Erosion and Sediment Transport Monitoring Programmes in River Basins (Proceedings of the Oslo Symposium, August 1992). IAHS Publ. no. 210, 1992.

The design and operation of sediment transport measurement programmes in river basins: the Chinese experience

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ABSTRACT Experience in the design and operation of sediment measurement programmes in China is reviewed in the paper. Evaluation of water and sediment flow and its variation in tributary streams and measurement of sediment transport in main rivers are discussed and some of the results of observations are illustrated. Methodologies and instrumentation currently adopted in routine measurements are briefly reviewed. A sediment measurement programme should be oriented to the sediment problems encountered in river basin development and also to monitoring the whole process of sediment yield, transport and deposition in a river basin, including both natural and man-made variations.

INTRODUCTION

Sediment measurements in river basins may be classified into two major categories. The first aims to assess or evaluate the spatial and temporal variation of water and sediment runoff in the light of river basin development. The second aims to provide a database for studying sediment problems related to specific projects. According to incomplete statistics, there are more than two billion tonnes of sediment entering the coastal areas of China every year. Proper management of sediment has become a key issue in the development of the basins of sediment laden rivers and also, of rivers with moderate sediment content. Wolman(1989) and others have pointed to the importance of long term efforts in erosion control and reservoir management. A long term data collection programme in the river system is indispensable. In this paper, sediment measurement programmes will be discussed in close association with sediment problems encountered in the development of water resources in a river basin.

SEDIMENT MONITORING PROGRAMMES FOR EVALUATION AND ASSESSMENT OF WATER AND SEDIMENT IN A RIVER BASIN

Since the early fifties, hydrometric stations have been gradually set up according to the network planning, in which, measurement of sediment loads in the rivers is an important item. Spatial and temporal distribution of sediment yield as well as its size gradation can now be defined on the base of systematic collection of data in the field for about forty years. It has been found from data analysis, for many sediment-laden rivers in China, that the source area of a large portion of the sediment is confined to a limited area. For instance, in the Yellow River basin, nearly half of the coarse sediment, being greater than 0.05 mm, originates from an area representing less than 7 % of the drainage area (Long, 1986). The finding is so significant that, for mitigation of serious flood prevention problems in the lower reaches due to aggradation, it would be possible to focus our effort on constructing structural or nonstructural measures for reducing the sediment output from these area. As a matter of fact, since the early seventies, the sediment load entering the lower Yellow River has been gradually reduced by an average of 0.2-0.25 billion tonnes per year, representing nearly one eighth of the annual sediment load.

Needless to say, sediment measuring programme in river basin should be well planned and implemented. They should be problem-oriented, cost effective and well coordinated in operation. For studying the spatial and temporal variation of water and sediment in rivers fed mainly by storm rainfall, such as the middle Yellow River basin, hydrometric stations in the tributary basins, most of which may be classified as second grade stations, are established in such a way that each station represents a certain physiogeographic region, usually with a drainage area varying from 500 - 5000 km^2. For regions with no station, the hydrological characteristics are expected to be interpolated from stations located in similar geographic areas where data have been collected over a long period. In addition, to take account of the uneven distribution of rainfall and sediment yield, a number of third grade hydrometric stations were established in small watersheds with an drainage area less than 500 km^2 are incorporating a group of rain gauges scattered throughout the watershed. Accuracy requirements and the frequency of taking measurements are higher at second grade stations.

In order to illustrate the methods adopted in obtaining the preliminary assessment of the temporal variation of sediment loads, the study of Dai (1991) is cited here as an example. The tributary under study has an drainage area of 5891 km^2 above the station and is located in the middle Yellow River basin. Since the late sixties, many desilting dams were built in the basin leading to a remarkable reduction in the output of water and sediment. There are several hydrometric stations and a number of raingauges distributed over the basin with a record of nearly 30 years.

