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I fear that, in recent years, too many ecologists have yielded to the temptation of finding a problem that can be studied on a conveniently small spatial and temporal scale, rather than striving first to identify the important problems, and then to ask what is the appropriate spatial scale on which to study them.
-Robert M. May, 1994

CHAPTER 6

TEMPORAL AND SPATIAL SCALES

Robert R. Ziemer

Human activities have degraded substantial portions of the nation's ecological resources, including physical and biological aquatic systems. The effects are continuing and cumulative, and few high-quality aquatic ecosystems remain in the United States. Concern about these diminishing resources has resulted in numerous restoration programs. Some are well conceived and address complex ecosystem interactions. However, most restoration begins with a broad ecosystem issue and quickly narrows because of jurisdictional politics, land ownership, user interest, funding, or time. Too often, this narrowed view leads to restoration that is well designed and well intentioned but irrelevant and ineffective. In some cases, expensive projects are conducted where they will have little effect. In other cases, a restoration project is completed only to be destroyed by the next moderate storm. In still other cases, restoration designed to benefit one component of the ecosystem severely damages other components.

A common thread through such failed restoration is that the plans consider only a particular site or problem and ignore the greater context of geography, time, and ecology. For example, restoration to address a dwindling run of anadromous salmonids (salmon or trout that live in salt water but migrate to spawn in freshwater) must not only discern the complex reasons why the run is dwindling, but how local projects might contribute to the solution. In some cases, a proposed local project may be ineffective because it covers too small an area or because of conditions outside the project area. Successful restoration is based on more than a thorough understanding of the problem. It also is based on understanding the interaction of the problem with other ecosystem components, both locally and beyond the project's boundaries.

RESTORATION AS PART OF A BROADER STRATEGY

In the Pacific Northwest, polarized views concerning use of public forest lands have produced lawsuits and counterlawsuits on widely varied issues. The resulting gridlock over federal forest management led President Clinton to convene the Forest Conference in Portland, Oregon, on 2 April 1993. Following the conference, the President formed the Forest Ecosystem Management Analysis Team (FEMAT). Their task was to identify management alternatives that attain the greatest economic and social contribution from the forests while conforming to the Endangered Species Act, National Forest Management Act, Federal Land Policy and Management Act, National Environmental Policy Act, and other laws and regulations. More than 600 scientists, technicians, and support personnel contributed to that effort.

An important part of the FEMAT (1993) report is the Aquatic Conservation Strategy. This strategy includes four main components.

1. *Riparian reserves*-portions of the watershed that govern the hydrologic, geomorphic, and ecological processes that directly affect streams, fish habitat, and riparian ecosystems (land areas flanking streams).
2. *Key watersheds*-a system of large watershed areas throughout the Pacific Northwest where genetic lines of fish can take refuge and survive despite hostile environmental changes elsewhere. These watersheds contain the best remaining habitat for at-risk fish species or they contain degraded habitat of high restoration potential.
3. *Watershed analysis* - an assessment that characterizes a watershed's human, aquatic, riparian, and terrestrial features, conditions, processes, and interactions.
4. *Watershed restoration*-a comprehensive, long-term program to restore watershed health, riparian ecosystems, and fish habitats.

Note that watershed restoration is only one of the four components of this strategy. Restoration should not be considered independently of other land management prescriptions.

MODELS OF RESPONSE TO DISTURBANCE

Most aquatic conservation strategies assume that salmonid habitat quality deteriorates as watershed disturbance increases. It is well documented that the best habitat for wild salmonids is the least disturbed, whereas greatly disturbed areas are where salmonids are most likely to have been wiped out. Less well documented are the rates and degrees of the relation between disturbance and habitat quality. We will examine two models of this relation, shown in Figure 6.1.

