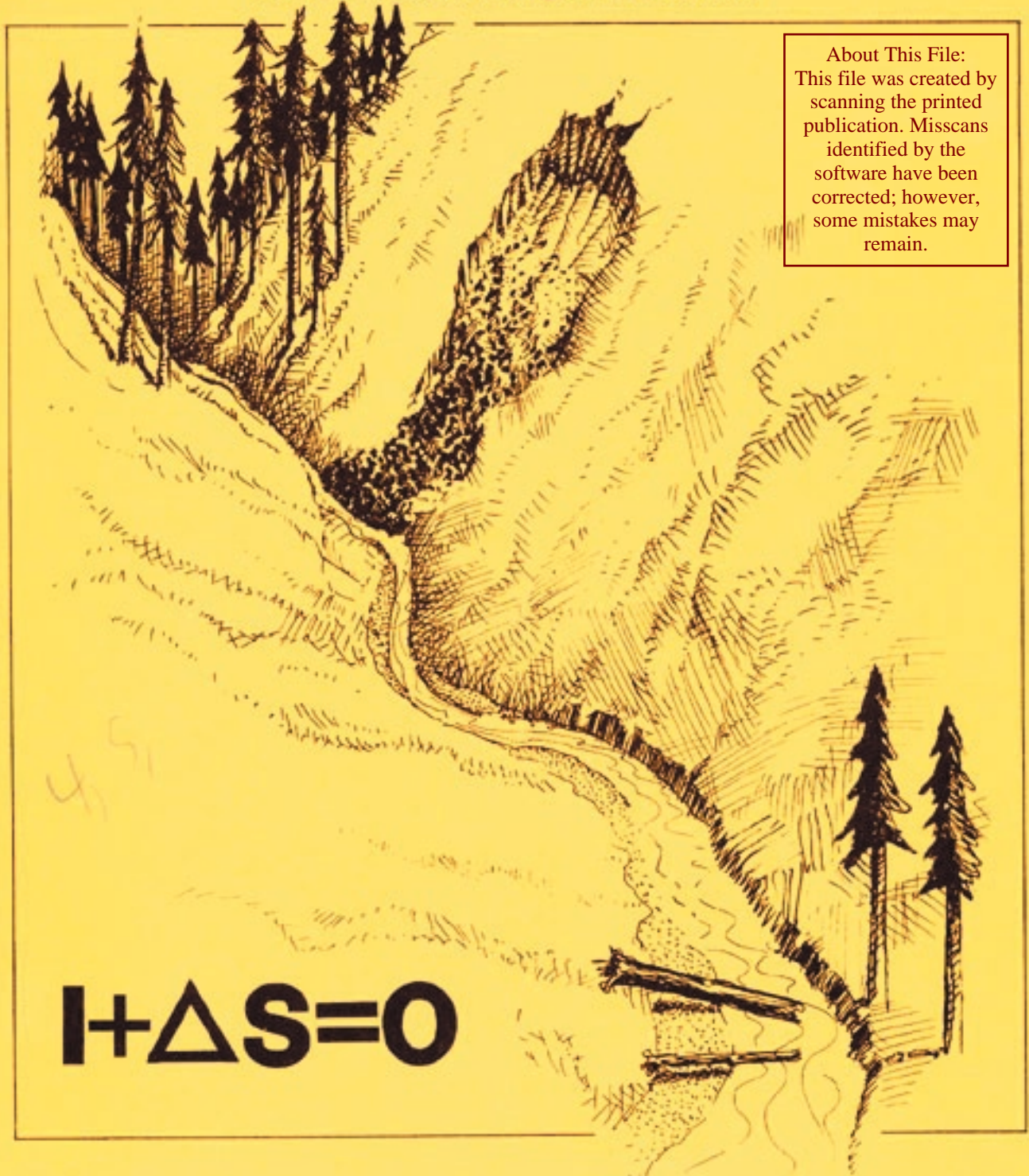# Sediment Budgets and Routing in Forested Drainage Basins

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Summary: Sediment Budget and Routing Studies

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ABSTRACT

Sediment budget and routing studies have been useful in dealing with a variety of basic and applied problems over a wide range of scales in time and space. Further research and application is needed to: define and quantify sediment storage; improve knowledge of mechanisms of sediment-transport processes; quantify frequency and magnitude of episodic processes; integrate biological factors into quantitative analysis of sediment budgets and routing; improve knowledge of effects of weathering on sediment routing; and mesh better the computer simulation of sediment routing with field studies of conditions in forested mountain land.

