream. In addition, flooding is a concern throughout the region, and any influence of instability and channel aggradation on flood frequencies will likely be considered important.

Vegetation

The effect of instability on vegetation is widely appreciated: landslides and gullies have an immediate and profound effect on the onsite plant community. These changes, and the progression of changes that follow them, are the attributes most commonly used by earth scientists to map and date landslides. Landslides and gullies also can affect downstream conditions by causing aggradation that changes flood characteristics and floodplain hydrology. These changes then alter the species composition and disturbance regime of riparian vegetation communities. Gullying can strongly affect soil moisture and has caused profound changes in alpine meadow vegetation (Hagberg 1995) and in riparian vegetation of the American southwest.

Some types of plants are associated with particular types of instability. Prairies are an important vegetation type in the Redwood Creek watershed, and these are often located on earthflows. The endangered Santa Cruz cypress (*Cupressus abramsiana*) is generally found on the scars of shallow debris flows, and a variety of other species are most common on disturbed soils. In a natural system, hillslope instability helps maintain the naturally changing mosaic of vegetation types and ages. In our modern, altered world, however, the ecosystem value of individual sites is tempered by their overall distribution. If landslides are extremely frequent, then the ecosystem value of a particular slide scar may not be high. Similarly, if riparian vegetation is highly disturbed for other reasons, the added instability contributed from landsliding may be detrimental.

The interaction between vegetation, instability, and ecosystem values becomes particularly important to understand when planning rehabilitation measures for landslide scars and when evaluating the offsite influence of instability. If inappropriate vegetation is planted, soil conservation goals may be attained at the expense of the ecosystem as a whole. The nature of vegetation on potentially unstable sites is important to downstream habitats. If these sites are logged, then the quality of materials provided to channels is altered, even if the rate of failure is not. Instead of a few immobile, long pieces of wood, the channel will receive many small pieces plus a few disemboled rootwads. The ROD's proscription on logging unstable land is intended in part to ensure that the composition of the freight carried by future slides is not altered.

Vegetation can strongly influence hillslope stability. Vegetation change may be associated with changes in root cohesion or hydrology, which can trigger landsliding or gullying. The vegetation pattern that was present before European occupation has been altered throughout western forests, so an understanding of historic vegetation patterns can aid in deciphering natural erosion characteristics.

Soils

Soil conditions strongly influence vegetation characteristics and the distribution of soil fauna and fungi. Soils have generally been assessed through description and classification, but there is increasing interest in evaluating the processes through which particular soils developed. Soils preserve information about prior vegetation characteristics and disturbances and thus contain evidence of their own history. A processbased approach to soil assessment requires more detailed spatial information than existing soil maps provide. However, observations of soils associated with landforms or slope positions at particular sites can be used to characterize broader soil classes. Soils information is particularly useful for evaluating the past distribution, age, and characteristics of unstable lands. Soils are stripped at the disturbance site and accumulate at sites downslope, so even the distribution of soil thickness can provide clues to past hillslope instability. Some types of landslides can repeatedly bury remnant soils downslope, and an excavation of their deposits can reveal the history of their activity.

Existing soil maps can provide useful information about characteristic grain size distributions of sediment likely to be mobilized by instability. However, few soil reports describe the entire regolith, so field observations are necessary for estimating the grain sizes moved by failures that incorporate subsoil materials. In addition, landslides often occur in small, atypical inclusions in larger soil units. The description of the dominant soil in the map unit thus may not apply to unstable sites.

Channel morphology

Much of the concern over unstable lands focuses on downstream changes in channel morphology. Morphologic change not only influences aquatic habitat, but also damages structures in or near channels and alters flood frequencies. Channel changes due to unstable lands are usually caused by increased sediment loads, although increased woody debris loads can also cause problems.

Increased fine sediment loads can fill pore spaces in gravels, preventing some species from living there and decreasing the survival of salmonid eggs and young. Fine bedload-sized sediments accumulate preferentially in pools, decreasing the size and utility of an important habitat element. Coarser sediments contribute to generalized aggradation in low gradient reaches, destroying habitat and increasing flood frequencies. How much sediment gets deposited at which sites depends on the grain size of the sediment, the channel form, and the flow characteristics at the time the sediment is introduced.

