Washload and Fine Sediment Load

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Introduction

Einstein (3) does not take credit for designing the washload concept, but he describes it very distinctly. He stated that if the sediment is added to the upstream end of a concrete channel and the channel is swept clean, and the sediment has not left any trace in the channel, its rate of transport need not be related to the flow rate. This kind of sediment load has been called washload because it has just washed through the channel. He further stated that all particle sizes that are not significantly represented in the deposit must be considered as washload. This washload concept, which is generally accepted by professionals working in the field, means that on the high plains of the United States the washload normally consists of silts and clays (1,7). As a result the misconception that washload consists only of the fine sediments, silts and clays is quite common.

Many investigators dislike the term "washload" and often substitute "fine sediment" for "washload." The late Paul Benedict always insisted that his colleagues use the term fine sediment instead of washload. However, the use of the term fine sediment load for washload helps perpetuate the confusion that sometimes occurs.

Load and Discharge

The term "load," which refers to the material that is being transported, has sometimes been used in place of "discharge," which refers to the rate of transport of the material. Therefore, "sediment discharge" refers to the transport rate of sediment load. The term "bed sediment load" should be used instead of bed material load because "material load" is redundant. Similarly, "fine sediment load" should be preferred to "fine material load."

Fine Sediment Load

Fine sediment load is defined as the load of silts and clays, which have diameters smaller than 0.0625 mm. The fine sediment load includes the electro-chemically interacting clay particles which affect the fluid properties and settling velocity of larger particles.

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Washload

The concept of washload was introduced by Einstein, Anderson and Johnson (2) and defines the size fractions of total sediment load not present in significant amounts in the sediment bed and which is easily washed away by the flow. Washload depends upon the upslope supply of fine sediments and the upstream flow conditions. Einstein (3) suggested that the largest sediment size of washload may be arbitrarily chosen as the grain diameter D_{10} of which 10% of the total bed sediment is finer. The sediment load excluding the washload is termed the bed sediment load. Einstein and Chien (4) experimentally verified that the washload could not be predicted from Einstein's bedload function. The limiting sediment size between washload and bed sediment load corresponds to the point at which the sediment transport capacity equals the sediment supply from upstream (9). Washload does not have any direct relation to the size of the sediment although many engineers assume the limiting size of washload to be approximately 0.0625 mm which corresponds to the fine sediment load defined above.

In summary, three criteria have been recommended to separate the washload from bed sediment load: (1) Grain diameter D_{10}; (2) transport capacity and supply curves; and (3) sediment size finer than 0.0625 mm. Some difficulties in the use of these criteria are analyzed in the following examples.

Large Concentrations of Fines

With large concentrations of fine sediments in suspension, the range of particle sizes in the bed broadens to the extent that the sediment size corresponding to D_{10} is arbitrarily defined. Fine sediments are found in large proportions in the bed and the D_{10} can be much smaller than 0.0625 mm as shown in Fig. 1.

The backbone of Einstein's concept based on D_{10} implies continuous exchange between the particles in suspension and those found in the bed. With increasing concentration of fines, the viscosity increases and the settling velocity of sand-sized particles is reduced significantly (11).

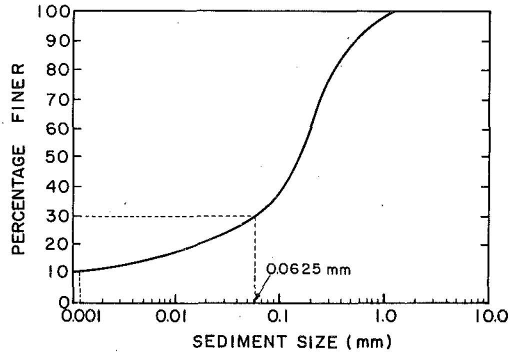

FIG. 1.—Bed Sediment Size Distribution

Once particles larger than D_{10} in the bed are brought to motion, their sedimentation diameter becomes so small that there is virtually no exchange between these particles and those remaining in the bed. In this case, particles larger than D_{10} can be considered as part of the washload.

