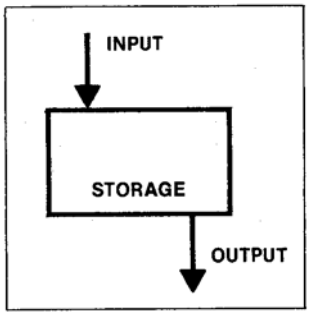

The Use of Flow Charts in Sediment Routing Analysis

Leslie M. Reid

THE USE OF FLOW CHARTS IN SEDIMENT ROUTING

Flow charts are a widely used means of diagramming relationships among transport processes and storage sites during analyses of sediment routing. Because they have taken so many different forms, however, it is very difficult to use published flow charts to compare geomorphic systems. Though they generally are constructed to achieve the same purpose, flow charts differ in the definition of the material being transported, type of transport processes involved, and the kinds of landscape elements considered to be sediment storage sites. In addition, the structure of flow charts may vary greatly. During this discussion, we attempted to probe the advantages and disadvantages of the different types of charts in hopes of arriving at a general form that would facilitate direct comparison of sediment budgets from different environments. Though a general form was not attained, many criteria necessary for a general flow chart, and for flow charts in general, were recognized.

Formally, a flow chart is a schematic representa tion of a series of operations. In the context of geomorphology, these operations are generally processes such as landslides, sheetwash, and solution transfer, which transport material from one storage site to another. Operations might also include processes such as chemical weathering and abrasion which change the character of the material, or information flow, which controls interactions between processes. Which operations are selected depends ultimately on the understand ing of how the system operates, the amount of information available about the system being diagrammed, and the use to which the flow chart will be put.

Flow charts can be used to organize information, to describe a system, or to provide a framework for predictive calculations. At the least sophisticated level, a flow chart can be used to expose conceptual holes in our understanding of the relationships in a system. Such a chart need only be qualitative, though as the level of understanding increases and the recognized conceptual gaps occur at finer scales of resolution, the complexity of the flow chart and the need for quantification also increase. The same kinds of charts may be used to pinpoint critical, rate-controlling steps deserving more careful evaluation.

Flow charts are also useful for describing a specific system once data have been collected. Here, too, the level of sophistication may vary from a qualitative diagram of process interactions to a quantitative sediment budget. A corollary of this function is the use of flow charts to compare systems in different environments, and it is for this use that a need for some uniformity in struc ture and definitions becomes apparent. The most common means of comparison has been the single number index of sediment yield per unit area, both because it is the only parameter that has been widely reported and because it is relatively easy to measure. But important differences in processes and rates in different basins cannot be described by a single number. More useful would be a com parison based directly on sediment production and transport processes. A standardized flow-chart form would provide a means of organizing data for such a comparison.

At the most sophisticated level, a flow chart may allow prediction of the response of a basin to

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changes in environmental variables. The construction of such a model requires a quantitative understanding of all process rates and feedback controls operating in the system, as well as of the dependence of those rates on the driving variables.

The need for three types of flow charts can thus be recognized. Descriptive-qualitative charts organize information about relationships, and descriptive-quantitative charts attach average or instantaneous transfer rates to the qualitative framework. The third type of chart, a predictive-quantitative flow chart, includes measurements of feedback mechanisms and dependencies upon driving forces and thus allows calculation of the effects of changing conditions on the parameters of interest. Construction of such a chart, however, requires data not currently available for any natural geomorphic system.

The descriptive-qualitative flow chart has been the most widely used in geomorphology, largely because difficulties in measuring the rates of gain and loss of material to storage have prevented quantification of the charts. The traditional form of a descriptive flow chart is a series of boxes joined by arrows showing a temporal or spatial sequence. Boxes, however, can stand for many different items or concepts. Recent geomorphic flow charts have used boxes to represent (1) idealized locations as geometrically defined landscape units (e.g., units of a segmented landscape discussed by Simons et al., this volume), (2) geomorphically defined locations (swale--channel banks--channel bed of Lehre, this volume), (3) sediment deposits (soil--wedge--fan--channel bed, as described by Dietrich and Dunne 1978), (4) transport processes (creep--slump--debris slide--debris torrent shown by Swanson et al., 1982), and (5) material character (bedrock--saprolite--soil). The arrows then correspond to transport processes, weathering processes, or merely indicate sequential development.

Appropriate definitions of elements of a flow chart depend on the purpose of the flow chart. The limitations of each approach to flow-chart development must be recognized. Over long periods, for example, landforms and idealized locations may evolve from one kind to another (swales may fail, form channels, and gradually refill) and deposits may erode away or new kinds form. Storage elements, too, are difficult to evaluate, because storage and transport form a continuum that may be distinguished only by an arbitrary selection of a minimum residence time to define storage. Charts based on processes tend to be complex because most processes interact with others. Complexity is also introduced because a change in material character may be interpreted as an indirect expression of mass transfer; weathering may change bedrock to saprolite in situ, for example. In any case, care must be taken to avoid mixing different types of elements in one diagram, unless the elements are distinguished symbolically.

The more complete the flow chart, the more difficult it is to interpret, and the less useful it becomes as a graphical description of a system. Increasing complexity may be avoided by breaking the flow chart into several charts, each dealing with a separate subsystem. The subsystems may then be recombined by way of a master chart that treats each subsystem as a separate compartment. Each subsystem may represent an individual process, landform, or time segment.

A similar approach may be used to handle the change of process type and rate as channel order increases. Debris torrents, for example, are an important transport process in steep, low-order basins. But as the channel gradient decreases with increasing basin order, torrents become less important and eventually disappear altogether. Such an effect cannot be shown on a simple chart, but if a separate flow chart is constructed for each order of channel, the effect becomes evident. These separate charts are then combined by way of a master chart that specifies the transfers between channels of different orders.