Several things must be known about unstable lands if their potential influence on downstream channel form is to be understood. To evaluate downstream changes, knowing the amount of sediment and wood delivered to the channel is more important than knowing the amount moved on the slope. The grain sizes delivered must also be characterized, as well as the timing of the input. For example, landslides and gully erosion that occur during small storms may have disproportionately severe effects because channels may not be able to flush away the debris. Finally, different types of channels react to sediment and wood in different ways. Thus, the distribution of channels of different characteristics must be understood before the channel system's response to unstable slopes can be explained.

Existing approaches to analyzing unstable lands

Several methods for evaluating unstable lands have been used by various state and federal agencies. The most common approach is to use landslide maps, field observations, and sequences of aerial photographs to identify factors that control landslide character, frequency, and distribution. The result can range from simply the recognition of an association between landsliding and a particular land use activity and site type (e.g. mid-slope roads on steeply dipping sandstones), to a map showing the relative stability of different sites. This approach has often been used to identify lands unsuited for particular types of management.

The Klamath National Forest recently used landslide maps compiled during the 1970s and 1980s to associate landslides with particular landforms, hillslope gradients, and geologic materials. These attributes were used to stratify the forest into land types, which could then be characterized according to the type and frequency of landslides. The stratification also allowed analysis of the types of land use that caused instability in each land type, and of the volume of sediment likely to reach the channel. Adjacent national forests have used similar approaches but have interpreted the unstable component differently, leading to inconsistent classifications across administrative boundaries.

During the past three years, soil scientists, geologists, and vegetation specialists from national forests in northwest California have been working together to integrate mapping strategies by defining "ecological units" that are identified by a combination of vegetation, soil, and landform characteristics. These units are being mapped over large areas, and relative slope stability hazard is being assigned to the map units.

Approaches to evaluating slope stability are even more disparate across agency boundaries. The BLM, for example, has placed less emphasis on evaluating unstable lands and has few employees trained in such methods. Identification of unstable lands has generally been the responsibility of soil scientists in the BLM, while geologists are the major players in Forest Service efforts.

Redwood National Park has taken still a different approach. Stability is an issue both in the Park and on private lands upstream of the Park. However, Park personnel have little access to the private lands. Aerial photos and existing landslide maps have been used to estimate sediment inputs to the channel and to identify the types of areas responsible for major sediment inputs. Within the Park, most effort is devoted to evaluating road stability to prioritize segments for rehabilitation. Stability analysis is extremely detailed for this purpose: individual culverts are assessed for their probability of failure. Both gullying and landsliding is of concern on Park lands.

Stability assessments carried out by the California Department of Mines and Geology (DMG) were originally motivated by the need to protect life and property, but the Department quickly assumed a role in environmental protection. Unstable land is now assessed at two scales. DMG personnel review Timber Harvest Plans (THPs) on private lands to ensure that planned management activities are appropriate on unstable lands. The Department also compiles landslide maps for large areas and is participating in an inventory of erodible watersheds. The inventory will classify the intrinsic stability of approximately 50,000-acre watersheds through an assessment of geology, soils, and topography. DMG personnel are finding it increasingly easy to work on private lands because landowners have found the information to be useful. Efforts are currently being made by the DMG and the Forest Service to develop a consistent nomenclature for unstable lands based on the widely used Varnes (1958) classification system.

In each case, efforts have been devoted primarily to delineating areas where landslides or gullies are likely to occur in the future. By characterizing the distribution and attributes of instabilities on different land types in an area, it is possible to predict the effects of future activities on similar lands that have not yet been developed. But although the overall goals are similar in each case, the approaches and definitions have varied widely. The ROD is intended in part to introduce consistency of approach, values, and management assumptions across federal management boundaries. In some cases, different approaches are warranted because special issues demand special approaches. However, in most cases, inconsistencies develop simply because of a lack of communication and coordination between agencies and between administrative units within agencies.

Watershed analysis for unstable lands

As Table 3-1 shows, there is a lot of information that would be nice to have for unstable lands, and all of it is important to some component of the ecosystem. Unfortunately, it is impossible to gather this much information for landslides and gullies throughout a watershed, so some prioritization of information needs must be carried out. To do this, the context of the problem must be kept in mind: although instability is important, it is not the center of the FEMAT world. If we insist on collecting more information than is actually needed, we risk losing our credibility as watershed analysts. Time and resources for watershed analysis are limited, so the importance of any piece of information is determined by its usefulness in producing the required project. We must develop new strategies to evaluate unstable land that identify and provide the information necessary at an appropriate level of precision, and that are both efficient and valid.

