SILTATION IN IMPOUNDMENTS

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Parameters related to impoundment siltation are outlined and the areas of uncertainties and research are identified.

The basic needs for irrigation, the ever-increasing demand for water supply and power, and the recent emphasis on water-oriented recreation have stimulated the wide-spread construction of man-made lakes or impoundments. In planning for the overall effective use of impoundments, it is important to consider the unavoidable problem of siltation. This report is an attempt to point out the parameters related to the phenomenon of siltation and to identify the areas of uncertainties and future research.

WATERSHED MANAGEMENT AND EROSION

Sediments originate with some erosive action upon the watershed area (1). Therefore, watershed management, which is defined as the "most efficient use of the land within its capability for sustained production of crops, grass, and trees as well as for nonagricultural purposes" (2), becomes a significant factor. In describing erosion, the ASCE Task Committee (3) reports that, usually, fine-grained sediments result from sheet erosion, while coarse-grained sediments result from channel erosion, and that total prevention is impossible. Consequently, concentration of efforts entirely on remedial measures is unacceptable because it is then too late to do any good. Preventive and remedial measures, implemented simultaneously, appear to be more effective with small watersheds than with large ones. Moore and Smith (2) present information relative to the benefits derived from pilot projects; they state that additional advantages accruing from such control measures are improvement in water quality and improved fish and wildlife habitat.

TRANSPORTATION AND DEPOSITION OF SEDIMENTS

Since the publication of the Task Committee's Progress Report in 1962 (3) our knowledge of transportation and deposition of sediments has not advanced materially. This has been true because the mechanism of turbulence is so vastly complex and may never be solved except in a gross statistical way. The classical hydrodynamics approach, which stipulates that deposition is a direct function of the weight of the suspended particle in the water medium and, consequently, of its diameter, continues to be the principal postulate (4). As an extension of this observation, critical or threshold conditions for the initiation dislocation mechanism and subsequent movement of sediments have been advanced and presented in the 1966 Progress Report of the Task Committee (5). There still exists, considerable degree of inaccuracy involved in the equations predicting both transport and deposition. It appears that the unpredictability arises from the interdependence of the flow characteristics on the properties of the sediment itself; in turn, the silt load is under the peculiarly mutual influence of bedload and suspended load. Attempting to delineate these influences, Einstein (6) observed that silt particles moving over a gravel bed settle out by filling first the bottom voids of the gravel bed. He further proposed the "half-life T" concept, defined as the time a particle may stay in suspension until its concentration has been reduced to half the original value by deposition in the gravel bed.

The relation of sediment transport, Q_s, to streamflow, Q, is depicted through a general equation of the form

$$Q_s = kQ^n \qquad \text{Eq. 1}$$

Unfortunately, the difficulty in correctly evaluating the variables k and n diminishes the sensitivity of this equation and, therefore, the prediction of Q_s is in error, oftentimes. In fact, this general relationship is a quantified observation from the several postulations of sediment load theories. Vanoni (7) in 1961 applied the eight most important and best known sedimentation formulae to several North American streams. The results indicated that most of the formulae were a good "ball-park" estimate of the measured condition of sediment load in the streams. Nevertheless, in the absence of a better methodology, equation 1 provides for a useful design tool for estimating sediment inflow to impoundments, but its reliability does not exceed 75%.

To explain the processes of transportation and deposition, it is imperative to gain an understanding of the pertinent properties of sediments, *e.g.*, size distribution and shape of particles, specific weight, sediment concentration, and mineralogical composition. These and a treatment of the parametric dependability of sedimentation are described in Reference 3.

The mineralogy of sediments, traditionally, has not been of major concern. Current studies by the University of Oklahoma School of Civil Engineering and Environmental Science, at Lake Thunderbird in Norman, indicate that the mineralogical composition of sediments less than five microns in diameter is an important parameter because it gives rise to particular electrochemical behavior of these sediments. It was observed that sediments having kaolinitic-illitic mineralogy settled at a higher rate than those having montmorillonitic mineralogy, possibly because the former were constituted in denser flocs than the latter. Thus, the montmorillonitic particles stayed relatively dispersed in the suspension. Due to the predominance of calcium the effect of the adsorbed ions could not be assessed, except that phosphate activity in the water medium tended to cause larger settling velocities because phosphates tended to cement the particles together. Although laboratory studies suggest that warm temperatures may cause greater amounts of deposition for equal sediment loads, delineation of these influences from temperature effects have not yet been carried out in the field.

SILTATION SURVEYS AND SEDIMENT ANALYSIS

The useful life of an impoundment is terminated when the volume of deposited materials assumes a level sufficient to prevent the impoundment from serving its intended purpose. Following Brune's work (8), the trap efficiency of reservoirs can be computed using the specific weight for a deposited sediment. There are some difficulties inherent in this predictive method. For example, while a 40-50-10 (clay-silt-sand) combination is reported to be not unusual for settled material, the texture of the bed load may vary depending on geological factors, detention time, and runoff characteristics.