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INTRODUCTION

Studies of sediment budgets and routing have increased understanding of a broad spectrum of geomorphic and ecological problems (Jackli 1957; Rapp 1960; Leopold et al. 1966; Caine 1976; Dietrich and Dunne 1978; Kelsey 1980; Swanson et al., 1982). By sediment budget, we mean the quantitative description of sediment movement through a single landscape unit; sediment routing, is either the computation of sediment movement through a series of units or the more qualitative concepts of sediment movement through a drainage basin. Much early work centered on computing total denudation and assessing the relative importance of individual erosion processes. Other workers have applied sediment budget studies to practical problems associated with the effects of human activities on geomorphic processes and associated landform changes (Kelsey 1980, Reid 1981). Applications of sediment budget and routing analysis in Redwood Creek basin (California) (Kelsey et al. 1981), areas near Mount St. Helens (Washington), and elsewhere deal with a variety of management-related issues, including the persistence of high rates of sediment transport.

The basic ingredients of complete budgets are: identification of storage sites, transport processes, and linkages among them, and the quantification of storage volumes and rates of transport processes. Despite these common elements, papers on sediment budgets published here and elsewhere display marked differences in the time scales considered and the relative emphasis placed on storage and transfer processes. These differences reflect contrasts in objectives and site-specific conditions such as vegetation, land-use history, and dominant erosion process. Of particular concern at this workshop were the distinctive effects of forest vegetation on sediment storage and transport.

Although the utility of sediment budgets has been amply demonstrated, they continue to be little used. Increased application of the sediment-budget studies, even where data are seriously limited, would increase understanding of geomorphic and ecological systems--this volume was compiled to encourage such increased use. Here, we summarize some advantages of the sediment-budget approach over studies focused on individual processes or on sediment-yield data alone, six major themes that recur throughout the papers and workshop discussions, and new and continuing research needs.

RATIONALE FOR MAKING SEDIMENT BUDGET AND ROUTING STUDIES

Enthusiasm and need for quantification of erosion and sediment transport have led to many field measurements and computer simulation models of sediment production on hillslopes and along streams. Monitoring of drainage-basin sediment yield provides an integrated, "black box" view of how sediment output from basins responds to average conditions, fluctuations in weather, and management and other disturbances. Monitoring of hillslope erosion can provide more detailed information on processes than can measur-

ing basin sediment yield alone. This approach, however, has often been weakened by lack of attention to sampling problems and by uncertainties of how particular mechanisms fit into the sequence of processes that transport sediment out of a drainage basin. Measurement of both sediment yield and rates of processes offers little information on the role of temporary storage or the linkage between transport processes.

Some of these problems are reduced by drawing up a conceptual sediment budget or sediment-routing scheme early in the investigation of sediment movement. This requires explicit recognition of how sediment is generated, transferred, and modified during its passage through drainage basins. The initial conceptual model may be only qualitative or approximately quantitative, but it must be based on field work. Dietrich and Dunne (1978), Dietrich et al. (this volume), Lehre (this volume), and Kelsey (this volume) have all stressed the need for careful classification of transport processes and storage sites in the landscape under investigation. This preliminary analysis draws attention to the most important processes and aids the design of appropriate measurement strategies. No single approach to the definition of a sediment budget or routing scheme exists because of the variety of processes, materials, and disturbing factors even in the restricted setting of drainage basins covered by temperate forests.

Field observations of sediment transfer and storage also suggest how the accounting of sediment can be carried out. The investigator is forced to consider how sediment moves between sites and whether errors can result from adding together contributions of sediment to a channel by processes that act in series. An example occurs where soil creep merely supplies sediment to sites of landsliding which then conveys it to a channel. Dietrich and Dunne (1978) have pointed out that adding these two inputs would be double accounting and would overestimate the sediment flux to the channel.