Analysis strategy

The ROD is ambiguous about what types of information watershed analysis is to provide about unstable lands. Analysis is intended to "...identify processes that are active within a watershed, how those processes are distributed in time and space, the current upland and riparian conditions of the watershed, and how all of these factors influence riparian habitat and other beneficial uses" (ROD p. B21 par. 4). Results are to include "maps of the location, frequency, and magnitude of key processes" (p. B23 par. 1). Further, analysis "...will be an informationgathering and analysis process, but will not be a comprehensive inventory process" (p. E20 par. 6). Concerning Riparian Reserves, "Watershed analysis will identify critical hillslope, riparian, and channel processes that must be evaluated in order to delineate Riparian Reserves that assure protection of riparian and aquatic functions. Riparian Reserves are delineated during implementation of sitespecific projects based on analysis of the critical hillslope, riparian, and channel processes and features" (p. B13 par. 3).

Although the Federal Agency Guide for Watershed Analysis (Furniss and McCammon 1994) was written before the ROD and thus contains directives that have since been reversed, the description it provides of a recommended method for evaluating landslides indicates the type of strategy envisioned for watershed analysis.

The watershed is stratified according to variables that influence site stability, and representative subareas are sampled to identify the association between instability and environmental changes. This information can be used to map the relative stability of different landscape elements.

Either of two types of analysis products would fulfill the intent expressed by the ROD:

1. A package consisting of a description of the stability and characteristics of different types of sites in a watershed, an assessment of the influence of each type of instability on issues of concern, diagrams showing the relationships among various types of sites, and a map showing the parts of the watershed in which each type of site is likely to be found. This is similar to the catena concept that is commonly used to describe the distribution of soils within a mapped soil unit: we do not know the specific location of each soil type, but we know how they relate to one another on a hillslope, and we know the part of the watershed for which the relation holds. Range maps for animals or plants are similar: we know from Peterson's field guide that tailed frogs are found in the coastal Pacific Northwest, but it takes a reading of the text to learn the types of sites they frequent.

If used properly, the stratification approach is an efficient way to evaluate large areas quickly. Satellite imagery, geologic maps, and topographic maps might be used to stratify the area; air photos to identify instabilities and map their distribution in representative subareas; and field checking of selected sites to determine their relationships to causal factors and ecosystem responses. This is the approach described by the pilot watershed analysis guide (Furniss and McCammon 1994).

2. A map of the distribution of unstable and potentially unstable sites throughout the watershed, along with descriptions of each type of instability, their causes, and their influences on the issues of concern in the watershed. Such a map would be constructed using the same types of information as for case 1. A landslide map, by itself, is insufficient because it does not identify those lands that are unstable. More useful would be the "Ecosystem Unit Inventory" maps being produced in national forests of Region 5. In this case, the mapped ecosystem units would provide the basis for landtype stratification, and analysis would proceed by evaluating the stability and ecosystem relations in each ecosystem unit. However, it takes approximately a year to inventory ecosystem units in a 320km² watershed, so this approach will not be useful for watershed analysis unless inventories already exist for the watersheds that are to be analyzed. Existing ecosystem unit inventories were not designed to satisfy the needs of watershed analysis, so they may not be adequate for this application. However, watershed analysis results might be very useful for designing future ecosystem unit inventories that can satisfy multiple needs.

In either case, some degree of landslide mapping is required to determine the distribution patterns of landslides as they relate to landscape elements. It is not necessary that the maps be areally complete or up to date, however: they are needed simply for recognizing distribution patterns. The site mapping that is required later, when Riparian Reserves are delineated for particular projects, will provide detailed information that can be used to refine the stability relationships when watershed analyses are updated.

In either case, also, the potential influence of instability cannot be evaluated without understanding how different parts of the channel system will respond to different types of instability. This problem will require an approach similar to that of the stability analysis: the channel network can be stratified by reach characteristics and the response of each reach type evaluated. In some cases, essentially irreversible changes in channel regime may cause channel impacts even though a natural disturbance regime persists on the hillslopes. For example, construction of a dam may result in aggradation at the mouths of pristine tributary watersheds downstream because peak flows have decreased to the point that the natural sediment loads can no longer be removed. Such changes must be understood if ecosystem responses to future land use are to be evaluated, and if appropriate monitoring variables are to be selected for evaluating management performance.

Both approaches require stratification and subsampling to provide the necessary information: types of sites are characterized according to detailed observations at representatives of those site types. This approach is essential for watershed analysis. Understanding the implications of different types of instability for ecosystems requires detailed field observations, yet this level of detail is impossible to attain for the entire watershed. Instead,

categorization and characterization are used to reconcile the low-resolution information that can be obtained for an entire watershed with the detailed observations needed to interpret the low-resolution information.