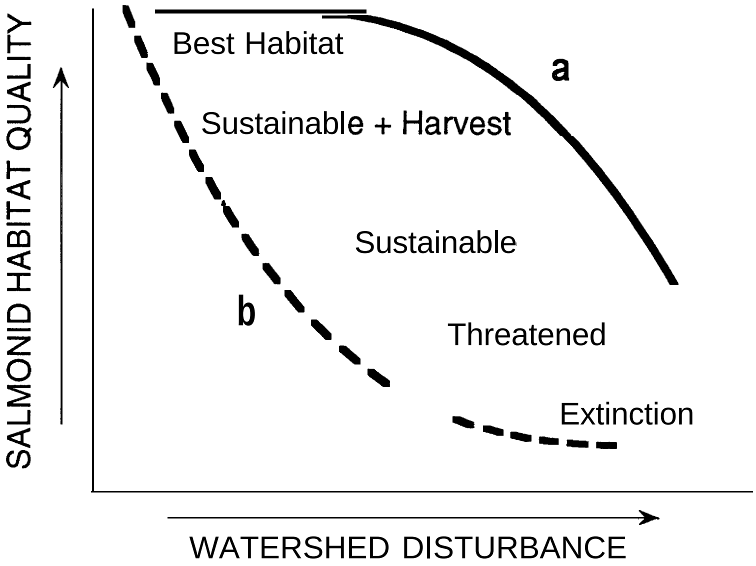

FIGURE 6.1. – Two conceptual models of the relation among watershed disturbance, salmonid habitat, and risk to fish stocks (local populations): (a) habitat quality is not degraded until substantial watershed disturbance is reached; (b) habitat quality is degraded most quickly during initial stages of disturbance.

Historically, watershed restoration has focused on improving the most severely degraded areas. Managers have assumed that commodity extraction can safely proceed where habitat is still good. That is, the least-disturbed areas have been assumed to be where future land-disturbing activities can proceed with the least concern. This strategy assumes a disturbance threshold beyond which degradation becomes significant (shown by the curve in Figure 6.1a). Before that level is reached, land use is assumed to cause watershed disturbance but without significant environmental cost. However, once that disturbance threshold is reached, habitat quality declines quickly with even a small additional disturbance.

According to this model, managers should become concerned about habitat degradation only when some threshold disturbance level is approached. A management and restoration strategy based on Figure 6.la, then, would attempt to prevent the level of disturbance from reaching the threshold. This curve's shape also implies that, should the threshold level be exceeded, limited and focused restoration could quickly push watershed conditions back into the "good" habitat range.

A very different management approach is required if habitat quality degrades faster during the initial disturbance stages than during later stages, as shown by the curve in Figure 6.1b. In this case, protection becomes important from the first disturbance. This implies that any remaining good habitat is a valuable and fragile resource. Further, it implies that degraded habitat requires substantial work before recovery occurs. Highly disturbed areas require disproportionately more effort for an incremental habitat improvement than less-disturbed areas. Under this model (Figure 6.1b), for a given funding level it is better to focus on protecting or improving the best remaining habitat and allowing natural long-term processes to heal the most damaged areas.

Given the broad response range between the curves in Figures 6.1a and b, it is important to determine the correct response model when designing a restoration strategy.

Reeves et al. (1995) provided an excellent example of management strategies to maintain and restore freshwater habitat for anadromous salmonids in the Pacific Northwest. These strategies are based on designing a new disturbance regime around human activities. (Disturbance regime refers to the characteristics of a disturbance-timing, duration, and intensity.) The purpose is to create and maintain habitat conditions within and between watersheds that mimic conditions produced during natural cycles of disturbance and recovery.

Judging which model is correct for a given situation has important implications, not only for managing commodity outputs but for formulating an appropriate restoration strategy.

PRIORITIES FOR RESTORATION

Both models in Figure 6.1 assume some level of disturbance beyond which incremental restoration becomes ineffective. This might seem to dictate restoration priorities, but other realities include:

- A social imperative operates in our society to identify and concentrate restoration on the worst cases, regardless of their amenability to recovery. This is evident in legislation such as the Comprehensive Environmental Response, Compensation, and Liability Act (commonly called Superfund), which targets precisely those areas that often have the lowest probability of success in restoring the land to “satisfactory” condition.
- The public generally demands quick results, despite the fact that ecological recovery may require decades, if not centuries.
- Given limited financial and human resources, the incremental success (“bang for the buck”) is usually greatest when a given expenditure is applied to preventing potential problems, rather than to fixing existing problems.
- A strategy of repairing many small problems before they become large problems is more effective than attempting to repair a single huge problem.

In the U.S. Bureau of Land Management’s Proper Functioning Condition assessment for riparian areas, neither the best nor the worst areas receive the highest priority for restoration. The highest priority is assigned to those areas that are on a declining trend and are nearing some assumed threshold of loss of ecological function (Prichard et al. 1993).

Recalling the FEMAT four-component Aquatic Conservation Strategy (riparian reserves, key watersheds, watershed analysis, restoration), an oft-expressed approach is to “protect the best, restore the rest.” The first two components, riparian reserves and key watersheds, fall under “protect the best.” The fourth component, restoration, falls under “restore the rest." The third component, watershed analysis, bridges the “best” and “rest” by identifying the issues, displaying their linkages, and considering alternative solutions. For example, the watershed analysis might identify upslope restoration as the most effective way to protect the best remaining aquatic habitat by fixing potential problems at the source before channel disturbance actually occurs.

