Discussion Group Summaries

Evaluating and Mapping Sources and Temporary Storage Areas of Sediment

Leslie M. Reid

INTRODUCTION

Legislation to regulate forest practices, water quality, and management of federal lands has increased the land managers' need for efficient methods of identifying and mapping sources of sediment in forested basins. At the same time, theoretical analysis of landscape evolution has led research geomorphologists to the consideration of many of the same sedimentation problems as those confronting land managers. This discussion session demonstrated that, although many of the fundamental questions addressed by these groups are identical, the approaches taken in answering those questions differ widely.

APPROACHES AND GOALS

Land managers are interested in the effects of varying land use on sediment production. Often they are asked to map the distribution of and predict sediment production from natural as well as management-induced and management-enhanced sources. They may also wish to predict distri bution of sediment sources and rates-of sediment production for different management alternatives in specific areas. They are interested in such questions as how timber harvesting or roadbuilding affects slope stability in an area, how the amount of sediment currently in storage in flood plains will be affected by a change in land use, and what happens to sediment introduced into a stream system by a change in land use. Usually answers are desired quickly.

Research geomorphologists may try to answer these same questions from a theoretical standpoint. They are interested in the distribution of erosional processes, for example, in order both to understand the importance of various external controls on those processes and to infer the importance and specific influence of the processes on landscape form and development. The goal of a land manager's investigation is a prediction specific to a locale, but the research geomorpholo gist's goal is usually an understanding of a general principle. Such general principles may be useful to a land manager as tools for making predictions in a specific area, but if other methods give adequate results more quickly or more economically, there is no compelling reason to use a theoretical approach.

The difference in approach stems from a basic difference in intent. The land manager must answer site- or area-specific questions quickly, but the researcher is interested in elucidating general principles and has the luxury of working on a more relaxed time scale.

Land managers have used the landscape stratifi cation approach--also referred to as terrain mapping or morphogenetic classification--to characterize erosion processes over wide areas quickly. Underlying this approach is the assump tion that areas of similar climate, topography, bedrock, vegetation, and land use experience the same kinds of erosion processes, produce sediment at similar rates, and respond in a similar manner to a given land use. The criteria used to define stratification units are chosen not only because of their genetic importance in controlling distri bution and rate of erosion processes, but also because they are visible on aerial photographs

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Leslie M. Reid, Graduate Student, Department of Geological Sciences, University of Washington, Seattle, Washington 98195.

Participants:
R. Brown, T. Chamberlin, D. Dethier, S. Duncan, D. Harden, M. Harvey, B. Hicks, R. Janda, A. MacDonald, M. A. Madej, W. Megahan, M. Nolan, L. Reid, J. Schramek, S. Trimble, and O. Williams

or, as is often the case with bedrock geology, have already been mapped. A representative area in each defied unit can then be examined in detail by using field mapping, transects, monitoring programs, or more detailed aerial-photograph interpretation, and the results of the studies may be used to determine a characteristic sediment yield, process distribution or rate, or, if a disturbed area is selected, response to land use. The values for a representative area are then used to typify that unit or to provide the basis for revised stratification criteria that are more appropriate or the area of interest. This method has been widely used to evaluate slope stability (examples from T. Chamberlin, B. Hicks, and W. Megahan) and has also proved useful in assessing an predicting effects of logging on channel stability (example from O. Williams). In this last example, topographic maps and aerial photographs ere used to classify the channels into one of even stability classes. Observations of the response of representatives of each stability class to a given logging practice were then used to predict the response of a specific channel to that practice.

The stratification approach cannot be used when site-specific answers are needed. This approach can predict the kind of landslide likely to occur and the average failure frequency in an area, but it cannot be used to determine the locations of individual failures or the conditions under which a given site will fail. Nor can the stratification approach be used reliably to predict process distribution or response beyond the range of the impacts already existing on each stratification unit. For example, a stratification-based approach may use data from a 10-year-old clearcutting to predict that clearcutting of a certain basin will result in a threefold increase in yearly sediment production from landslides. The approach can give no indication, however, of how long the effect will last unless a series of progressively older clearcuts exists in the same stratification unit. Similarly, the effect of a management plan for which no prototype exists on that stratification unit cannot be evaluated. Finally, the method is restricted to areas and processes for which controlling variables are easily mapped. In areas where debris avalanche occurrence is controlled by the distribution of deep soil wedges or of localized bedrock joints, stratification by hillslope gradient, vegetation, and bedrock lithology, each of which may have little relation to the primary controls, would be of little value.