Although Riparian Reserves are not to be delineated during watershed analysis (ROD, p. B13, par. 3), some information about their site-specific distribution is necessary at this stage to assess ecosystem needs at a watershed scale. Although reserve delineation requires information on slope stability that can only be observed in the field at each site, general patterns of reserve distribution can be estimated from the information produced by either of the approaches. For example, it may be important to evaluate the extent of interbasin migration corridors for wildlife at various times in the future. If there are areas that are particularly important, it may be worthwhile to map unstable lands and low-order channels in those areas using aerial photographs and to use this information to approximately define the riparian corridors.

On the other hand, if information about reserve distribution is needed throughout the watershed, accurate mapping of channels and unstable land is impractical. Instead, one of two approaches might be taken. First, patterns of instability and channel extent might be used as a basis for drawing approximate, hypothetical boundaries. For example, watershed analysis will not locate every channel head, as is essential for Riparian Reserve design, but it might show that a particular drainage area usually is necessary to support a channel (e.g. Montgomery and Dietrich 1988). This information then can be used in a geographic information system to estimate the location of channel heads. Similarly, analysis might show that a particular unstable landform is found in a certain type of setting. This setting then could be mapped to estimate the distribution of the unstable form. This information would be combined with information about site potential tree heights and airphoto-based maps of floodplain widths and riparian vegetation to draw the approximate distribution of Riparian Reserves. This method would be most useful for estimating the extent of interim reserves, the "defaults" that would apply in areas for which watershed analysis is not required. It would be less useful for estimating the extent of reserves where interim boundaries are to be modified to better suit site conditions.

The second approach is to describe the reserves using stratification and characterization. The watershed would be divided into subareas of distinct character, and representative sites examined in each to provide a sample of likely reserve designs in each subarea. The site visits would allow local conditions to be assessed. Preliminary reserve boundaries would be mapped for the sites examined in the field, and these would be considered representative of other reserves within the stratum. This information could then be used to describe the reserve system, and would allow estimates of its area. Although the method would not necessarily reveal the distribution of a particular condition, it could provide an estimate of the relative frequency of the condition and its potential influence on reserve design. The site-level information obtained using this approach would be necessary where the character of modified (i.e. noninterim) Riparian Reserves must be determined.

Scope of the analysis

Watershed analysis is intended to provide more information about unstable lands than is required simply for Riparian Reserve design. Analysis results are expected to contribute to later prescription of land management activities, planning of watershed restoration, and development of monitoring programs (ROD, p. 10, par. 3). All intended applications require a description of the causes of instability, their patterns of distribution through the watershed, the natural instability regime, the influence of land management activities on instability, and the effect of the instabilities on ecosystem values and beneficial uses.

In general, the causes of instability, effects of management, and patterns of distribution are expected to be relatively well understood on the basis of information already existing for most watersheds. We certainly will never have "enough" information about landslides in a watershed, but for most watersheds we already have a pretty good view of what types of landslides are caused by what types of activities in what types of areas. This level of information is likely to be sufficient for many watershed analyses, particularly during the early stages of implementation of the President's Forest Plan. Understanding the natural stability regime is expected to require some work, but this often may be estimated from information about the relation of existing instabilities to management practices. For example, if 80% of the debris avalanches, 10% of the earthflows, and 95% of the debris flows in an area are road-related, the natural disturbance regime would have been characterized by significantly fewer debris avalanches and flows than now occur.

The remaining task, that of understanding the effect of instability on ecosystem values and beneficial uses, is the most difficult, the least understood, and among the most important for planning restoration work. The task is difficult for three reasons. First, it requires strong interdisciplinary work, and resource professionals and researchers have little experience in tackling interdisciplinary problems. Second, the linkages between an instability and its offsite effects are often obscured by time lags, long distances, and hosts of intervening processes. In most cases, linkages between ecosystems and instability will be made only qualitatively. Too many factors influence populations to be able to single out the effects of particular types of instability. Finally, many issues require analysis of the system as a whole to sort out the potential effects. For example, instabilities in some areas may be more critical than in others because of the importance of those sites as refugia for particular species or because they are along major migration paths. Similarly, some parts of a watershed are better connected with downstream reaches than others, and landslides at those sites are more likely to influence downstream values. Distribution patterns of both instabilities and values are therefore important, yet this is a scale of analysis that we have had little practice in dealing with.