The FEMAT (1993) report identified eight guidelines to assist in developing restoration strategies or in choosing among potential projects. The strategy or project should

1. begin with a watershed analysis;
2. provide a broad range of benefits to riparian and aquatic ecosystems;
3. address the causes of degradation, rather than the symptoms;
4. have a well-defined project life span and understanding of expected benefits over time;
5. be self-sustaining once completed, requiring minimum maintenance or operation;
   contribute to restoring historical composition, biodiversity, and disturbance regime;
7. link refugia and other isolated habitat units; and
8. integrate watershed protection, including adjustment or cessation of management practices that are responsible for degraded habitat.

WATERSHED ANALYSIS AND MULTIPLE VIEWPOINTS

The Regional Interagency Executive Committee (1995a) offered the following definition of watershed analysis:

> Watershed analysis is a procedure used to characterize the human, aquatic, riparian, and terrestrial features, conditions, processes, and interactions within a watershed. It provides a systematic way to understand and organize ecosystem information. In so doing, watershed analysis enhances our ability to estimate direct, indirect, and cumulative effects of our management activities and guide the general type, location, and sequence of appropriate management activities within a watershed. As one of the principal analyses for implementing the Aquatic Conservation Strategy ... it provides the watershed context for fishery protection, restoration, and enhancement efforts. Federal agencies are conducting watershed analyses to shift their focus from species and sites to the ecosystems that support them in order to understand the consequences of actions *before* implementation. Analysis teams identify and describe ecological processes of greatest concern, establish how well or poorly those processes are functioning, and determine the conditions under which management activities, including restoration, should and should not take place. Watershed analysis is not a decision making process. Rather it is a *stage-setting* process. The results of watershed analysis establish the context

ANALYSIS SCALES

REGIONAL
Multi-state

RIVER BASIN
1,000s of square miles

WATERSHED
20 - 200 square miles

PROJECT
<1 square mile

FIGURE 6.2.-Hierarchy of four scales to establish the need for and context of restoration.

for subsequent decision making processes, including planning, project development, and regulatory compliance.

Watershed analysis originated from a recognition that planning directed at single issues by individual agencies does not work. For example, a single-issue management plan to harvest timber may meet the silvicultural and economic objectives of one landowner, but that plan may not adequately consider the effect of that activity on other owners, values, or activities within the watershed (such as spotted owls, fish, erosion, fire hazard, or restoration).

Similarly, a single-issue conservation plan protecting spotted owls also needs to incorporate plans for conserving fish, reducing fire hazard, controlling erosion, restoring and maintaining roads, and maintaining forest commodity production (timber, recreation, water, hunting, etc.). A timber program that requires substantial investment in restoration, and continued maintenance may not be cost-effective or ecologically effective, either in the short term or the long term.

For these reasons, the FEMAT report identified four analysis scales needed to establish the context of a plan (Figure 6.2): specific site prescription (less than 1 square mile), watershed (20 to 200 square miles), river basin (1,000s of square miles), and region (multiple river basins).

Watershed analysis simply identifies conflicting values and expectations and the social, biological, and physical processes that are important when viewed at the watershed scale (roughly an area of 20 to 200 square miles). This size of watershed is small enough to provide a useful level of precision, while being large enough to exhibit many of the interactions important to environmental issues. How to accomplish a watershed analysis has been described in procedural guides for private and public lands in Washington State (Washington Forest

TABLE 6.1. -Steps for conducting federal watershed analysis in the Pacific Northwest. (Regional Interagency Executive Committee 1995a.)

Step	Purpose	Information resources
1 Characterization	Identify dominant physical, biological, and human processes affecting watershed function; provide context to larger-scale processes	Existing maps, planning documents, literature
2 Key issues and questions	Focus analysis on key elements most relevant to managing the watershed	Existing basin plans, results of public meetings, interviews
3 Current conditions	Evaluate physical, biological, and human elements affecting key issues in the watershed	Existing reports, surveys, inventories, maps; narratives and anecdotal information
4 Changes that have occurred	Identify the rate and kinds of change occurring in watershed over time	Historical information, knowledge of basic ecosystem processes
5 Interpretation	Compare current and reference conditions to explain how and why key elements in watershed have changed over time	Evaluation of information obtained during previous steps
6 Recommendations	Determine efficacy of alternative practices to manage key elements and issues in watershed	Information from previous steps and objectives of the public and watershed managers

Practices Board 1993) and federal lands in the Pacific Northwest (Regional Interagency Executive Committee 1995a, 1995b).