In the data analysis, base flow is extracted from the observed hydrograph and correlations are established between rainfall parameters, surface runoff and sediment discharge using data observed prior to 1970, during which human activities were not so pronounced as in the later periods, as demonstrated in (cf. Fig.1). Using the observed

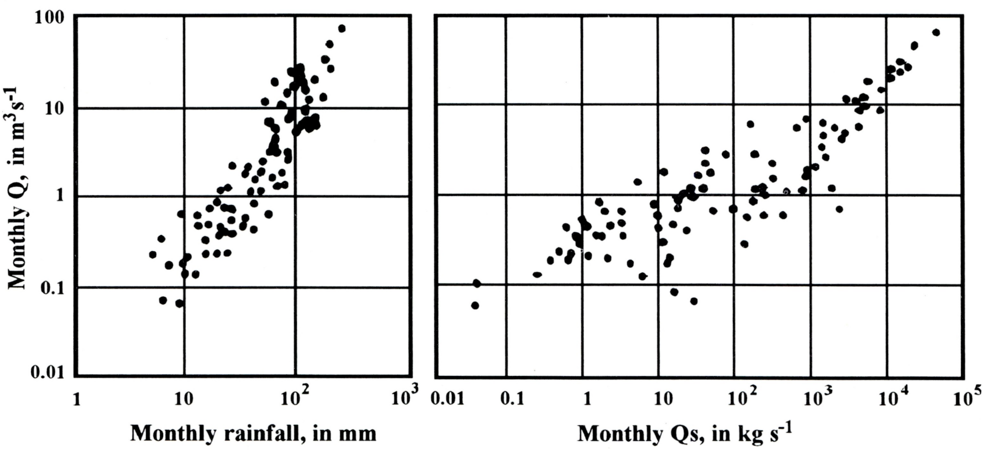

FIG. 1 Relationships between monthly rainfall,discharge and sediment discharge for the Ganguyi Station on the Yanhe River.

rainfall data in the later period, these relationships were used to estimate the water and sediment runoff which can be compared with the observed value to distinguish the variation of water and sediment runoff due to the intensive human activities from the natural variations. In a river basin located in the semi-arid temperate zone fed mainly by storm rainfall such as the basin cited above, similar methods are used to study the influence of human activities on the variation of water and sediment which is rather pronounced. In addition to the network of hydrometric stations, experimental stations were established to study in detail the rainfall-runoff process in small watersheds. The process of sediment yield may be simulated by using the unit hydrograph concept. However, a sufficient number of automatic recording raingauges is required to define the rainfall intensity and these may not be available in large basins.

A SEDIMENT MEASUREMENT PROGRAMME FOR STUDYING RIVER SEDIMENTATION PROBLEMS IN AN ALLUVIAL RIVER

It is well known that an alluvial river will respond to the modification of flow and will adjust its sediment transport capacity through changes is the bed composition, slope and its morphology in conformity with the oncoming sediment load. The modification may be caused by the regulation of flow associated with large hydraulic structures, by reduction of sediment inflow due to retention in the upland area or by human interference of the flow boundaries. The status of sedimentation in an alluvial river, in particular its lower reaches, could have a great influence on flood prevention, navigation and water withdrawal for irrigation or municipal use in areas in proximity to the river, which are usually densely populated.

In order to study the problem, it is necessary to set up an observation network including a series of hydrometric stations taking measurements of discharge or water stage along the river, and a series of cross sections for repetitive sedimentation surveys in river reaches, reservoirs and in the estuarine area. In addition, experimental work has to be conducted to study specific problems related to fluvial processes. Monitoring programmes are to be planned from time to time to collect essential data, not only to clarify the existing status and the physical basis of sedimentation, but also to provide a data base for studying in depth the behaviour of the river in response to flow modification using modelling techniques.

Sanmenxia Reservoir is a key project built on the main stem of the Yellow River which commenced operation in 1960. Due to the rapid rate of deposition in the reservoir and the unexpected upstream extension of the backwater deposits, the outlet structures of the dam were reconstructed to facilitate a change of the operational mode from impoundment to storing only clear water in the nonflood season and discharging the muddy water during the flood season. The whole process of deposition and erosion in the reservoir and in the lower reaches has been monitored by similar arrangements as cited above. Data collected in this programme provide valuable realtime information on river sedimentation and are used in the planning of flood prevention as well as in comprehensive river basin development. As an example, the result of observations are shown in Fig. 2. It can be seen from the process of sedimentation in the Sanmenxia Reservoir, in its broad sense, that little deposition in the reservoir has occurred since the change in the operational mode in 1974 involving storing water only in the nonflood season. By regulation of the flow released from the reservoir, the rate of aggradation in the lower reaches of the reservoir was reduced.