A distinction can be made between evaluating the likelihood of occurrence for an instability and assessing the potential impacts that it may cause. The occurrence likelihood can be evaluated objectively. Evaluating how severe the consequences of an instability may be, on the other hand, is possible only if the value judgments associated with an impact are considered. Thus, lands with a high probability of failure may be of little concern if the failures are not likely to affect anything considered to be important. The watershed analysis will assess the risk of instability and will describe the types of environmental changes those instabilities can cause, but it will not indulge in value judgments concerning the significance of those changes. Later recommendations for managing the unstable lands will require more input to prioritize activities and evaluate the tradeoffs between different environmental values.

Analysis standards

Previous work on unstable lands has been plagued by inconsistent nomenclature and interpretation. Similar features are called by different names or different features by the same name, and the level of hazard associated with a particular type of feature is assigned different values in neighboring political or administrative units. This lack of consistency hinders communication between units and between agencies, and makes compilation of information over wide areas difficult. On the other hand, each area has a different range of conditions and a different set of issues, so different types of analyses and techniques are necessary. Some standardization is required, but enough flexibility must remain to allow appropriate analyses to be carried out for each area.

Easiest to achieve is consistency in nomenclature. Most slope stability specialists have adopted some version of the Varnes (1958) classification system for landslides. In California, the Forest Service Regional Office and the California Division of Mines and Geology are cooperating to standardize terminology for State and Forest Service landslide work, and standardization is converging on the Varnes system. One caveat is necessary for classification systems: once categories are constructed, all observations are usually forced into the identified categories, and less effort often is put into understanding individual landslides. Workers must use classification systems with the understanding that no system does justice to the full range of conditions. Care must be taken to examine the classification system critically with respect to the field conditions actually encountered, and to realize that if something does not fall neatly into a category, it is likely to be the fault of the classification system. Some things just don't fit, and these need to be described and evaluated in their own right.

A standard nomenclature for gullies has not been developed. Instead, gullies are often classified operationally on the basis of their cause or the type of landform with which they are associated. It would be useful to establish a standardized nomenclature for gullies to use in parallel with the landslide classification system.

The type of information required during a stability evaluation is much more difficult and less useful to standardize, since different areas have different processes, conditions, issues, and data availability. For example, most attempts at standardization establish a minimum size class of feature to be mapped. This size class may make sense where the most important failures are larger than the minimum, but in areas dominated by high frequencies of very small failures, adherence to the standard would produce a useless product. Similarly, requirements for specified measurement precisions, field verification levels, and types of data to be collected

would not be attainable in many watersheds. Most watersheds contain some private lands, which are not accessible to agency watershed analysis personnel; no interagency agreement on standardization is going to provide standardized information from these areas. Watershed analysis thus must be able to proceed without a uniform or complete data base. Data standards, data requirements, and uniform analysis approaches certainly make it easier to communicate and compare results, but the bottom line for which data to collect and how to collect it must be a judgment of whether a particular standard or approach is suitable for the conditions present.

Despite these problems, it is useful to establish a set of recommended data standards that could provide a model for an "ideal" data set that would be sufficient for most applications. A future landslide inventory could then use the standards that are relevant to that particular case as a guide for designing the inventory. Future inventories would be more consistent than they have been in the past, even if many of the recommendations are unattainable in particular areas. Approaches to stability analysis are expected to become more consistent as watershed analysis results are published and compared. Methods that are most useful for particular situations will be more widely adopted, while those that do not work will be abandoned. If standardization is attempted too early, however, we will undoubtedly select a less than adequate standard. In any case, no single standard approach will ever be possible, because conditions vary so widely through the area for which watershed analyses are required.

On the other hand, a certain amount of consistency is required of analyses within a river basin if results are to be combined into an overall view of instability within the basin. The basin assessment team will be in the best position to identify the minimum level of information necessary to address a particular problem throughout the basin, or it could specify the parts of the basin for which that type of information is necessary.

The easiest route to consistency is to maintain close communication between the various groups working on watershed analyses in a river basin or province, or even across the entire region. Communication between adjacent groups will allow interpretation of "boundary discontinuities" in definitions or data precision, even if the differing requirements between adjacent watersheds will continue to produce such discontinuities. Thus, it is essential to organize informal working groups, and to ensure that neighboring groups visit characteristic sites in each area to discuss their varying approaches. Further, peer review of the initial watershed analysis efforts will aid convergence on the most effective analysis approaches and the type of information that will need to be included.

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