The federal guide describes six steps for conducting watershed analysis in the Pacific Northwest: (1) characterize the watershed, (2) identify key issues and questions, (3) describe current conditions, (4) describe changes that have occurred, (5) interpret how and why they happened, and (6) recommend how the watershed's condition might change with alternative activities in the watershed. These steps are summarized in Table 6.1.

Those conducting a watershed analysis can become overly concerned with procedure and thereby distracted from the objective of the analysis. The principal objective of any watershed analysis is simply to expand the way we think about issues and their interactions. We need to consider the effect of multiple projects and activities of all landowners and managers within the watershed and river basin. We need to consider the overlapping, often contradictory objectives of individuals and multiple agencies at the private, local, state, and federal levels, including landowners, land managers, regulatory agencies, economic development agencies, and social agencies.

We need to involve the views of multiple disciplines when we evaluate an issue. In the past, "interdisciplinary" analysis typically has meant presenting a particular problem to a representative of each "appropriate" discipline, expecting each to comment from that discipline's perspective. But a better approach is for each discipline to be intimately represented as part of development, planning, and implementation from beginning through completion. These representatives should not be consultants but active team members with a stake in the outcome.

Often, nontraditional disciplines have been excluded because they were presumed to be noncontributing or threatened to confuse the issue by introducing irrelevant concerns. For example, a stream restoration team might traditionally include a fisheries biologist, hydrologist, geologist, and possibly a forester, but not a sociologist, economist, or terrestrial biologist. Serious consideration of these "irrelevant" concerns is precisely what is needed to avert failure of restoration projects designed with the tunnel vision of focused “action” groups.

SPATIAL SCALE

Just as it is a mistake to plan restoration in isolation, without knowledge of other projects in the vicinity, it is a mistake for watershed analysis to be concerned only with a single watershed. In part, watershed analysis is a scoping exercise to identify ecosystem processes and needs, including restoration, at the intermediate watershed scale, and to place these within the broader context of the larger river basin and regional settings.

The FEMAT strategy contains a hierarchy of four geographic scales: regional, river basin, watershed, and site (Figure 6.2).

1. Regional-the regional scale is used to evaluate how resources can be targeted to best influence values or concerns throughout a large multistate region. It is at this scale that an interconnected regional network of habitat protection might be established, based on regionwide habitat conditions or availability of refugia.
2. River basin-river basins within the region can be ranked by importance, based on opportunities and ability to contribute to meeting specific restoration objectives.
3. Watershed-within river basins targeted for restoration, individual watersheds can be further ranked by importance to identify the most effective placement of resources to accomplish restoration objectives.
4. Site-within the selected watersheds, individual sites can be identified and specific projects designed that will be most effective in accomplishing the objectives identified at the other three scales.

Using this hierarchy of scales, we can ask questions: What issues does the restoration attempt to correct? How large a program is necessary to significantly improve the situation? Which owners and agencies need to be involved? Where are the priorities of places that require restoration? What processes must be corrected to accomplish the objectives?

Traditionally, restoration has been tactical rather than strategic in nature. Much restoration has been small-scale and site specific, done for individual projects covering areas smaller than a few acres. Increasing concern exists about off-site problems that affect restoration and about the restoration’s impact on other on-site and off-site values. Historically, off-site issues have been considered only in the immediate vicinity of the restoration, such as individual pools or lengths of streams that drain small upland watersheds. But it is becoming more apparent that to be successful, restoration must evaluate the effectiveness of a proposed project, not only within the context of small watersheds, but in the context of entire large river basins. For some restoration issues, such as restoring salmon runs, even an entire river basin is too small for establishing context. Consequently, a regional perspective is necessary, often covering multiple states.

It is at the larger scales that the efficacy of proposed restoration can be evaluated. For example, assume a problem of excessive sediment in a stream. The budget is sufficient to repair 20 culverts within a watershed to reduce the risk of failure and subsequent erosion of a stream crossing. But the watershed analysis suggests that 2,000 culverts have a comparable risk within the watershed. Further, 200,000 culverts exist within the river basin. One must question the efficacy of repairing just 20 culverts!

