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USE OF WATERSHED AND STREAM RESEARCH IN THE CONIFEROUS BIOME FOR FOREST MANAGEMENT

Frederick J. Swanson

Research Associate, Dept. of Forest Engineering
Oregon State University, Corvallis, Oregon

and

James R. Sedell

Formerly Research Asst. Professor, Dept. of Fisheries and Wildlife
Oregon State University, Corvallis, Oregon
(Currently at Weyerhaeuser Company, Centralia, Washington)

INTRODUCTION

Understanding how nature has "managed" forest stands, streams, and watersheds has been central to Coniferous Forest Biome research. This historical, total-ecosystem understanding serves as a basis for evaluating impacts of management activities in relation to natural ecosystem perturbations and for setting guidelines for future practices that will least disrupt natural biological and physical processes and features land managers seek to maintain. While not precluding experimental research strategies, this natural history approach has been favored by the existence of large tracts of land in the Pacific Northwest where influences of European man are minor. For example, in the 6400-ha H. J. Andrews Experimental Forest--the principal site of Oregon-based Coniferous Forest Biome research--and adjacent areas of the Willamette National Forest, roughly half the landscape is covered with virgin forest. The tree-ring record there carries a history of more than 800 years of wildfire, erosional events, stream channel changes, and other processes which set the stage for the start of intensive forestry activities about 30 years ago.

Although the core of Coniferous Forest Biome work has been basic ecosystem understanding, studies relevant to management at both broad planning and site-specific project levels have been a major focus. Land managers need this understanding to assess the need to modify practices to better meet regulatory requirements, and to develop technical rationale to improve existing regulations.

Our paper emphasizes results of erosion and stream studies approached by both natural history and experimental research and discusses several management-related topics that exemplify the products of interdisciplinary research efforts.

EROSION STUDIES

Erosion Processes

Erosion studies in the Coniferous Forest Biome are designed to measure natural rates and patterns of soil and sediment movement (routing) through forest watersheds, to determine impacts of forest practices on this routing system, and to provide a basis for improving practices to mitigate impacts. Studies have addressed three scales: (1) process-level, in which specific erosion processes are monitored on small plots (surface erosion) or as individual geomorphic features (e.g., earthflow, slump); (2) small watershed-level, where process-level information is integrated to develop an overall picture of soil-sediment routing down hillslopes and into and through stream channels, and (3) extensive survey-level, in which key processes such as debris avalanches (shallow, rapid soil mass movements) and earthflows (slow, deep-seated earth movement) are mapped over areas of more than 10 km^2 and aged by dendrochronologic and other methods. Results of these studies have a variety of implications for forest land managers.

Process-level studies measure erosion rates in relation to principal driving factors such as precipitation. In a cooperative, ongoing Biome-U.S. Forest Service study, for example, a 20-ha earthflow, 6- to 10-m thick, in the H. J. Andrews Experimental Forest has been monitored for moisture input from precipitation and snowmelt, change in groundwater level, and earth movement (Swanson and Swanston 1977). By measuring hydrology-movement relations, we will estimate how reduced evapotranspiration due to clearcutting affects earthflow movement. If the effect is significant, this knowledge of hydrology-movement interaction will help land managers design roads and schedule clearcuts on earthflow terrain to diminish impact. Reconnaissance observations suggest that practices affecting water movement into and through earthflows can cause erosion problems, but by rolling road grades with topography and not disrupting drainage patterns (except perhaps to help channel water off an unstable area), management impacts can be minimized. Earthflow management is important in many areas of the Pacific Northwest, where earthflows cover more than 10% of the landscape (Swanson and Swanston 1977) and function as important contributors of sediment to channels.

When process-level erosion data are combined into a watershed-level budget, we can judge the relative importance of erosion processes affecting the landscape. This analysis shows a land manager on which erosion processes to concentrate to protect site productivity and water quality. But it is difficult to compare erosion processes because of tremendous variations in their characteristics. Some processes, such as transport of dissolved material in solution, are slow, pervasive, and continuous; others, like debris avalanches and torrents, occur suddenly and violently, though probably only once in several centuries in a small (< 10 ha), steep watershed. For instance, hillslope erosion has been studied in Watershed 10 (Table 1), a steep (average hillslope gradient = 60%), 10-ha, western Oregon watershed forested with old-growth Douglas-fir (Swanson et al. in press). This area was clearcut in summer 1975, and we are now compiling post-cut erosion budgets to quantify erosional response and recovery following logging.

Table 1.--Characteristics of hillslope processes that transfer organic and inorganic matter to the stream in old-growth Douglas-fir, Watershed 10, H. J. Andrews Experimental Forest, Oregon.