Processes should be classified to help define the temporal and spatial requirements of a sampling scheme. Do the processes operate over extensive areas or in a limited number of restricted sites? Which processes operate persistently and which are episodic? Whether a process is viewed as persistent or episodic in part reflects the time reference of the budget. Most geomorphic measurements have been carried out over too short a time and at too few sites for adequate definition of long-term average sediment yields, their sources, controls, and response to disturbance. Field work necessary for construction of a sediment budget or routing scheme focuses attention on the need for spatial stratification of measurement sites and for lengthening the period of record by means of dendrochronological and other techniques (Brown and Brubaker, this volume).

A sediment budget or routing procedure and attendant assumptions may apply. to a particular time scale only. The procedure of Dietrich and Dunne (1978), for example, is founded in the long-term view of sedimentary petrology and steady-state geomorphology. The steady-state assump-

Table 1—Channel storage in relation to mean annual sediment discharge. Definition of channel storage varies from study to study, but generally includes readily mobilizable material. Note that (storage/annual discharge) is a measure of residence time of sediment in storage in years

Stream (author)	Drainage area	Storage	Annual sediment discharge	Storage − annual discharge
	Square kilometers			
Watershed 10, OR (Swanson et al., 1982)	0.10	510 t (subject to debris torrent)	6.6 t Total particulate transport including episodic debris torrents	77
Average of seven streams in Idaho batholith (Megahan, this volume)	1.27	171 m^3 "behind obstructions"	11 m^3 debris basin accumulation	15
Rock Creek, OR (Dietrich and Dunne 1978) First-order tributaries Third-order tributaries Main channel, active sediment	16.2			[1]/19 yr [1]/231 yr [1]/619 yr
Big Beef Creek, WA (Madej, this volume)	38	49,200 t "active, to depth of scour"	1,000 t bedload	50
Redwood Creek, CA (M. A. Madej, Redwood National Park, personal communication)	720	7,200,000 main channel only	1,860,000 total sediment load	3.9
Otamarahu River, New Zealand (Mosley 1977, cited in Pearce and O'Loughlin 1978)				35-40

[1]/Residence time for particle entering channel of this order at midpoint of channel segment.

tion is invalid for other time scales, however. Nonsteady-state behavior occurs where significant change in storage takes place, whether as a result of human activities or major storms (which affect geomorphic systems on the scale of years and decades), climatic change (on the 10^3 year scale), or drainage development (on the scale of 10^3 years and longer). Swanson and Fredriksen (this volume), for example, stress the value of not assuming steady-state conditions when examining sediment routing on the time scale of vegetation disturbance and recovery.

The sediment budget and routing approach led Dietrich and Dunne (1978) to consider the relation of weathering to transport of soil entering channels and to grain-size distribution of sediments transported down stream channels. The grain-size distribution of stream sediments is important because it influences channel form, fish-spawning habitat, sorption of nutrients and other chemicals, and rates at which large, short-lived influxes of sediment can be flushed from a system.

MAJOR CONCLUSIONS AND RESEARCH NEEDS

Sediment Storage

Sediment storage is an essential but poorly understood part of the geomorphic system. Geomorphologists have traditionally emphasized transport processes. Storage of sediment, however, is an equally important aspect of long-term movement of material through drainage basins. Total stored sediment, duration of storage at various sites, changes in volume of material stored, and changes in the physical properties of materials while in storage have important implications in analysis of sediment routing.

Quantitative data on sediment storage in channels is meager, but more abundant than information on storage of material on hillslopes. Available quantitative studies of sediment storage in channels in forested areas (table 1) define and measure storage in different ways. Nonetheless, these data indicate that the volume of temporarily stored alluvium is commonly more than 10 times larger than the average annual export of total particulate sediment. Mean residence times are on the order

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of decades and centuries. Thus, moderate changes in storage can cause major changes in sediment yield even if sediment supply from hillslopes remains constant.

Rough estimates of mean residence time of soil on hillslopes are several orders of magnitude greater. For a soil loss rate of 100 t/km^2 per year (on the low side of typical rates for mountain land), the mean residence time of a 1-m soil profile is 10,000 years. This is somewhat less than the residence time of soil on hillslopes computed by Dietrich and Dunne (1978) and Kelsey (this volume) for very different terrains.