One also must ask whether the available resources could be better spent on an alternate program to reduce the sediment delivered to the stream. For example, for the same cost, one might reduce the diversion potential for the entire 2,000 culverts in the watershed by simple road engineering techniques, such as constructing dips in the road and grading the road surface to slope outward. This would prevent water from being diverted down the road in the event of culvert failure. Reducing the potential volume of erosion and sediment delivery to the stream network caused by diverted water from 2,000 culverts might be much more effective than preventing the failure of only 20 of the 2,000 culverts at risk.

In addition, the watershed analysis might reveal that, while culverts are being upgraded in one part of the watershed on one ownership, roads are being constructed in other portions of the watershed by other owners who are using the old inadequate design. In other words, the watershed analysis would suggest that this restoration is not accomplishing the overall objective of reducing culvert vulnerability or sediment input on a watershed scale. A river basin analysis, in turn, might reveal that restoration resources could be more effective in an entirely different watershed.

Identification of the appropriate scale is often ignored. Unfortunately, no single scale fits all issues. For example, the appropriate regional scale for restoration of anadromous fish extends throughout the Pacific Northwest and includes the land, the streams, and the ocean. In contrast, the entire range for a species of salamander may encompass only a small portion of a single river basin. Forcing any analysis to some standardized scale will be incorrect most of the time. The spatial scale must be appropriately tailored to the problem being considered.

TEMPORAL SCALE

Selecting an appropriate time scale upon which restoration is evaluated is as important as selecting the appropriate spatial scale. The time scale that is conventionally considered appropriate usually depends on the audience. A number of examples follow. Corporate decisions are often based on quarterly budget reports. Political decisions are driven by election cycles of 2, 4, or 6 years. A domestic water user might be concerned about changes in turbidity during a single storm. Changes in insect populations might be resolved at annual scales. Trends in anadromous fish populations might need a sequence of several cycles of 4 to 6 years. Silvicultural concerns traditionally operate in time frames of 50 to 100 years.

Geomorphic processes that determine the physical condition of streams operate at time scales from decades to several centuries. For example, coarse sediment introduced by placer mining into streams of the Sierra Nevada in California during the 1840s continues to enter the Sacramento River system 150 years later. In many cases, rare and unusual events like wildfire or flooding are the principal mechanisms that set the physical or ecological structure of an area for decades.

Consequently, planning of any restoration must consider the appropriate time scale upon which natural systems operate. If projects are designed using inappropriate time scales, at best the restoration will be ineffective, and at worst it may produce additional degradation of the very resource it was intended to repair.

CASE STUDY: REDWOOD CREEK

A specific example to illustrate some of these points is Redwood Creek in northwestern California. Redwood Creek drains a basin of 285 square miles and flows into the Pacific Ocean near Orick, California (Figure 6.3). In 1968, Redwood National Park was created to protect representative stands of old-growth coastal redwood. The park includes several groves that contain the world’s tallest trees. They grow along the lower stretches of Redwood Creek, on natural terraces formed of stream alluvium.

In 1964, 1972, and 1975, flooding, bank erosion, and deposition of coarse sediment in the main channel of Redwood Creek damaged these unique alluvial groves. Accumulating evidence strongly suggested that timber harvesting and associated road building on private lands within the Redwood Creek watershed were partially responsible for the flood damage (Harden et al. 1978).

Nationwide concern over the threat to park resources and particularly the long-term safety of the Tall Trees groves culminated in the transfer of an additional 48,000 acres in the lower portion (northern end) of Redwood Creek basin from private ownership to an expanded Redwood National Park. Presently, the lower 40% of the watershed is within Redwood National and State Parks, whereas the upper 60% remains mostly in private ownership (Figure 6.3).

Because the land was purchased as a legal “taking” from private owners and given protection under national park status, this action implied that land management by the previous owners was abusive. Thus it became both technically and politically necessary to restore that abused land to protect the Tall Trees groves and other park values.

The accuracy of the abuse implication has aroused heated debate for several decades. Resolution is not simple because the geology of Redwood Creek is very unstable and numerous natural landslides throughout the basin were activated