Process	Frequency	Area of slope influenced %	Delivery to stream T/yr
Solution	continuous	100	3.3
Litterfall	continuous seasonal	100	0.3
Surface erosion	continous	100	0.8
Creep	seasonal	100	1.1
Root throw	~1/yr[1]	0.1	0.2
Debris avalanche	~1/370 yr[1]	1-2	6.4
Slump/earthflow	seasonal[2]	5-8	0[2]

Source: Swanson et al. (in press).

[1]Area influenced by one event.

[2]Inactive in past century in Watershed 10.

Surprisingly, under forested conditions in the steep terrain of Watershed 10, the most infrequent processes--debris avalanche and debris torrent--produced the greatest sediment transfer, exceeding the more continuous, pervasive processes. Thus, investment in management techniques to reduce debris avalanche and torrent occurrence should more effectively maintain water quality and aquatic habitat than efforts to minimize rates of other erosion processes. We find that erosion "problems" may arise from small, identifiable portions of the landscape that are topographically and geologically distinct.

Soil-Sediment Routing

Soil and sediment movement have been emphasized, but the overall picture of soil-sediment routing through watersheds also involves storage within the system. Soil-sediment routing in a watershed can be viewed as processes transferring material from one storage compartment to another until it eventually leaves the watershed. Storage occurs in sites such as behind logs on land and in streams. Increase in sediment yield from a watershed may indicate increased soil erosion from hillslopes, or release of sediment from storage in the channel system.

In the past, interpretation of sediment yield data from small watershed studies has been largely based on a "black box" approach to watershed behavior, rather than on understanding internal dynamics. Standard practice has been to interpret sediment yield data in terms of change in hillslope erosion rates. On evaluating results of several experimental watershed studies from a routing perspective, we feel that change in sediment storage in stream channels, principally that associated with large organic debris, can be a major factor determining quantity and timing of sediment yield from undisturbed and perturbed watersheds over about a decade. Changes in channel storage during this period may make sediment yield from a manipulated watershed a substantial over- or underestimate of hillslope erosion. Thus, understanding sediment routing is essential to interpret results of watershed studies, which are often the sources of fragile impressions and semiquantitative data used to judge forest practices and set regulations.

Debris Avalanche Inventory

Extensive inventories of debris avalanches have been used to quantify the impact of management practices on debris avalanche erosion. In steep terrain this is a dominant erosion process whose scattered occurrence requires a broad landscape, long time scale analysis. Based on inventory studies in the debris avalanche-prone portion of the H. J. Andrews Experimental Forest, clearcuts have had a debris avalanche erosion rate about 2.8 times greater than forested land; debris avalanche erosion from road right-of-way has been 30 times the forest rate over the first 25 years of management (Swanson and Dyrness 1975). However, clearcutting and roading had negligible effects on debris avalanche occurrence in the portion of the forest with stable soils and bedrock. Levels of management impact in debris avalanche-prone areas were comparable to those observed in several other areas of the Pacific Northwest (Swanston and Swanson 1976).

Taken at face value, these results can be misleading in several respects. As is generally accepted, roads appear to be the overwhelming source of accelerated debris avalanche erosion. The smaller but significant impact of clearcuts, however, affects a much larger proportion of the landscape than roads. In a well-managed forest where yarding is predominantly by cable systems, road right-of-way may involve only about 6% of the landscape. Balancing low magnitude, large area impact of clearcuts against high magnitude, small area impact of roads, clearcuts and roads contributed about equally to accelerated debris avalanche erosion in the H. J. Andrews Forest (Swanson and Dyrness 1975).

Although measuring the relative importance of roads and clearcuts is complicated by several factors, we see that in steep terrain, clearcutting alone can have a significant impact on debris avalanche erosion--roads are not the sole source of problems. In fact, in the Mapleton Ranger District, Siuslaw National Forest, Oregon, a gradual switch appears to be in progress; clearcuts are increasingly important sites of debris avalanche erosion compared to roads, based on debris avalanche inventories spanning from about 1960 through 1978[1] (Ketcheson and Froehlich 1978, Greswell et al. in press). This transition probably results from: (1) reduced road failures due to improved location, design, construction, and maintenance, particularly during major storms, and (2) increased debris avalanches in clearcuts as higher proportions of unstable land are included in each year's cut. To reduce debris avalanches in clearcuts, the Forest Service is attempting to identify and avoid highly unstable sites, at least until development of logging methods that will not aggravate erosion problems. An effort is also under way to maintain soil-stabilizing, root networks in debris avalanche-prone headwall areas by not broadcast-burning residual brush and, in special cases, leaving some standing trees where blowdown potential is judged low.