Changes in sediment storage can drastically affect interpretations of erosional conditions within a drainage basin based on sediment-yield data alone (Janda 1978). The timing and magnitude of erosion of soil and its ultimate delivery as sediment to a downstream point may be very different. Kelsey (1980), Trimble (1981), and others have demonstrated that storage in channels and flood plains may delay and subdue the peak of downstream delivery of sediment introduced from hillslope sources. Conversely, increased peak flows because of altered hillslope hydrology can result in increased erosion and downstream transport of stored sediment without increased hillslope erosion (Park 1977). Management impacts on hydrology or sediment availability can therefore have cumulative effects on sediment routing downstream, an issue of growing concern in many areas of forest-land management.

Residence time of sediment in storage determines the opportunity for stabilization by rooting of vegetation on the scale of years and decades and for changes in size distribution of material by weathering over centuries and millenia. Weathering of deposits in gravel bars, flood plains, and other storage sites facilitates breakdown of sediment, thus changing the relative importance of transport as dissolved, suspended, and bedload (Bradley 1970, Dietrich and Dunne 1978). Effects of weathering are particularly important in tectonically active areas, such as the Pacific Rim--much of which is underlain by mechanically weak rocks. On the time scale of significant weathering, geomorphologists can learn much through application of the techniques developed by Quaternary stratigraphers and sedimentologists (Birkeland 1974, Tonkin et al. 1981).

Erosion Processes—Mechanisms and Linkages

The mechanics of erosion processes and their controls are not well understood. These problems limit efforts to model movement of sediment through drainage basins. Several examples of these limitations sparked vigorous discussion at the workshop. One example is the widespread application of infinite slope assumptions to stability analysis of shallow debris slides, despite knowledge that many sites prone to debris sliding may not be well represented in hydrologic and other respects by infinite slope assumptions (Pierson 1980). This is true for "hollow" (Dietrich and Dunne 1978) and "swale" (Lehre, this volume) types of failure sites, which appear to be essentially the same and are hereafter referred to as hollow/swale sites.

Mechanics of surface-erosion processes in steep forest land in areas with low to moderate intensities of rainfall are also poorly understood, as evidenced by continued interest in applying to steeplands the Universal Soil Loss Equation (USLE) developed empirically by Wischmeier and Smith (1955) in lowland environments. The USLE was developed to estimate surface erosion by rainsplash and sheetwash on gradients of less than 20 percent. Overland flow is rare in forested landscapes. The surface-erosion processes that do operate, such as dry ravel and splash, may have very different relationships between transfer rate and slope length, rainfall characteristics, soil characteristics, and gradient than those described by the USLE.

Analysis of individual erosion processes in their overall geomorphic context is also critical. The rate or frequency of one process may be closely linked to the rates of other processes. Long-term erosion by debris slides, for example, may be limited by recharge of slide-prone hollow/swale sites by soil creep, root throw, and other processes. Thus measuring soil creep into hollow/swale sites would help in estimating rates of filling of slide-prone portions of the landscape. These data could then be used to judge effects of management practices on refilling rates as well as on initiation of debris slides. Similarly, progressive downslope movement of streamside earthflows may temporarily buttress the toe of the slope, impeding further movement. Subsequent stream erosion of the earthflow toe can remove support and accelerate movement, hence interpretations of earthflow movement rates should consider recent stream history.

Sediment transported as suspended load or bedload has been the subject of extensive, sophisticated analyses by hydraulic and civil engineers. Application of their equations in sediment-routing studies in steep forest lands is difficult, however, because sediment transport there is commonly limited by the rate of sediment supply from hillslopes, fans, and the streambed below an armor layer. These equations are not well suited for dealing with the coarse, poorly sorted sediment and large woody debris that forms the complex roughness elements typical of forested mountain streams. Channel form and pattern in these environments may be controlled by vegetation, bedrock, and hillslope mass movements rather than channel hydraulics and sediment properties that predominate in lowland streams.

Problems Posed by Episodic Processes

Many sediment-transport processes, such as creep and bedload transport in sand channels, are persistently active, although at widely varying rates. Debris slides and other processes are episodically active for only short periods. The distinction between persistent and episodic processes are muted in dealing with periods much longer than the time between episodes of activity. Geomorphologists have had a long-standing interest in the importance of episodic processes in longterm transfer of material and landscape sculpture (e.g., Wolman and Miller 1960). Episodic processes are generally considered to be the dominant mode of sediment

transport in steep forest land, but no concensus exists on how to deal with them quantitatively in studies of sediment budgets and routing. Estimating sediment transport by episodic processes is an essential but difficult part of computing a sediment budget. For example, alternative approaches to estimating debris-slide erosion have been proposed. Dietrich and Dunne (1978) and Dietrich et al. (this volume) attempt to quantify frequency of failure at a particular site; others (Swanson et al., in press; Lehre, this volume) apply a geographically broader inventory method of computing erosion per unit area and time.