Changes in viscosity by several orders of magnitude have been observed at very low concentrations of montmorillonite and kaolinite clays (8). In addition to major increases in viscosity, the fluid gradually behaves as a non-Newtonian fluid due to the cohesive properties of the clay particles. The criteria based on sediment supply and transport capacity then proves difficult to apply since large concentrations of fines affect both the fluid properties and the transport capacity.

Experiments by Einstein and Chien (5) with a wide range of sediment sizes showed segregation of bed material which makes the determination of a representative bed sediment size rather difficult. Flume studies by Simons, Richardson and Haushild (10) showed that sand bed channels can be impregnated with clays. Nordin (6) also reported field evidence of clay-cemented channels in which the bed is armored with clays. These additional effects of segregation of bed sediment, impregnation of clays and clay-cemented channels invalidate the definition of washload at large concentrations of fine sediments.

Gravel and Cobble Bed Streams

The concept of washload in coarse bed streams also poses some difficulties. Unlike the previous example, all the material transported is basically non-cohesive. Flow velocities in steep mountain streams are sufficiently large to transport large sediment sizes without significant

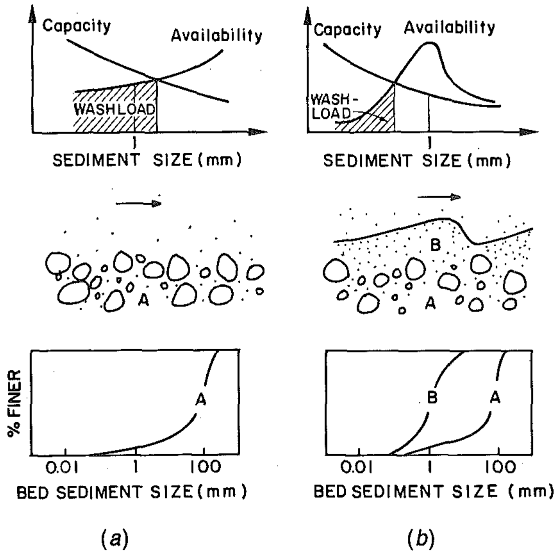

FIG. 2.—Washload versus Bed Sediment Load in Coarse Bed Streams: (*a*) Sand-Free Cobble-Bed Stream; (*b*) Sand-Covered Cobble-Bed Stream

deposition on the gravel or cobble bed. As a result, sand-sized particles may be included in the washload.

Two cases are illustrated in Fig. 2. When the sediment transport capacity exceeds the availability of sediments, or supply, the sand particles transported as washload are not found significantly in the armored bed illustrated in Fig. 2(*a*). In some cobble-bed streams the sand supply varies periodically and at times may increase until it exceeds the transport capacity of the flow. Deposition then occurs until the cobble-bed stream is completely covered with sands [Fig. 2(*b*)]. Sand particles can then be treated temporarily as part of the bed sediment load of a sand-covered channel. Schematically, the bed sediment size distribution shifts from Curve A to Curve B when the sediment supply exceeds the transport capacity, and returns to Curve A when the transport capacity exceeds the supply. Consequently, in a given channel the same sediment size can be included either in the washload or the bed sediment load, depending upon the availability and the transport capacity for that size fraction.

Conclusions

"Washload" and "fine sediment load" are not synonymous. Fine sediment load refers to silts and clays and washload refers to the part of the total load that is washed through the channel and not found in significant quantity in the bed. The term sediment load denotes the material that is being transported and the term sediment discharge designates the rate of transport of the sediment load.

In streams with large concentrations of fines, the sediment size D_{10} may be much smaller than 0.0625 mm. The fluid becomes very viscous at low concentrations of clays and the reduced settling velocity inhibits the exchange of sediment particles between the bed and the suspension. The sediment transport capacity under those conditions remains very poorly defined.

In coarse bed streams, sands and fine gravels can be considered as washload as long as the sediment transport capacity remains larger than the availability of sediment. Intermittently, different conditions prevail when the upstream supply exceeds the transport capacity.

Appendix.—References

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