Results of the debris avalanche inventory in the Mapleton Ranger District suggest a broader application of inventory as a tool for forest management. Inventories should be a self-supporting part of land management; cost of repairing several road washouts equals the cost of the inventory that could have identified problem sites and prescribed preventive measures. In many areas, particularly on National Forest land in the Northwest, expensive road construction methods, such as full benching and end hauling, are now being used; perhaps better placement and more frequent use of culverts could provide adequate but less costly erosion protection. The payoff in reduced erosion from these and other impact-reduction methods is unknown, but could be determined with an up-to-date debris avalanche inventory spanning several decades and a variety of road engineering systems. Such an inventory should play an important part in evaluating costs and benefits of new methods and identifying old methods currently creating problems worthy of correction.

Inventories may be based on study of air photos, field observations, and management records to develop a 20- to 30-year history of debris avalanche occurrence and management activity, but should be updated with each debris avalanche-triggering storm. Debris avalanche erosion rates can then be estimated for each hectare of clearcut or kilometer of road with a particular management history. Erosion impacts of various practices could be compared and evaluated. Some Coniferous

[1] F. J. Swanson, M. M. Swanson, and C. Woods. 1978. Inventory of mass erosion in the Mapleton Ranger District, Siuslaw National Forest. Unpub. Rep., 62 p. Siuslaw Nat. For., Corvallis, Oreg.

Biome and related studies are currently addressing methods of developing and analyzing debris avalanche inventories.

Subtle difficulties confound analysis of management impact on watershed ecosystems. One of the more important problems recognized in erosion studies arises from using a forested area as a "control" or reference point for assessing conditions in clearcuts or areas with other management histories. Under natural conditions, many severe disturbances of forest watershed ecosystems occur. Therefore, we must take a broader view of natural and managed systems, comparing frequencies and consequences of major distubances under both management and premanagement regimes. In recognition of this problem, we have begun to study fire hiscory in the central western Cascade Range, Oregon. Preliminary results have been intriguing (such as the very uneven-aged distribution of Douglas-fir in "even-aged" stands), but their implications for forest management have yet to be determined.

STREAM RESEARCH

Logging Effects on Fish

Aquatic studies in Coniferous Biome research have focused on complete understanding of how the stream ecosystem works--its patterns of nutrient cycling and storage (Triska et al. in press, a) and relationships between biota and physical environment of the stream (Swanson et al. 1976, Sedell and Triska 1977, Meehan et al. 1977, Triska et al. in press, b). Of greatest interest to forest land managers is impact of logging practices on fisheries and water quality.

Coniferous Forest Biome studies in moderate to high gradient Cascade Mountain streams have shown higher numbers and biomass of cutthroat trout in clearcut reaches than in forested sections immediately upstream (Aho 1977, Murphy 1978, Hall et al. in press). These results are based on both an intensive, four-year study on one stream (Mack Creek in the H. J. Andrews Experimental Forest) and an extensive, one-year study of nine paired clearcut-forest reaches on streams with drainage areas ranging from 0.4 to 17.1 km^2. Higher fish production in clearcut areas is thought to result from increased food resources due to stepped-up primary production occurring where the canopy has been opened (Lyford and Gregory 1975). Furthermore, these high gradient Cascade streams tend to be "sediment-poor"; sediment that does enter the stream due to accelerated inputs is probably moved quickly downstream through high gradient reaches. These food and habitat factors seem to combine to actually enhance fish production under certain stream environment and logging conditions.

In the longer term, however, the stand surrounding a stream develops and eventually closes its canopy over small streams. Consequently, aquatic primary production decreases and fish populations follow.[2] Depending on stream width and rate of regrowth, this process may take from five years to several decades. The canopy of vigorous, young second growth tends to be much denser than old-growth canopy cover. In sites studied, standing crop of cutthroat trout in streams under young stands is lower than in more open old-growth stands.[3]

Resident fish respond to changes in both food and habitat. Several research groups are currently trying to define the threshold at which poor habitat conditions override favorable food resources, resulting in decreased fish production. Except for channels scoured to bedrock, increased food resources in the first decade after logging appear to outweigh adverse changes in habitat of western Cascade streams. However, these results have two limitations: (1) in geomorphic provinces with abundant bedload and suspended sediment, fish populations may be more sensitive to habitat alteration; and (2) western Cascade studies have been limited to small- and intermediate-sized streams, and research on management impacts in larger river systems is needed.

Coniferous Biome research is defining relations between stream biota and physical environment, including changes in riparian vegetation 30 to 40 years following logging and 100 to 150 years following wildfire (Swanson and Lienkaemper 1978). Results of these studies will provide a clearer assessment of long term forest management impacts on aquatic resources in relation to past natural disturbances of forests and streams. Further knowledge of stream-forest relationships may lead to judicious thinning of the stream corridor for habitat enhancement and increased stream productivity.

Effects of Large Organic Debris

The sources, fates, and roles of large organic debris in small streams on forest lands have important implications for land

[2] M. L. Murphy, unpub. data, Oregon State Univ., 1978.