An important difficulty in dealing with episodic events is evaluating the interaction of successive major disturbances within a drainage basin (Be van 1981; Kelsey, discussion group report, this volume). The approach to magnitude-frequency analysis proposed by Wolman and Miller (1960) assumes independence of successive events, but studies in a variety of areas indicate that major floods may change the quantity of sediment available for transport (Brown and Ritter 1971) and channel conditions (Ritter 1974, Baker 1977) encountered by subsequent events.

"Geomorphic recovery" after major disturbances is an essential part of judging effects of episodic events on sediment yield, but it is a concept interpreted in many ways. Wolman and Gerson (1980) discuss channel recovery in terms of return to predisturbance geometry, but judge recovery of landslide scars on the basis of degree of revegetation. Geomorphic recovery from a sediment-routing standpoint could be viewed as the refilling of storage sites and their readiness to fail again. The rate of such recovery for landslide scars varies greatly depending on the scale of the feature. Massive slope failures of essentially entire, first-order drainage basins (Kelsey, this volume) recover by rock weathering and soil formation. A much smaller proportion of a drainage basin fails in hollow/swale sites. Hollow/swale sites are recharged by transport of colluvium from adjacent areas, so their recovery is likely to be more rapid than that of the more massive failures where recharge is limited by weathering rate. Over several episodes of sliding, however, weathering must be the rate-limiting process in both systems.

Clearly the long-term significance of episodic events in sediment budgets and routing systems is difficult to quantify because the meager record of past events is dominated by the most recent one or two and the longer term sequence and timing of past events is important. Here again, the geomorphologist may have to rely on the tools of the dendrochronologist and Quaternary stratigrapher to place limits on the timing of past events.

Biotic Factors in Sediment Routing

Biological parts of landscape systems contribute important components of sediment, act as agents of sediment transfer, form sediment-storage structures, and record forest and geomorphic history. Biological influences on geomorphology are particularly well developed in forest vegetation--reflect-

ing, in part, the massive size and relatively slow decomposition rate of woody material in many forest environments.

The role of organic matter as a soil component is better understood than its role as sediment. Organic matter in soil is an essential part of both nutrient cycling and mineral weathering, which strongly influences soil stability. Sediment-transport studies by hydrologists and geomorphologists typically disregard the importance of organic matter in sediment both in deposits and in transit, but ecological research on drainage basins has emphasized the importance of streams in exporting organic matter from ecosystems (Arnett 1978). Organic matter may comprise a large proportion of sediment in transport, thus potentially complicating sediment sampling and confounding interpretation of the data (Arnett 1978). Sedimentologists have long been interested in the alteration of sediment characteristics during transport through a drainage basin, but interest among geomorphologists in extending these concepts to soilsediment relations is rather new (Dietrich and Dunne 1978). Aquatic ecologists are becoming increasingly interested in the parallel issue of variation in the quantity and type of organic matter transported or temporarily stored throughout a drainage network (Naiman and Sedell 1979, 1980). Interactions between dissolved and fine particulate organic and inorganic matter (Jackson et al. 1978) present problems for sampling, distinguishing, and interpreting dissolved and suspended sediment yield from a sediment-routing standpoint. These interactions affect the fate and persistence of pollutants in ecosystems.

Plants and animals also affect soil and sediment movement and temporary storage in a variety of ways, many of which are described in papers in this volume. Effects of fauna and flora on individual erosion processes have been quantified in some detail, ranging from Darwin's (1881) work on erosion by earthworms to recent studies of tree-root effects on the potential for shallow mass movements (O'Loughlin 1974, Ziemer 1981). Where vegetation decreases the effectiveness of sediment-transport processes, it enhances sediment storage and increases the residence time of sediment by dissipating the energy of sedimenttransporting media and by holding sediment in place. Large woody debris in streams and on hillslopes and tree roots are examples of biological materials that retain sediment at temporary storage sites.

The multiple, cumulative effects of vegetation on sediment routing through small (less than 100 ha) drainage basins have been demonstrated by studies in both forested and disturbed conditions (Bormann et al. 1969, 1974; Fredriksen 1970; Swanson et al., 1982; and others).