For such areas, an approach frequently adopted by researchers may be useful. Individual erosion processes a conceptually isolated and the controls on the rate and distribution of each process are quantified (Dietrich et al., this volume). Long-term impacts of current management activities or the effects of a proposed management activity may then be predicted by analyzing the response of the processes to the changing primary controls. Sediment production from gravel road surfaces, for example, is largely controlled by factors such as overland flow length, road gradient, and road use. These relationships have been defined in a Clearwater basin, Washington, and can be used to estimate sediment yields from new road designs and use patterns by determining the effects of the changes on the factors controlling sediment production (L. Reid). If process controls are adequately understood, site-specific process rates may be predicted using a combination of this technique and a probabilistic, treatment of the driving variables.

The process approach thus can be used not only to solve the same kinds of problems that the stratification approach deals with, but also to make predictions for specific locations and for conditions without prototypes. The process approach requires an initial investment of effort that may make it impractical for short-term reconnaissance work, but if more specific questions are anticipated or if the necessary scale of stratification is expected to become more detailed, the stratification criteria will need to be more process oriented. In such a case, an initial commitment of time toward the development of a quantitative understanding of primary controls of process distribution and rate may be most economical in the long run.

METHODS: DISCRETE SOURCES

The methods used to evaluate sediment sources can be applied to both the stratification and process approaches. Methods such as field mapping and aerial photograph interpretation are standard techniques for evaluating discrete sediment sources such as landslides. If these techniques are to be used quantitatively, however, care must be taken to avoid comparing areas of different resolution without making allowances for that difference. For example, debris-avalanche frequencies cannot be compared by counting landslide scars if the scars heal more quickly in one area than in another, and a count of scars in a logged area compared to one in a forested area has little meaning unless the size of the smallest scar recognizable beneath the tree canopy is known.

Analysis of sequential aerial photographs is of particular value in determining frequencies and recovery times for different processes, but in many areas, few photograph sets are available. A source of aerial photographs frequently overlooked is county tax records in courthouse files: since the early 1940's, governments of many timber-producing western counties have been taking aerial surveys at 4- to 10-year intervals to assess timber holdings (R. Janda, D. Hardin, M. Nolan).

Ground photographs, too, may facilitate the evaluation of past geomorphic and vegetative change or even allow the reconstruction of process distribution and rate in areas before disturbance. In addition, both sequences of aerial and ground photos may be used in conjunction with climatic records to assess the impact of specific storms (S. Duncan, D. Hardin). Historical photographs of the area of interest may exist locally, and during the 1930's the Soil Conservation Service compiled a series of high-quality photographs documenting erosion problems in each State. Though the emphasis of the series was on agricultural and range lands, other land use categories were included. The photograph collection is preserved in the National Archives (S. Trimble). The U.S. Geological Survey also maintains a collection of historical photographs (R. Janda).

Other remote-sensing techniques have recently been applied to geomorphic problems. Both aerial infrared and radar imagery have been used successfully to map areas of landslide hazard. Lineations observed on infrared photographs in New Zealand were found to correspond to moisture differences between ',coherent bedrock and more slide-prone, crushed zones, and thus correlated well with landslide distribution (M. Harvey). In Idaho, lineations made visible by radar imagery also correlated very well with landslides (W. Megahan). Computer-rectified side-scanning radar images, because of their fine resolution and low-angle illumination, are useful in discerning subtle differences in relief such as those produced by landslides; but like visible-light photography, radar imagery cannot penetrate forest cover. These techniques can be used not only to map sediment-source distribution, but also to help map the distribution of rate-controlling variables such as vegetation, hillslope gradient, and bedrock geology. Other controls, such as soil depth and ground-water level, are less amenable to analysis by remote-sensing techniques.