[3] Ibid.

managers. Forests adjacent to streams are the source of large debris (boles, root wads, large limbs). Erosion processes may contribute debris to streams and account for its downstream transport. Organic debris in streams increases diversity of aquatic habitat by forming pools and protected backwaters, serves as a source of nutrients and substrate for biological activity, and affects sediment movement and storage by dissipating energy of flowing water and trapping sediment.

For a variety of reasons, aquatic ecologists, hydrologists, and geomorphologists generally ignored the importance of large organic debris in streams until recently. We now realize that large organic debris has historically been an abundant and significant part of natural, forested streams. Recognition of its importance in streams in western states developed from a forest management perspective (Heede 1972, Froehlich 1973) and from an ecosystem perspective (Swanson et al. 1976, Sedell and Triska 1977, Meehan et al. 1977, Swanson and Lienkaemper 1978). Biome and related research on the biological effects of wood in streams has dealt with its role in nitrogen cycling (Triska et al. in press, b), support of invertebrate communities (Anderson et al. 1978, Anderson and Sedell in press), and fish habitat (Murphy 1978).

Good management of large debris is a key to good management of all aquatic resources in small- and intermediate-sized streams. Excessive cleanup of debris by hand and especially by sophisticated yarding systems is costly and may damage aquatic resources. Poor debris management may also result in damage to bridges and other structures by debris torrents (catastrophic flushing of steep, headwater streams) or floating logs carried by flood waters.

Forest practices may affect debris loading by a variety of immediate and delayed mechanisms (Swanson and Lienkaemper in press). Felling, bucking, and yarding operations may increase loading, while cleanup by hand or with yarding equipment may decrease it. Clearcutting and roading may also increase the potential for soil mass movements transporting large woody debris from hillslopes to channels; however, thinning or clearcutting a stream-adjacent stand reduces the source of large debris for streams. Intensive timber management would eliminate large woody "waste," in the long term depriving streams of natural levels of large debris input. Logging and roading may also alter downstream transport of organic debris by increasing potential for debris torrents and increasing debris mobility by removing large stable pieces.

Based on a few studies in western Oregon (Froehlich 1973) and southeast Alaska,[4] commonly employed logging systems (free falling, no buffer strip) may cause increased concentrations of large organic debris (> 10 cm diameter) in streams. However, Froehlich (1973) observed no increase in large debris loading at study sites where buffer strips or cable-assisted directional falling was used. Debris loading following logging may eventually give way to greatly reduced loading as in-stream material decomposes and washes downstream, and management of the surrounding timber stand precludes future production of additional large organic debris. A broad-scale reduction of large debris would effectively "channelize" small forest streams by reducing in-channel sediment storage (and, thus, area of aquatic habitat important to fish and other organisms), and by increasing the rate of sediment movement through the stream network. Reduction of large debris in streams is less significant where stable boulders provide channel control.

Suggested guidelines for management of stream debris during logging are to leave natural material, introduce no new material, and remove organic matter, particularly green needles and boughs in slow-flowing streams, that inadvertently enters the channel. These guidelines reflect the importance of debris in aquatic ecosystems and the expense of debris cleanup, but they stop short of addressing the long range problem of continued supplies of large debris for streams in managed stands. Maintaining natural levels of large debris loading in forest streams will probably best be accomplished by innovative management of buffer strips. Management of stream debris requires a flexible approach--while present concerns are for contributing too much debris to streams, future concerns may be about contributing too little.

FINAL COMMENTS

Coniferous Forest Biome studies have been aimed at developing basic understanding of the structure, composition, and function of the western conifer forest and stream ecosystem. Results are useful at both the project scale and broad planning levels of forest management, and in the education of future and practicing forest watershed managers. Results of Biome research suggest how erosion impacts from forest practices can be better assessed and more economically minimized, and how streamside vegetation and in-stream organic debris

[4] F. J. Swanson and G. W. Lienkaemper, unpub. data, Oregon State Univ., 1978.

might be managed for maintained or improved aquatic habitat and productivity. In general, we feel that increased understanding of watershed ecosystem behavior will lead to better overall forest land management and fewer wasteful regulations.

Management issues facing foresters in the Pacific Northwest focus on regulations set by Forestry Boards that prescribe "best management practices" and regulatory agencies that establish water quality standards. These regulations are designed to protect the quality and fishability of waters. Effective, environmentally and economically sound regulations should be based on results of actual field experiments and inventories of streams in natural "benchmark" areas.

Coniferous Biome research in the H. J. Andrews Experimental Forest provides one such baseline study for wild cutthroat trout and fish habitat. Additional studies in relatively undisturbed, low elevation watersheds of the Pacific Northwest are needed to determine natural variability of fish populations and habitat to judge management impact and set regulations.

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