CHAPTER 14

ESTIMATING QUANTITIES OF SEDIMENT SUPPLIED BY STREAMS TO A COAST

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Most beaches which are in equilibrium depend for their maintenance upon a continuous supply of sediment. This supply rate has been estimated for instance for the beach at Santa Barbara to be of the order of magnitude of 350,000 cu. yards of sand per year (Johnson, 1948). As long as this supply rate prevails no accumulation of sand occurs on the beach. The sand must, therefore, be used up at the beach either by wear or by transport along the beach and, eventually, by deposition into some deeper water. A continual supply of that order of magnitude very rarely becomes available at the shore itself by wave erosion, instead the bulk of supply of sand to beaches usually is derived by rivers. The appraisal of the different river channels for their sediment supply to the beaches near their mouth becomes thus a major factor in the maintenance work of many beaches.

Usually, the sediment load of a river is given as an average annual rate or if somewhat more care is used in the determination of the load, it is divided into a bed-load rate and a suspended-load rate. Even this unfortunately is insufficient for an estimate of the contribution to the beach. This is because most beach sediments are much better sorted than the river sediments. In order to predict the rate of the rather narrow range of grain sizes that contribute to the beach load, the rates of transport in the river must be known individually for all grain sizes. This is a rather ambitious problem, but it may be solved today, at least in part, for most rivers. Before the procedure of such a load determination is described, it is necessary, however, to describe the process of the transportation of sediment in such rivers.

It is most helpful to begin this discussion with the trivial sounding remark that all sediment particles which pass from the river to the beach must have been eroded somewhere in the watershed and must then be transported from there to the beach by the stream system. The significance of this statement lies in the fact that both conditions must be fulfilled and that either one of the two may limit the rate. It becomes actually advantageous to introduce special terms for the two parts of the load: it is customary at present to call the part of the load which is limited in its supply by the availability through erosion the "wash-load", while that part which is limited by the ability of the stream to transport it, is called "bed-material load", or for short, "bed load" (Einstein, Anderson, and Johnson, 1940). This definition of the two parts suggests already that the two parts must be determined in an entirely different manner.

The rate of transport of the wash-load of a river is governed by the erosion on the watershed. It is known today that the rate of erosion in an entire watershed depends on a large number of parameters such as the geology, the steepness of the terrain, the plant cover (as divided into perennial cover -- such as forests and pasture, temporary cover as some broadcast crops and row crops), the climate (the seasonal distribution of the precipitation, duration of frost periods), the size of the watershed, and many other influences. Some attempts have been made to predict the sediment production of watersheds on a statistical basis from available reservoir surveys (Brown, 1945). In most of the cases considered in this latter analysis the bulk of the load was wash-load, and the contribution of the bed material load may be neglected in view of the low degree of accuracy of such an estimate. The prediction of a breakdown of these total rates into different grain sizes has not been attempted as yet.

The most promising present day approach in the determination of the wash-load of a river is the direct measurement by suspended-load sampling (Iowa University, 1948). This method is expensive, however, and time consuming. It may take from one to ten years of continuous observation to predict the wash-load of a river,

depending on the regularity of its flows. The expense is high, not only because of the cost of sampling in the field but to a large part also due to the analysis of the samples in the laboratory.

Most beaches contain only particles which are measurable by sieving, making the analysis of finer sediment fractions by other means unnecessary. It is possible, therefore, to reduce the laboratory cost of such a load study for beach supply to a minimum, if sieving of composite samples is used exclusively.

An entirely different approach may be used for the prediction of the rate at which bed material is moved. The presence of these particle sizes in the stream bed already indicates that sometimes, at least, larger rates of these particles become available in the watershed than the stream is able to move away. This surplus of material, therefore, was accumulated in the bed and represents a reservoir of such particles. Over such a bed a rate of movement will be maintained which is a strict function of the flow condition. Not only will a surplus of supply above the carrying capacity be deposited in the bed, but also any deficiency of supply is eliminated by scour from the bed. Thus, bed material always moves according to capacity.

The capacity rates for bed material may be calculated by so-called bed-load equations, which are more or less general relationships between the flow-variables, the particle size and weight, and its rate of movement. Theoretically, at least, these equations permit the prediction of the transport rates of bed particles over a bed of known composition as caused by any given flow. In reality, however, most such equations are derived for a bed of uniform particle sizes, and if applied to a mixture of different sizes of bed materials, the assumption is made that the mixture will not undergo any segregation, and that the size analysis of the transport is the same as that of the material forming the bed. Very often, especially where the range of grain sizes is small and where the rates are large, this assumption leads to the correct result; in many other cases, however, it is entirely misleading. This fact led to the recent development of newer formulas which permit the prediction of the individual bed-load rates of the different bed components in terms of discharge (Einstein, 1950).

While it is advisable to determine, or at least to check the otherwise derived wash-load rates by direct measurement in the stream, such a measurement often is impractical for the bed-material load. Here, the analytically determined capacity load is usually more reliable than the measurement unless there is for instance a fully effective basin available in which the load can be measured volumetrically and analyzed by sampling. But if such a basin is available in a stream, it will prevent the sediment from moving all the time, and what we measure is not the rate of sediment supplied to a beach, but the part which is diverted from the beach. With the measurement of the bed-material load often impossible and almost always impractical, it is most important to base the load calculations on an appropriate description of the channel and of the flow conditions in the channel. This description must include the following items:

1. The geometry of the channel, as described for instance by a longitudinal profile and a set of cross sections.
2. The bed composition, as determined by sampling in the surface layers and by size analysis.
3. All causes of hydraulic friction, in addition to that on the bed, must be known, such as banks, vegetation, islands, or severe meandering.
4. A dependable record of the expected flow rates, preferably in the form of a flow duration curve or in any other form which may be reduced to a flow duration curve. If past flow records are used, they must cover a significantly long duration and apply to the reach in question.

Practical work in this field has revealed that, particularly here in the West, the lack of flow records (especially for smaller watersheds) presents today the most stringent restriction on the application of bed-load formulas for the purpose of total-load determination.

The limiting size between bed-material load and wash load may be derived according to definition as the lower limit of sizes found in the bed in significant amounts (the size of which 5 or 10 percent are finer has been proposed) (Einstein, Anderson, and Johnson, 1940.) Present investigations at the University of California, Berkeley, however, point to the fact that this simple division into the two modes of transport by a limiting grain size is oversimplified and, thus, not logical. A more general and basically more satisfactory description is found if the transition between wash load and bed-material load is made gradually. The capacity load on a movable bed has been defined as the rate at which the different sizes of bed material may be moved by the flow without any change of location or composition of the bed. Experience indicates that there often exists for the finer components of the bed not only one rate at which this condition is fulfilled but an entire range of rates, the lower limit of which has been studied in the past while the upper limit is under investigation today. These two limits diverge more and more from one another as the particle size decreases. The known lower limit may be interpreted as the minimum rate necessary to maintain the bed under the given flow conditions, while any additional rate up to the maximum as given by the upper limit must be classed as wash load. The two limits seem to diverge very fast with decreasing grain diameter, such that the assumption of a single limiting size is unsatisfactory only in a small transition range of diameters. But, if just this size range is an important component of the beach material, the rates for these sizes must be estimated from the watershed erosion like the wash load proper.

In conclusion it may be summarized that the rates at which an alluvial stream transports the sediment sizes of its bed can be calculated by means of bed-load equations, while the finer components in many instances must be measured or estimated from measurements in similar watersheds.

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