Wedges--areas of deep soil on hillslopes with otherwise uniform soil depth--are very important in determining the location of debris avalanches in some areas, yet because wedges may have little or no surface expression, they are very difficult to recognize in the' absence of road cuts. Portable seismic units have shown promise in measuring soil depth if the soil-bedrock interface is distinct (S. Duncan), and a portable conductivity meter is being developed for this purpose by the Bureau of Land Management. A ,prototype already on the market has been used successfully in southern Oregon. The conductivity meter is used to measure the depth to a subsurface contrast in conductivity, and because such a contrast may be the result of any of several factors including material, density, and moisture differences, readings must be calibrated for each area by digging test pits (B. Hicks). Eventually an understanding of how wedges form may make possible the prediction of their frequency and distribution in specific areas.

Mapping of peak or time-averaged piezometric levels is fraught with similar difficulties. Because the temporal occurrence of landslides is so closely tied to the occurrence of,major storms and thus to high piezometric levels, maps showing the probable duration of a given piezometric level may prove useful in determining landslide potential in an area (T. Chamberlin). But as yet, the use of piezometers is the only widely available method for measuring ground-water pore pressures, and the time and effort necessary to install piezometers has restricted their use to networks covering only small areas. In this case, a more process-oriented approach, where the controls on piezometric levels are determined in detail in a small area and then projected to the larger area of interest, may be most useful (S. Duncan). The technology necessary for remote sensing of soil thickness, ground-water depth, and other process controls may already exist; it may require only a closer working relationship with specialists in remote sensing to link the geomorphologist's needs with the capabilities of remote sensing.

METHODS: DISPERSED SOURCES

In many areas, dispersed sources such as surface wash, rill erosion, and small-scale bank erosion may contribute as much or even more sediment to stream channels than large, discrete sources. Even in areas where the net contribution from dispersed sources is small, they may be important as persistent sources of fine material. In addition, dispersed sources may prolong the impact of a landslide by preventing its revegetation, and in the case of bank erosion, may locally create the potential for discrete failures.

Because of the more continuous nature of their sediment production and because they are not discernible by remote sensing, dispersed sources require a more process-oriented approach to analysis even for purposes of stratification. Empirical correlations of sediment yield with different types and intensities of land use have in the past dealt implicitly with such sources, but because these studies require a large data base and do not distinguish specific source types, they are generally useful only in broad stratification schemes.

Direct monitoring of individual sources provides information that can be projected to stratification units of any size based on the distribution of rate-controlling variables. Monitoring methods depend, of course, on the types of processes in question. Surface erosion by such processes as rainsplash and rilling has been monitored using erosion pins on slide scars and gully walls (Lehre, this volume); erosion pins have also proved useful for measuring back-cut retreat on roads. With frequent observations it is possible to isolate the effects of specific storms and freeze-thaw, and careful selection of study plots allows the isolation of other variables such as aspect, lithology, slope angle, and slope length. Gerlach troughs are effective in monitoring sediment loss from the same sources (R. Janda), as are repeated measurements of surface elevation and sediment character on erosion plots (R. Rice). Erosion-plot studies using measurement of erosional landforms such as rainsplash pedestals and gullies have also been used to estimate effects of timber harvest and road construction on soil movement (Hauge 1977). Surface erosion by overland flow on gravel roads is also a significant source of fine sediment and can be monitored by measuring sediment concentrations in surface or culvert drainage. Sites must be selected carefully to isolate rate-controlling variables such as road gradient, drainage area, back-cut contribution, road use, and storm intensity. Use of a portable rainfall simulator may add flexibility in site selection (L. Reid).

In some areas, surface erosion can be measured by observing the depth of soil profile truncation. Because profile truncation is a criterion used in describing soil series, the extent of surface erosion may on occasion be mapped directly from existing soils maps (S. Trimble). Similarly, buried profiles indicate net accumulation or storage.

SEDIMENT STORAGE

Once sediment has entered the transport system, it may be stored for periods ranging from minutes to millions of years in landscape elements such as hollows, streambeds, gravel bars, and terraces. Though measurements of sediment production rates are important in determining the amount of sedi ment entering stream systems, an evaluation of sediment storage is necessary if the location, magnitude, and duration of the long-term impacts resulting from sediment production are to be determined. In addition, many sediment-related impacts of major concern involve a change in the location o sediment storage or in the character and amount of the material stored; such impacts include steam siltation, infiltration of fine sediment into spawning gravels, filling of pools, and channel destabilization. Finally, any account ing of sediment production that attempts to relate production rates from individual sources to a basin sediment yield must also take account of changes in volume of material in storage, because sediment may be either gained from or lost to storage during transport.