Several approaches have been used to show quantitative sediment budget data on flow charts. The relative importance of different elements or transport routes may be shown by the relative sizes of the element boxes or the thickness of interconnecting arrows, even if the actual values are not known.

If process rates and storage volumes have been measured, a quantitative, descriptive flow chart may be constructed. Rates of material transport can be shown by appending the actual transport rates to the flow chart. This method is useful in that it preserves the visual impact of the generalized chart and facilitates direct comparison of flow charts, but it becomes unwieldy as the complexity of the chart increases.

Highly complex systems can be quantitatively described using transitional matrices. With this method, locations (absolute or idealized), landforms, or storage elements are used as labels for columns and rows of a matrix (fig. 1). Sediment is considered to be transported from the location noted in a row to that noted in a column, and transport processes are differentiated by planes in the third dimension; mass transfers are filled in according to source, destination, and transport process. Sequence--an important aspect of flow charts and a critical factor in understanding a geomorphic system--is difficult to discern, but may be partially reconstructed by comparing inputs and outputs from different locations. Though visually obscure, the result makes the organization of information relatively easy and is useful in accounting; change in storage volume may be easily determined by comparing the totals in the rows and columns for each location. This operation also makes apparent the restrictions of this budget and any other descriptive-qualitative budget that is based on short-term measurements and does not deal explicitly with probabilistic variations in driving variables; the budget can reflect only what is happening at a specific time or the average result over a longer period. Otherwise, loss of material in transport to storage would imply infinite aggradation.

The third type of flow chart--the predictive-quantitative model--requires a quantitative understanding of process rates, driving variables,

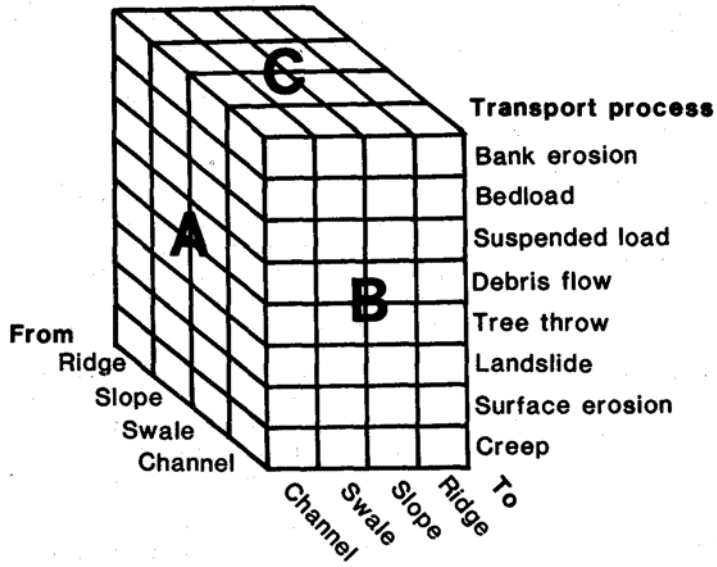

Figure 1.--Hypothetical three-dimensional matrix for tabulation of material transfer rates be tween storage locations in a forested basin. Material is moved from source A to location B by transport process C. Hypothetical tabulations, in t/km^2 per year, are shown in lA, 1B, and 1C. Change in storage at a location can be calculated by subtracting total output from total input at that location. In the example given, the rate of change of the volume of material stored in swales would be (total (1B) - total (lA)) = -5 t/km^2 per year.

A Destination

	Channel	Swale	Slope	Ridge
Bank erosion	3	1	–	–
Bedload	17	1	–	–
Suspended load	30	.5	–	–
Debris flow	40	3	–	–
Tree throw	5	12	–	–
Landslide	12	4	–	–
Surface erosion	1	1	–	–
Creep	–	38	–	–

From swale

B Source

	Ridge	Slope	Swale	Channel
Bank erosion	–	–	1	–
Bedload	–	–	1	–
Suspended load	–	–	.5	–
Debris flow	–	2	3	–
Tree throw	–	15	12	–
Landslide	3	19	4	–
Surface erosion	–	1	1	–
Creep	–	63	38	–

To swale

C Landslides

From	Channel	Swale	Slope	Ridge
Ridge	–	3	1	–
Slope	28	19	23	–
Swale	12	4	–	–
Channel	–	–	–	–

and information flow; each is incorporated into the chart to form a model of the real system. When values for the driving variables are specified, the chart can be used to predict the response of any part of the system or of the system as a whole. The complexity of a realistic model, and the necessity to handle driving variables probabilistically, usually requires the model to be programmed onto a computer, leaving only the framework to be represented as a chart.

After discussing flow charts in general, we attempted to develop a general qualitative chart to describe sediment movement through steep, forested landscapes. We failed. After several hours, we had just begun to resolve the difficul-ties and confusion that arose in settling on a particular type of flow chart, definitions of storage sites and transport processes, and rules for showing linkages among them. The makeup of the flow chart was found to depend heavily on the specific objectives for its use, even though a general form was desired.

The consensus among discussion participants was that flow charts are extremely useful in organizing thoughts about a sediment-routing system and in comparing different landscape units. Such comparisons, however, require that flow charts be developed using a common set of rules and definitions, so that differences in flow charts for different geomorphic systems reflect real geomorphic differences. Guidance for develop ing a useful flow-chart form could come from other fields, such as hydrology, nutrient and energy cycle modelling for ecosystems, and network theory. Developing common definitions of landscape units and processes requires extensive discussion and a knowledge of what is geomorphically important in a wide variety of environments.

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