KEYNOTE ADDRESS, THEME 3

New directions in assessing human impact on erosion in steep lands

F J Swanson

USDA Forest Service, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, Oregon, USA

INTRODUCTION

The issue of man's effects on erosion from steep lands has long been a concern from the standpoints of damage to downslope and downstream resources and reduced on-site productivity, be it forage, timber, or other commodities. Research to date has concentrated on measurement of on-site impacts primarily by studies of rates of individual erosion processes, changes in conditions on small plots, and sediment yield from small drainage basins. This session of the symposium provides excellent examples of each of these approaches to the problem of on-site effects of human activities. These types of studies of on-site erosion problems have been instrumental in improving land management practices, but land managers in the United States, at least, are increasingly asking questions which cannot be answered from results of traditional approaches to erosion research. As development has progressed in virgin forests on federal land, management concerns have shifted somewhat from short-term, site-specific to broader time and space dimensions. The issue of cumulative impacts in basins of a few thousand hectares and larger comes up repeatedly.

At the same time, geomorphologists have become increasingly interested in sediment routing and budget studies to advance basic understanding of geomorphic systems and to improve analysis of management impacts on sedimentation. Sediment routing here refers to the overall movement and storage of sediment (including soil) in drainage basins. A sediment budget is a quantitative statement of the input, output and change in storage of sediment in a landscape unit.

Earliest studies and recent work of this sort have centred on the basic problem of quantifying the relative importance of sediment transport processes in a drainage basin (Rapp, 1960; Leopold *et al.*, 1966; Caine, 1976; Kelsey, 1980; Lehre, 1980; Pickup *et al.*, 1981). Dietrich and Dunne (1978) extended this approach to geomorphic studies by considering the physical changes of material as it moves through a basin. A number of workers in New Zealand, United States, and elsewhere have been applying sediment routing and budget studies in assessment of management impacts on sedimentation (Pearce and O'Loughlin, 1978; Janda, 1978). Both basic and applied aspects of sediment budget and routing studies for forest environments were discussed at length at a workshop held at Corvallis, Oregon, USA, May 30-June 1, 1979. A proceedings volume containing 15 papers and six reports of discussion groups is being prepared for publication as a U.S. Forest Service General Technical Report.

Many of the ideas and rules for sediment budget and routing studies come from systems theory and its application in hydrology and nutrient cycling studies. Purposes of recent sediment budget studies range from the purely academic (Dietrich and Dunne, 1978) to quantification of effects of dispersed management practices on downstream channel conditions (Janda, 1970) to the role of geomorphic processes in nutrient cycling within steep land forest ecosystems (Swanson *et al.*, in press) and to predicting filling rate of reservoirs.

Sediment budgets and routing studies will be used increasingly to measure man's impact on erosion of steep lands, particularly where the more complex issues of long-term cumulative impacts over larger drainage basins are concerned. The following comments touch on some of the issues concerning sediment budget and routing studies and cumulative management impacts that we will be dealing with in the next decade.

SEDIMENT BUDGETS AND ROUTING

In a paper in preparation, W. Dietrich, T. Dunne, and colleagues at the University of Washington define the ingredients in a sediment budget: (1) rate of movement of material from one temporary storage site to another, (2) volume and residence time of material in each storage site, (3) linkages among transfer processes and storage sites, and (4) change of material due to weathering, abrasion, and other processes as they move through the system. An essential but commonly neglected factor is storage; geomorphologists have emphasized measurement of erosion processes. Pearce and O'Loughlin (1978) and others argue that changes in sediment storage, particularly in channels, may be a major source of accelerated sedimentation due to management activities. A first impression is often that increased sediment yield is caused by accelerated hillslope erosion. Megahan and Nowlin (1976) and others, however, observe that sediment stored even in second- and third-order drainages greatly exceeds average annual export. Consequently, modest changes in sediment storage may account for substantial fluctuation of sediment yield from a basin with no change in hillslope erosion. From a management standpoint, it is important to pinpoint sediment sources in order to better estimate their persistence and to apply mitigative measures effectively and efficiently.

Measurement of change in volume of sediment stored in key sites should be an integral part of studies of management impacts on erosion and sediment yield. Sets of repeatedly resurveyed channel cross-sections are used for channel storage. Change in other, more slowly varying storage sites, such as the "hollows", or sites where debris slides are initiated, described by Dietrich and Dunn (1978) may require use of techniques such as dendrochronology.

Analysis of sediment routing and budgets offers a useful approach to quantifying the magnitude, persistence, and specific cause(s) of accelerated erosion. Better understanding of the storage component of a sediment routing system is an essential but often neglected part of this analysis.

CUMULATIVE IMPACTS

The phrase "cumulative impacts" is used in the United States to refer to the aggregate, downstream effects of numerous localized management activities, such as road building and clearcutting, in drainage basins of several thousand hectares and larger. These effects may occur as increased flooding or aggradation, widening, and general instability of river channels.

Although cumulative impacts and the possibility of scheduling management activities such as timber harvest to mitigate them have been discussed widely in the past few years, opinions about their occurrence are highly varied. Cumulative impacts seem to be most conspicuous along channels with mobile bed and banks in highly erosive landscapes where vegetation and even soil have been rapidly and dramatically altered over large blocks of land. The existence of cumulative impacts in channels with lower sediment loads and substantial bedrock control in areas of more moderate intensities of management is debated.

