Evaluating Sediment Production by Activities Related to Forest Uses — A Pacific Northwest Perspective

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Introduction

To deal with nonpoint sources of pollution, such as stream sediment produced by erosion from forest management operations, regulations require land managers to reduce onsite erosion to keep the amount of sediment discharged from each project area within acceptable limits. Activities developed to meet these regulations are sometimes referred to as best management practices (BMPs). BMPs are designed to reduce pollutant discharge from a single project but may not solve the larger problem concerning the cumulative effect of multiple projects. Land managers and regulatory agencies are increasingly required to address the cumulative effect of each proposed project within the context of all other projects within a specified area. To evaluate cumulative effects, using appropriate spatial and temporal scales is critical to analyze and evaluate physical and biological responses to interacting events or treatments that are separated in either time, space, or both.

Spatial Scale

Traditionally, impact analyses have concentrated on the onsite effects of land-management proposals. Onsite effects generally have scales that range from several square meters to several hectares. More recently, regulators and land managers have become increasingly concerned about offsite effects. Historically offsite effects have been considered to extend a relatively short distance from the immediate project — such as individual pools or individual stream reaches draining small upland watersheds, usually smaller than 100 ha. Managers are beginning to be required to evaluate the effect of a proposed project in the context of a drainage basin up to perhaps 20,000 ha. The size of the appropriate area of concern continues to expand. In some cases, land managers are now asked to evaluate effects of proposed projects within the context of entire drainage systems. An example is emerging concerns related to the influence of forestry operations, hydroelectric dams, agriculture, and other human activities on salmon production in the Columbia River Basin. Providing an answer to a question of such an enormous scale requires understanding land management's influence on survival of these anadromous salmonids from their hatching in the River's headwaters in Idaho and British Columbia, to their migration downstream through its estuary to the ocean, and finally, after several years in the ocean, their migration upriver to spawn. An analysis at this spatial scale is more demanding and comprehensive than simply evaluating onsite effects.

Temporal Scale

Similarly, impact analyses traditionally consider only short-term consequences of land management activities — usually several years at most. However, as with the spatial scale issue, temporal scale

effects have a wide range of appropriate scales that depend upon the question asked. For example, a domestic water user might be quite concerned about changes in turbidity during a single storm. Changes in insect production, which is in turn linked to fish growth, might be resolved using an annual scale. Changes that require a decade or more to become evident are, for example, filling of pools with sediment or reducing the large woody debris supply, which, in turn, causes the streambed to become unstable. Examples of changes that require a time period of about a century include failure of stream crossings designed to withstand the 50-year storm, aggradation of alluvial downstream reaches, and increased frequency of streamside landslides.

A specific example illustrates the long-term nature of some cumulative effects. In the 1840s, placer mining conducted in California's Sierra Nevada placed a large quantity of coarse-grained sediment in tributaries. Slugs of this material continue to enter the Sacramento River system 150 years later.

Interactions of Processes

Consequently, both environmental analyses and research programs must increase the size of the area of concern and the length of the time period of concern related to land management. In addition, the complexity of and interactions between issues must be emphasized. For example, integrating physical and biological consequences of land management actions is important. Simply regulating the quantity of increased sediment output related to land management will no longer suffice because that sediment's effect on riparian ecosystems must be better understood. The quantity of sediment doesn't often create the problem, but the amount of sediment within the context of channel morphology, historic sediment loads, and timing of that sediment relative to biological vulnerability do create problems. An organism's vulnerability to sediment loads is dependent not only on the species but also on the timing of the sediment relative to the organism's life cycle.

Value of Simulation Models

A serious problem with any evaluation or regulation of cumulative effects is that long-term cumulative effects cannot be measured within any meaningful timeframe. Increased measurement and monitoring at some point downstream from a proposed project is not an adequate strategy to evaluate long-term cumulative effects because, by the time a change is detected, projects that caused the change have often been contpleted — in some instances, several decades or perhaps even a century before. In such a case, no amount of onsite project mitigation could be effective. Consequently, the ability to predict the proposed project's consequences is necessary.

The cumulative effect of repeated timber harvests in a drainage could be estimated experimentally only in a study lasting several centuries. Even if an experimental approach was practical, study results would become available too late to take corrective action, which, by necessity, means that simulations must be used. But verifying model predictions is an imperative and inseparable simulation requirement.

A simulation approach is appropriate (apart from the time constraints previously mentioned) because of the forest ecosystem's complexity and uncertainty concerning the spectrum of environmental conditions that would prevail during a period spanning centuries. A Monte Carlo simulation permits explicit inclusion of variability estimates and uncertainty in a model. These properties are essential to characterize meteorological inputs and can be used to account for uncertainty in hydrologic and geomorphic parameters. For example, Monte Carlo simulations can evaluate ecological response to cltanges in hydrologic parameters forecast by global climate-change scenarios.