Dendrochronology may also be an integral part of sediment-routing studies by placing limits on the date of an event, rate of a process, and residence time of material in storage (Alestalo 1971; Schroder 1978; Hupp and Sigafoos, this volume; Brown, this volume; and others). Furthermord, general aspects of vegetation history can be interpreted by dendrochronologic analysis of events, such as wind storms and wildfire, and by palynological analysis of vegetation

response to change in climate. This knowledge affects extrapolation of sediment-budget information to periods longer than those covered by direct observational data.

Interest in these long-term interactions between biotic and geomorphic systems goes beyond basic, academic concerns, and forms a foundation for interpreting and predicting impacts of management activities on forest ecosystems and landscapes. The successional development of ecosystems after disturbance determines the pace of recovery of vegetative control of sediment movement and storage. Likens and Bilby (this volume), Swanson et al. (1982), and others have argued that analysis of geomorphic systems should be placed in the context of vegetative succession and disturbance history.

Weathering

Study of weathering and its effect on availability of plant nutrients, soil development, and soil stratigraphy is advanced compared with knowledge of weathering as a regulator of sediment routing. Weathering affects the availability of material for transport and the types and rates of transport processes operating in an area (Dietrich and Dunne 1978). Geological material enters the sedimentrouting system by weathering of bedrock, which makes it available for transport.

Dietrich and Dunne (1978) suggest that weathering is a critical rate-limiting factor in the longterm movement of sediment in many mountain environments. This may be particularly true in steeplands with shallow soils over competent bedrock; examples are the Oregon Coast Ranges (Dietrich and Dunne 1978) and the mountains of Hawaii (Scott and Street 1976). Weathering is less crucial in determining the availability of erodible material where primary sediment sources are deep soils, unconsolidated sediments, or tectonically shattered rock, such as recently glaciated terrain (Madej, this volume) and the tectonically active California Coast Ranges (Kelsey, this volume).

Once material is available for transport, the types and rates of movement depend strongly on soil depth and on physical properties of the material determined by parameters such as grain-size distribution and clay mineralogy (Dietrich and Dunne 1978). Dietrich et al. (this volume) argue that change in soil depth with refilling of "hollows" results in increasing susceptibility of the site to failure by additional debris sliding. Weathering processes and their interaction with biota alter soil cohesion, bulk density, and mechanical properties, consequently controlling the rates of virtually all hillslope transport processes.

Weathering changes material while it is in temporary storage at various sites within a drainage basin. The rates and types of weathering reactions may vary from one storage site to another, depending on characteristics of the local weathering environment, such as hydrology, temperature fluctuations, pH, and oxidation-reduction conditions. Glancy (1971) and others, for example, have noted the break up of

pebbles of sedimentary rock on gravel-bar surfaces over a period of months. They suggest that this is a bar-surface phenomenon only, so stones buried at shallow depths within the bar would not undergo this partial conversion from bedrock to suspended-load particle sizes.

The residence time of material in some storage sites stretches to. the time scale of significant weathering and soil-profile development. Workshop participants (Harden et al., this volume) argued that soil stratigraphic techniques could profitably be used to determine residence time of storage sites and sometimes to set limits on the time since the last mass movement at a site.

These few examples indicate that weathering studies have an important, but little used, place in sediment-routing research.

Modeling of Sediment Budgets and Routing

Computer simulation of sediment routing holds great promise for aiding compilation of sediment budgets and for simulating sediment-routing systems in ways useful for predicting system change in response to disturbances. A simulation model provides a rigorous statement of a sedimentrouting system and highlights the kind and quality of field data needed for prediction. Existing simulation models require much more development before they meet this promise, however.

Two types of models were discussed at the workshop: a model by Simons et al. based on physical processes and Rice's Monte Carlo simulation of sediment production in response to a long sequence of fires and rainstorms. Each approach has its benefits and limitations.