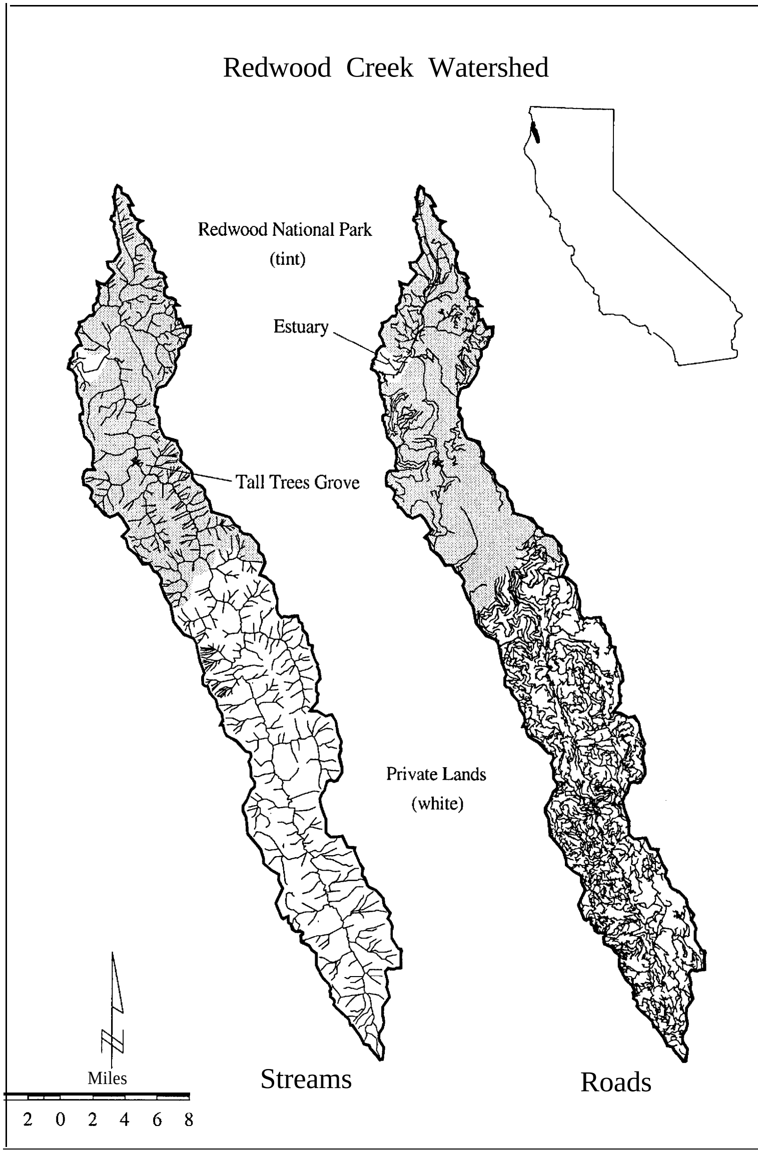

FIGURE 6.3.-Redwood Creek watershed. (Geographic information systems database provided by Redwood National Park.)

during the large floods in the 1960s and 1970s (Nolan et al. 1995). However, sufficient scientific evidence exists, both within the Redwood Creek watershed and elsewhere, to conclude that among land uses in mountainous terrain, roads are a primary cause of human-induced sedimentation (Kelsey et al. 1981; Hagans and Weaver 1987).

Extensive Road Network

The watershed's extensive road network (Figure 6.3) is the most important source of sediment delivery caused by humans to streams in the uplands. Roads modify the natural hillslope drainage and accelerate erosion. About one-third (400 miles) of the roads in the Redwood Creek watershed are on unstable bedrock, and about one-sixth (200 miles) are on soils that are particularly susceptible to landslides. In addition, common causes of accelerated erosion from the roads include unstable road fills, oversteepened road cuts, intercepted and rerouted surface and subsurface water, undersized and poorly placed culverts, and the diversion of streams at crossings.

A road survey in the Redwood Creek watershed revealed that about one-third of them either have been abandoned or are no longer maintained (V. Ozaki, Redwood National and State Parks, personal communication). Abandoned or unmaintained roads have been shown consistently to pose long-term problems. Such roads are increasingly likely to fail during large storms because road drainage features no longer function as designed and culverts deteriorate or become clogged with debris. This results either in failure of the road fill at the stream crossing or diversion of water from the stream channel and down the road to areas unaccustomed to increased water discharge.

The Redwood Creek watershed has experienced substantial land use over the past century. By the time the park was expanded in 1978, about 1,200 miles of roads (4.2 miles per square mile of watershed) and 5,400 miles of logging skid trails (18.9 miles per square mile) had been constructed within the watershed (Best 1984). In 1978, the road densities within and outside of the park were similar: about one-fourth (300 miles) of roads in the watershed were within the expanded park (D. L. Steensen and T. A. Spreiter, paper presented at the national meeting of the American Society for Surface Mining and Reclamation, 1992) and the remaining three-fourths (900 miles) were on private lands upstream of the park and the Tall Trees groves. Most of the road network present in 1978 was constructed before the introduction of modern forest practice regulations.