This debate raises a series of questions that should be addressed on technical grounds from a sediment routing perspective:

—Are there cumulative effects of numerous localized on-site impacts?

—If so, what are the causal links between on-site and off-site impacts, e.g., increased peak flows due to compaction or altered snow accumulation patterns and/or melt rate?

—Are some areas sensitive to cumulative impacts and others insensitive?

—Based on knowledge of links between on- and off-site effects and basin sensitivity, is it technically feasible to mitigate cumulative impacts by changing the type, timing, or geographic distribution of management activities?

—If it is technically feasible, is it socially and legally possible to mitigate cumulative impacts?

Our ability to answer the first four of these questions hinges on understanding overall routing of sediment through drainage basins, and this understanding is meagre. Research has not squarely addressed the problem of measuring and predicting cumulative effects of many individually quantifiable, on-site impacts, choosing instead to concentrate on the tidier problems of individual erosion processes and sediment yield from small drainage basins.

LONG TERM FLUCTUATIONS IN EROSION AND SEDIMENT YIELD

Judging cumulative impacts of management activities is further complicated by our poor understanding of natural major fluctuations of sediment movement through drainage basins. A related problem is finding a realistic point of reference for judging management impacts. In the Pacific Northwest of the United States, for example, we commonly use the stable, forested condition as the site for "control" conditions, and yet most of these ecosystems and landscapes have been subjected to intense, wide-spread wildfire with a return period of one or more centuries. A measure of natural erosion, therefore, should include periods of accelerated erosion following natural disturbance of the drainage basin.

An important part of judging long-term management impacts should include comparing natural and man-imposed disturbance and the associated frequencies, magnitudes, and durations of periods of accelerated erosion. This raises interesting problems along the coast of Oregon and Washington, for example, where individual major wildfires burned areas in excess of 1000 km^2. How does the effect of these widespread wildfires on fisheries compare with the more chronic impacts of sustained yield, even-flow logging, and associated roads and fire suppression?

Should we attempt to practice a form of sustained yield, even flow of sediment just as some of our timber manager colleagues are attempting to do with the forest resource? What are the sedimentological, geomorphic, and aquatic biological consequences of altering the regime of an ecosystem?

SUMMARY

In this discussion, I have raised several issues of growing importance concerning human impact on erosion and sediment yield from steep lands. The issue of cumulative impact will be raised increasingly by land managers over the next decade. This and other management problems can be best addressed from an understanding of the overall movement and storage of sediment in drainage basins. Basic understanding of geomorphic systems will also be advanced by more analysis of sediment budgets and routing.

REFERENCES

Caine, N. 1976: A uniform measure of subaerial erosion. *Geological Society of America Bulletin 87:*137-140.

Dietrich, W. E.; Dunne, T. 1978: Sediment budget for a small catchment in mountainous terrain. Zeit. für Geomorph. Suppl. 29, p191-206.

Janda, R. J. 1978: Summary of watershed conditions in the vicinity of Redwood National Park, Calif. *US Geological Survey, Open-File Report 78-25,* 82 p.

Kelsey, H. M. 1977: Landsliding, channel changes, sediment yield and land use in the Van Duzen River basin, North Coastal California, 1941-1975. *Ph.D. Thesis, University of California, Santa Cruz.* 370 p.

Lehre, A. 1980: Sediment mobilization and production from a small Coast Range catchment: Lone Tree Creek, Marin Co., California. *Ph.D. thesis, University of California, Berkeley.*

Leopold, L. B.; Emmett, W. W.; Myrick, R. M. 1966: Channel and hillslope processes in a semiarid area, New Mexico. *US Geological Survey Professional Paper 352-G,* p 193-253.

Megahan, W. F.; Nowlin, R. A. 1976: Sediment storage in channels draining small forested watersheds in the mountains of central Idaho. In *Proceeding, Third Federal Interagency Sedimentation Conference (Denver, Colorado),* p 4-115—4-126.

Pearce, A. J. O'Loughlin, C. L. 1978: Hydrologic and geomorphic processes on forested lands—a selected overview. In *Erosion assessment and control in New Zealand* (Conference Proceedings. New Zealand Association of Soil Conservators, August 1978). p62-76.

Pickup, G.; Higgins, R. J.; Warner, R. F. 1981: Erosion and sediment yield in Fly River drainage basins, Papua-New Guinea. In *Erosion and sediment transport in Pacific Rim steeplands* (Proc. of Christchurch, NZ Symp., January 1981), IAHS Publ. No. 132: p 438-456.

Rapp, A. 1960: Recent development of mountain slopes in Karkevagge and surroundings northern Scandinavia. *Geografiska Annaler 42:*71-200.

Swanson, F. J.; Fredriksen, R. L.; McCorison, F. M. (In press) Material transfer in a western Oregon forested watershed. In *The natural behaviour and response to stress of western coniferous forests.* (edited by R. L. Edmonds). Dowden, Hutchinson and Ross Inc., Stroudsburg, Pa.