On the other hand, certain depositional patterns can be established between gradation characteristics and location of deposition, but they are very general. For example, larger particles are deposited as a delta at the head of the impoundment and smaller particles are deposited farther down towards the retaining strucure; however, absence of strong currents and increased biochemical activity in shallow areas may cause excessive deposition of smaller particles in these areas. Also conducive to errors is the wide range of variability in specific weight of the deposited material which is reported (9) as varying between 19 to 106 lb per cu ft depending on whether the material is fine- or coarse-grained.

Sedimentation surveys may be predictive or actual. In the predictive method the bed load or the probable rate of sedimentation is calculated from data of the suspended sediment of the inflowing rivers. Stevens (10) estimated the bed load to be 15% of the suspended load. What reduces the reliability of this approach is its dependence on variables such as location of the site, management of the watershed area, nature and slope of the river bed, velocity, and depth and shape of the feeding stream.

The actual survey method consists of field measurements of the core type carried out to establish differences between periodic capacities of the impoundment, the differences being interpreted as siltation. Given possible maximum variations of 40 to 100% for water content, and 19 to 106 lb per cu ft for specific weight, it becomes evident that the imposition of various consolidating loads introduces errors even on systematic sedimentation volume or thickness survey. The specific weight equations proposed by Lane and Koelzer and modified by Milk (3) are empirical but the engineer today has no alternative except to rely on them. recently developed method of sedimen measurement employs an x-ray gauge (11). This is a continuous operation and it is based on measuring the ratios of the attenuation of x-rays through the river water and through a reference cell or distilled water. The ratio is functionally related to the concentration of the suspended sediment in the river water.

SEDIMENT CONTROL AND ECONOMIC ASPECTS OF SEDIMENTATION

Impoundments are the result of political decisions. Hopefully, engineering and economic data are used as inputs.

Sediment control can be effected by watershed protection projects (12) and by retarding basins (13). The former are applicable to large sheet erosion areas. Therefore, evaluating the reduction of sediment yield at the mouth of the watershed involves identifying component benefits which are not always measurable. Retarding basins have been applied to small areas such as channel erosion, and their effectiveness can be expressed in terms of "trap efficiency," usually approximately 30%.

Damage from sedimentation in storage reservoirs is estimated to have reached detrimental proportions. This damage could be reduced by providing upstream control or additional storage or removal of bed load. The problem, then, clearly lies in allocating resources according to competing financial considerations.

RESEARCH NEEDS

The foregoing leads to the conclusion that sedimentation requires in-depth study and research. This need can well be described by asking the following questions:

1. What is the relationship between physicochemical properties of sediments and flow characteristics?
2. How can sampling and sedimentation survey methodology be improved?
3. How does bed load affect sedimentation and vice versa?
4. What is the mechanism of physical sediment-water mixing?
5. How can the physical, biological, and chemical factors effecting sediment-water exchange of phosphates be quantified?

It appears, then, that the integrated efforts of the hydrologist, the soil scientist, the physiocochemist, and the microbiologist are needed. Furthermore, it should be recognized that the man-made lakes constitute a laboratory, otherwise unobtainable.

REFERENCES

1. Committee on Sedimentation, J. Hydraulics Div., Amer. Soc. Civ. Engr. 92 (Proc. paper 4746): 243-290 (1966).
2. W. R. Moore and C. E. Smith, J. Irrigation and Drainage Div., Amer. Soc. Civ. Engr. 94 (Proc. paper 6126): 321-331 (1968).
3. Committee on Sedimentation, J. Hydraulics Div., Amer. Soc. Civ. Engr. 88 (Proc. paper 3194): 77-127 (1962).
4. G. R. Alger and D. B. Simons, J. Hydraulics Div., Amer. Soc. Civ. Engr. 94 (Proc. paper 5949): 721-737 (1968).
5. Committee on Sedimentation, J. Hydraulics Div., Amer. Soc. Civ. Engr. 92 (Proc. paper 4738): 291-314 (1966).
6. H. A. Einstein, J. Hydraulics Div., Amer. Soc. Civ. Engr. 94 (Proc. paper 6102): 1197-1205 (1968).
7. V. A. Vanoni, N. H. Brooks, and J. F. Kennedy, *Sediment Transportation and Channel Stability*, Rept. No. KH-R-1, W. M. Keck Laboratory, California Institute of Technology, Pasadena, Jan. 1961, pp. 6-15.
8. G. M. Brune, Trans. Amer. Geophys. Union 34: 407-418 (1953).
9. M. Pais-Cuddou and S. N. C. Rawal, J. Irrigation and Drainage Div., Amer. Soc. Civ. Engr. 95 (Proc. paper 6789): 415-429 (1969).
10. J. C. Stevens, Trans. Amer. Soc. Civ. Engr. 111: 1231-1242 (1946).
11. C. E. Murphree, G. C. Bolton, J. R. McHenry, and D. A. Parsons, J. Hydraulics Div., Amer. Soc. Civ. Engr. 94 (Proc. paper 5868): 515-528 (1968).
12. Committee on Sedimentation, J. Hydraulics Div., Amer. Soc. Civ. Engr. 95 (Proc. paper 6438): 649-675 (1969).
13. L. W. Curtis, J. Hydraulics Div., Amer. Soc. Civ. Engr. 94 (Proc. paper 5951): 739-744 (1968).