Further, because of the large size of the old-growth trees being tractor-logged, many skid trails are large enough to have a hydrologic effect similar to that of a road. However, these large skid trails were constructed without even the basic engineering design and drainage features that would be required for a road.

The federal legislation that expanded Redwood National Park included provisions not only to pay for the acquired land, timber, and other assets, but to establish programs for displaced workers and to initiate a major restoration of logged lands and roads within the park. Congress directed the restoration to focus on minimizing erosion from past land uses, reestablishing native vegetation, and protecting aquatic and riparian resources along park streams.

As of 1986, US$364 million had been paid to companies and individuals for their lands, timber, and other assets that were included in the expanded national park (Redwood National Park 1987). In addition, as of 1986 more than $100 million in economic development and employee assistance benefits had been paid to displaced forest product workers. As of 1991, Redwood National Park had expended about $10 million for watershed restoration. The total expenditure for adding 48,000 acres (about 26% of the Redwood Creek watershed) to the park is about $500 million.

Redwood National Park personnel are undisputed experts in road restoration. They have developed, tested, and applied road restoration techniques at a scale virtually unprecedented worldwide. Since the park was expanded in 1978, 134 miles of the 300 miles of road within park boundaries have been restored or obliterated. This work has removed about 1,300,000 cubic yards of material from stream crossings, landings, and unstable road benches. This volume approximately equals the long-term average annual sediment discharge near the mouth of Redwood Creek (A. T. Ringgold, Redwood National and State Parks, personal communication).

To evaluate the success of removing this volume of material, one must know (1) the delivery mechanism, (2) the timing, (3) the proportion of removed material that would have reached the channel without restoration, (4) the quantity of new material from erosion caused by the restoration itself, and (5) the proportion of treated and untreated areas having comparable risk in the basin. But by any measure, the U.S. National Park Service has been successful in restoring and obliterating a large portion of the unstable roads within the park.

Despite this effort, road mileage in the Redwood Creek watershed increased from 1,200 miles in 1978 to 1,266 miles in 1992 (D. W. Best, Redwood National and State Parks, personal communication). Between 1978 and 1992, 200 miles of road and 1,421 new stream crossings were constructed within the watershed above the park boundary for harvesting timber (Ozaki, personal communication). Even these figures underestimate the actual road construction in the basin during the 14-year period because they exclude roads that are exempt from a state Timber Harvest Plan, such as ranch roads, access roads for home construction, and other local access. These new roads more than offset the 134 miles of road restored or obliterated by the U.S. National Park Service.

Redwood National Park personnel recognize the need to deal with erosion sources outside the park boundaries. A watershed analysis of the Redwood Creek basin has been completed and a number of potential restoration opportunities have been identified. Unfortunately, restoration outside the park often is constrained by legislation and whether cooperation can be obtained from the upstream landowners. The past political battle that converted private land into national park property was heated and strikes at the heart of the private property rights debate. Any suggestion of additional measures by the federal government to control activities on the remaining private land in the watershed is politically risky.

Recently, however, the U.S. National Park Service and the U.S. Fish and Wildlife Service have made progress in implementing cooperative erosion control on private land in the upper Redwood Creek watershed. Funding for this cooperative restoration on private land is now roughly equivalent to that available for restoration within the park (Ringgold, personal communication).

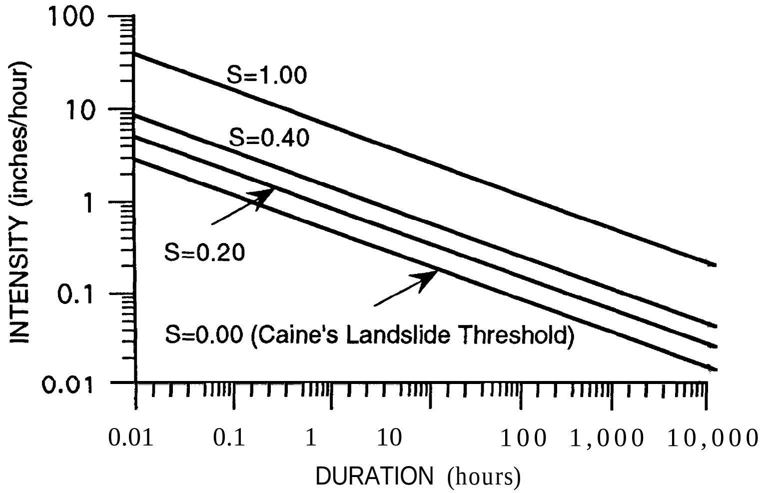

FIGURE 6.4. -Storm severity (S) as a function of the duration and intensity of rainfall. (Ziemer 1992).