Limitations of the model described by Simons et al. and of similar models developed for agricultural lands include: lack of treatment of mass wasting processes that can dominate sediment transport in steep land; uncertainty about the accuracy of some components of the model, such as the use of equations developed for sediment transport in deep stream channels to estimate transport by sheetflow; and the need for calibration of the model against a set of field data to obtain several parameters of the equations. Calibrations include such physically ill-defined concepts as soil "detachment coefficients" for rainfall and overland flow. Finding a set of coefficients that produce a good fit between predicted and observed water and sediment discharge does not necessarily lead to understanding of what is actually happening in the landscape, or even of where most of the sediment originates in a heterogenous landscape. Nor do such fits promote confidence in predictions of the consequences of some disturbance by climate or land use. More field experiments need to be conducted and generalized so that model parameters can be estimated a priori and tested against a few measured outputs. Nevertheless, information organized in such models is useful for developing other models and conducting field experiments to refine them.

Rice proposes the application of Monte Carlo simulation to describe the response of an erosionsedimentation system to random meteorological events that drive the sequence of fires and rainstorms and interactions among them. He questions the utility of process-based mathematical models because of the need for calibration. Particularly in a region where the sediment budget is strongly affected by random phenomena that vary greatly from year to year, the model should be calibrated against a large number of events covering the most important combinations of parameter values. Rice also points out, however, that in addition to frequently discussed difficulties with the structure of geophysical data, empiricalstatistical models suffer the same drawback as process models; the instrumental record is unlikely to contain sufficient important events to include adequate combinations of the most effective factors.

The refinement of studies of sediment budgets requires a combination of: field monitoring of processes coupled with measurements of the controlling variables, so that physically based process models can be developed; field experiments under controlled conditions to extend the range of observations on which the process models are founded; and the development of deterministic models of processes and their linkages. These models can then be used in Monte Carlo simulations, as suggested by Rice. A precedent in hydrology is the recent work of Freeze (1980) on runoff processes.

CONCLUSIONS

In this workshop, we took an interdisciplinary look at the state of knowledge on development and use of sediment budgets and routing studies for forest drainage basins and identified important directions for future research. Most analyses have considered channels as the major storage sites and budgets have included hillslope processes, changes in channel storage, and outflow by fluvial processes. Temporal scales range from one year to millenia, spatial scales from less than a hectare to tens of thousands of square kilometers. Objectives of current studies range from purely basic questions of how geologic materials move through drainage basins to analyses of impact of management practices on sedimentation and a variety of resources.

Central points identified and further research needs are:

Sediment storage is an essential but poorly understood and poorly quantified component of sediment budgets or routing analyses.

- Our ability to conduct field studies and to develop computer simulation models of sediment transport processes is limited by our knowledge of mechanisms of transport and the geomorphic context in which they operate.
- Episodic processes dominate sediment transport in many steep terrains, but theory and quantification of these processes are not well developed, particularly the interactions between successive events.

- Biota play a variety of essential roles in the production, transport, and storage of sediment, but knowledge of biological functions is poorly integrated into quantitative analysis of sediment budgets and routing.
- Weathering affects the availability and properties of sediment, but because significant weathering commonly occurs over long periods relative to traditional studies of processes, weathering has been little studied or used in sediment budget and routing studies.
- Computer simulation modeling is useful for predicting system behavior and for integrating concepts, process mechanisms, and field data. Modeling efforts, however, have not yet dealt with the types of storage sites and erosion processes that dominate in many forested mountain lands.

Advance of knowledge in each of these areas would be facilitated by improving theoretical analyses of processes, accumulation of long-term data sets, and more standardization of procedures and terminology. Economic considerations, in part, are leading to declining support by science managers for collecting long-term data sets, although scientists at the workshop were unanimous in their support of the need for such records. Computer simulation modeling, although a useful way of maximizing the value of field data, does not by itself provide useful surrogate records in geomorphic systems where infrequent events dominate sediment transport and where knowledge of interactions between successive events is weak.

Standardization of procedures and terminology in field and modeling efforts would facilitate future efforts to compare and contrast budgets and routing in diverse geomorphic systems. Efforts to standardize, however, must be tempered by the need to express adequately the sediment routing characteristics of particular terrain, climate, and vegetation types. The inability of the discussion group on use of flow charts in sediment routing studies to develop a single flow chart common to many landscapes reflects the difficulty of balancing details of local knowledge with the general need of achieving a basis for comparing diverse systems.

Use of sediment budget and routing analysis of drainage basins is in its infancy. Continued application of these methods in a variety of environments in studies with diverse objectives attests to increasing recognition of the value of sediment budgets and routing studies.

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