Trimble (1981) demonstrated the importance of this effect for the Coon Creek basin in Wisconsin, and further suggested that the present sediment load of many steams was determined by basin conditions over past decades or even hundreds of years. At Coon Creek, sediment originally produced by poor agricultural practices in the late 1800's was stored in the uplands for several decades. By the 1930's, it ad been transported downstream as far as the main valley, resulting in massive aggradation of flood plains, even though agricultural practices ad improved markedly by that time.

Similar effects are seen in the movement of sediment waves through stream systems. Coarse sediment introduced into a river at a point (as from a landslide) may travel as a slow-moving wave that may be recognizable only as an otherwise anomalous local change in channel morphology. This sediment is effectively in storage and is moving independently of any processes occurring at its source; its major impact at a downstream point will not be felt until the wave of sediment reaches that point. Such effects have been described in western Washington (Madej, this volume), northern California (Kelsey 1980), New Zealand (M. Harvey), and elsewhere. Thus, an analysis of sediment storage is necessary to answer such questions as what happens to sediment once it enters the transport system, what areas will be affected by an increase in sediment production, how long will the impact persist, and how will material already in storage respond to a change in land use.

A major problem in the evaluation of sediment storage is hat the distinction between a source and a sink or sediment is not always clear. Because of he continuum between transport and storage, a meaningful assessment of either must consider residence time of material (D. Harden). Most landscape elements can act in either capacity, depending on recent climatic conditions, location in a basin, magnitude of a specific climate event, or local environmental conditions. This last point is of special interest, because it implies that a change in land use, and thus in factors such as local water balance or apparent soil cohesion from root strength, maybe large enough to convert storage elements into active sources.

Location within the drainage network is also important in determining the response of a storage element to changing conditions. In the northern California Coast Range, for example, small headwater streams tend to aggrade their beds during small storms and degrade during large, peak-flow events, but sediment aggrades in larger streams during large events and is gradually eroded during the smaller ones (Janda 1978).

A further complication to the analysis of sediment storage is the discontinuous nature of sediment transport. Transport of gravel is accomplished by the alternation of long periods of stationary storage on the streambed with brief episodes of rapid transport during storms. Similarly, flume studies in Colorado suggest that coarse material introduced into a stream is transported as a series of prograding fans in channels (Harvey, this volume). A clast is stored in any given fan for a relatively long period before it is once again eroded out and transported to the toe of the fan. In each case, the sediment in "active" transport spends a large proportion of its transport time in storage.

On a larger scale, entire landscape elements may be undergoing similar cycles. Hollows, for example, are thought to gradually fill with colluvium until the fill--or wedge--reaches a critical depth. At this point, high pore-water pressure during a large storm can cause it to fail. The colluvial fill is transported downslope, and the slightly enlarged bedrock depression is left to refill (Dietrich et al., this volume).

The importance of time scale is evident in each of these examples. Wedges and low-order stream channels, which appear to be stable sediment traps during most of their cycles, are seen to be net sources of sediment when observed over several cycles. In addition, the dependence of geomorphic response on storm magnitude adds a probabilistic variable to any long-term evaluation of a landscape element.

SUMMARY

Maps based upon quantitative, process-based studies and those based upon empirical correlations of source distribution with landform parameters both have been used to evaluate sediment production. Which of these approaches is most useful depends on the purpose of the specific study, but methods that have been developed for measuring production rates can be used in conjunction with either approach. These methods include various mapping techniques, monitoring programs, and experiments. Analysis of sediment production in a drainage basin must take into account changes in sediment storage, but this is made difficult by the sensitivity of storage elements to factors such as climatic history, magnitudes of individual storms, and local physical and biological conditions. In addition, because the distinction between storage and transport is to some extent arbitrary, and because landscape elements may undergo natural cycles alternating between net sediment input and net output, the definition of sediment-storage elements is partially dependent on the time scale of interest.

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