Success or Failure?

Despite the unprecedented effort to acquire and restore land near the Tall Trees groves, there is yet no way to determine whether restoration is succeeding or failing. Such a determination can be made only following a major storm, because severe storms are a primary cause of erosion in steep forestland.

Caine (1980) presented a relation between rainfall intensity and duration that seems to describe a threshold for landslide occurrence worldwide (labeled curve in Figure 6.4). Rice et al. (1982) reasons that a good index of storm severity, and hence the probability of a landslide, might be how much larger a storm's intensity and duration are, relative to Caine's landslide threshold (Figure 6.4).

Amounts of erosion, sediment transport, and change in channel bed elevation depend on the timing and severity of storms (Figure 6.5). Most of the time the landscape and channel are recovering from the large rare events that produce nearly all of the erosion and channel changes. Consequently, before the success of restoration can be evaluated, the watershed must be subjected to a significant triggering event.

In a simulation, suppose a minimum storm severity of 0.25 were required to produce a triggering event to test a restoration program. That is, the size of the storm would be above Caine's (1980) landslide threshold (Figure 6.4). Only three storms (at years 44, 120, and 279) occurred during the 300-year simulation period (Figure 6.5). Between these three landslide-producing storms there were periods of 44, 76, and 159 years when there were no storms large enough to cause a landslide. Although Figure 6.5 is just a simulation, it demonstrates that only a few rare, large storms can be expected to test the effectiveness of restoration. A century or more may pass before the next large storm.

In the case of Redwood Creek, the 1964 storm produced massive hillslope

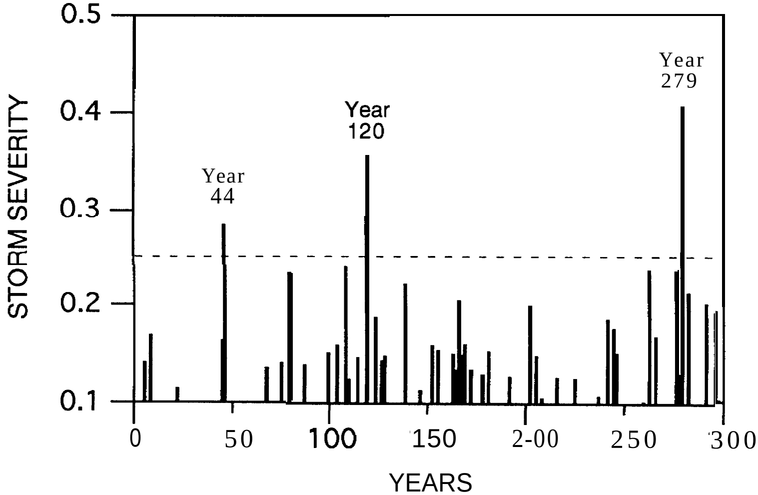

Figure 6.5.-Distribution of severe storms, based on measured rainfall duration and intensity in northwestern California during a single 300-year simulation (Ziemer 1992). Storm severity was calculated as a function of the duration and intensity of rainfall (Figure 6.4). The dotted line represents a storm severity of 0.25 (see text).

erosion and a large volume of coarse sediment was deposited in the channels of the upper and middle watershed. Landslides and other forms of erosion continue to deliver some coarse sediment to the channel each year. However, no significant storms have occurred for the past 20 years and sediment movement in Redwood Creek since the park was expanded and restoration began has been largely a redistribution of sediment deposited in 1964 (Madej 1984). The consequences of the next storm that equals or exceeds the 1964 storm in intensity will show the success or failure of the restoration program to protect the world's tallest trees.

CONCLUSIONS

The success of any restoration depends upon being able to identify a local concern, to objectively analyze the information, and then to design projects that effectively address concerns. This includes not only the local concern, but those at progressively larger spatial and temporal scales and complexity. It is at these larger scales that the efficacy of proposed local restoration can be evaluated. Each local restoration should be studied to determine whether the location, effort, and timing will produce a significant effect on larger-scale concerns. Without the larger-scale context, local restoration too often is of the wrong design and wrong size in the wrong location at the wrong time.

An excellent example of comprehensive restoration is the Aquatic Conservation Strategy in the FEMAT (1993) report. This strategy describes a process for analyzing problems across various scales (watershed analysis), identifies important portions of the landscape requiring protection (key watersheds and riparian reserves), and includes a component to improve degraded land (watershed restoration).

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