Paired-watershed experiments are frequently used to investigate effects of land use on hydrologic processes. Normally results of such experiments are assumed to be more "real" than those obtained from computer simulations, an assumption that should be scrutinized more carefully. To be sure, paired-watershed experiments record natural interplay of all relevant processes. They do so, however, at one location during a relatively short period. Furthermore, neither the location nor time period are chosen at random from populations they purport to represent. Therefore, statistical inferences of such studies apply only to study watersheds during study periods. All else is extrapolation based on professional judgment, not statistical inference.

A simulation has both strengths and weaknesses when compared to watershed experiments. Its greatest weaknesses are that a simulation is a simplification of nature and depends on the modeler's skill in programming natural processes accurately. A simulation's strength lies in the fact that it can represent mean conditions of the modeled area and explore the effect of a larger spectrum of possible sequences of events. Unlike a

watershed experiment, simulation results need not be distorted by the unique series of meteorological events occurring during the study — a particularly desirable property when considering long-range problems. Nonetheless, it must be remembered that simulation is a human artifact and that application of its findings to actual watershed problems is a professional judgment exercise. A simulation's main values are not to make numerically accurate evaluations of variables that quantify watershed behavior but to scale processes and variables in terms of their importance to integrated watershed behavior and reveal information gaps on linkages between watershed processes.

Responsiveness of Downstream Resources

A watershed model's core is the mobilization, transport, and storage of watershed products (water, sediment, organic material, and nutrients) because these products transmit watershed disturbance and are the independent variables that determine physical characteristics of stream channels and riparian areas. However, this top-down approach must be complimented by bottom--up evaluations of current adjustments of streams and their associated ecosystems to the present watershed regime and predictions of response to altered regimes. The top-down approach asks, "How will inputs to channels change?" Alternatively, the bottom-up approach asks, "How much change can channels take?" Without the latter, no way exists to evaluate the cost of predicted changes in production of watershed products to downstream resources or the risk associated with natural variability and uncertainty in modeled outputs. As stream-channel and riparian-area conditions worsen, less watershed disturbance becomes tolerable. The concept of "thresholds of concern" is widely used, but usually for hillslopes and tributary channels only. They should be extended far downstream in river systems because resources are potentially affected and based on future (as well as present) conditions.

Research Needs

At this time, some serious deficiencies prevent the successful modeling of erosion and sediment transport and their downstream effects in mountainous steeplands. Presently, researchers cannot accurately calculate the effect of sediment input and water flow on the rate of sediment accumulation and scour in channels. Further, researchers have a limited ability to assess results of interactions between processes. For example, changes in sediment input can alter channel morphology, which, in turn, may affect the rate of sediment input from bank erosion.

Sediment production from hillslopes can be measured and even predicted with some accuracy; however, when researchers try to predict its effect on channels downstream, they encounter a fundamental gap in knowledge: researchers do not know how to predict how quickly sediment will propagate downstream and how fast it will spread. Therefore, magnitude, timing, and duration of downstream changes in sediment transport cannot be predicted.

Further, knowledge of the linkages between sediment transport and biological response is exceedingly primitive. But, however rudimentary, enough is known about many environmental parameters, watershed processes, and consequent impacts to develop preliminary qualitative estimates of patterns and trends, but quantitative calculations of physical or biological responses are rarely possible.

For any model or evaluation procedure, independent verification is essential. First, individual modules must be tested by comparing predicted and measured values under a variety of field conditions at differing sites. Then, functioning of the entire model must be evaluated under a wide array of field conditions. Finding an adequate model verification program is rare; however, finding unverified model predictions for important management and policy decisions is common.

Conclusion

Although logging began in the coniferous forests of northwestern North America in the mid-1800s, intensive logging in much of the Pacific Northwest did not begin until the 1950s. Consequently, the present condition of most watersheds in northwestern North America represent only that of an initial entry or first crop rotation. In many cases, the trees' expected age at next cutting is about a century. Therefore, at least one century is required for treated watersheds to attain a "steady-state" condition.

With such long- response times, collecting contemporary field data to evaluate model predictions is difficult; however, without a long-term steady-state perspective, comparisons of environmental costs among alternative land management strategies will be incorrect. Monte Carlo methods

can be used effectively to identify critical gaps in knowledge that require additional research and data collection. For example, as a first approximation, rainfall threshold and storm severity can provide useful information when linked to other processes that the timber cutting to landslide occurrence, such as changes in root strength. However, the nature of the interaction between rainfall, vegetation, and landslides needs to be tested under local conditions for which the evaluation is intended.

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