These findings are important in the planning and operation of a reservoir built on a

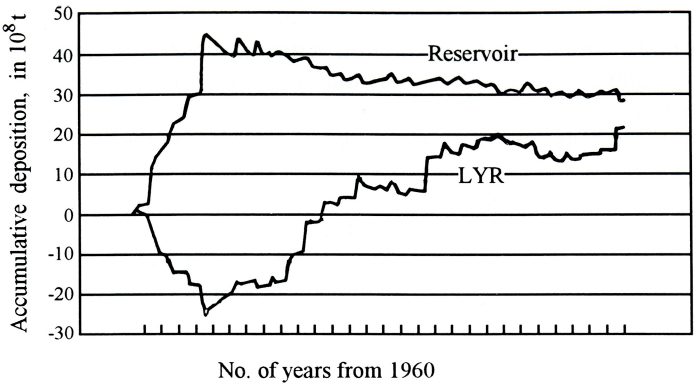

FIG. 2 Accumulative deposition in the reservoir and lower reaches.

sediment-laden river since they show that it is possible to construct multipurpose projects on the river to maintain useable reservoir capacity for long term use and to regulate the water and sediment outflow to be compatible with the transport capacity of the lower reaches and, therefore, to minimize aggradation.

In the measurement of sediment discharge at a hydrometric station, data relevant to sediment transport were also collected including discharge, width and depth of flow, velocity, water surface slope, water temperature, sediment concentration, size distribution of suspended sediment and bed material etc. The daily, monthly and yearly sediment load can be evaluated through data processing, and the data can also be used to study the total load transport of the river by applying procedures similar to the Modified Einstein Procedure proposed elsewhere in the literature. The problem is important, since there always exists an unmeasured zone in the vicinity of the river bed if the depth integrating method is used for sampling suspended sediment and also, the conventional method of computation of sediment discharge in a vertical by points would introduce error into the computation by assuming that the sediment concentration measured at the lowest point, around 0.9 - 0.95 relative depth, is the same as the sediment concentration at the bed. Hence, in the evaluation of the sediment load passing a section of the river, the fractions of coarser sediment are commonly underestimated (Lin, 1988). A comparison of the possible deviations between size fractions indicates that the error would be very large for sizes greater than 0.10 mm. The comparison is based on the analysis of the observed data and the application of the Modified Einstein Procedure, modified further to be applicable to our conditions, at the Tongguan Station.

The data base collected during the measurement of sediment discharge may also be used to study the transport characteristics of the river. Published transport equations can be checked or verified by means of these data to look upon their applicability to the local conditions, or, new equations may be developed to be adapted in studying river sedimentation problems.

For sediment measurement in an alluvial river, the sedimentation survey serves as an important constituent in the programme. Taking account of the permissible error pertinent to the measurement of sediment load at a hydrometric station, one cannot obtain a reliable estimate of the amount of erosion or deposition in a river reach by directly calculating the difference in sediment load between two adjacent stations (Lin & Long 1988). Repetitive survey is an irreplaceable way to obtain the information. A better understanding of the fluvial processes of an alluvial river through repetitive surveys is the key to developing, verifying, or improving either mathematical or physical models, which are becoming more and more popular for studying the river engineering problems.

OPERATION OF THE SEDIMENT MEASUREMENT PROGRAMME

In the operation of a sediment monitoring programme, there are three aspects to be considered. One is the standardization of the method used for field measurement and data processing. In China, national standards for sediment measurements and guidelines for hydrographic survey in reservoirs and river reaches were issued and have been implemented for years. In recent years, most of these were revised and updated including standards for measurement of the suspended load and bed load, sampling of bed materials and laboratory analysis of size gradations. The publication and implementation of these standards will nevertheless promote better data collection.

As for instrumentation, the author (1990) made a brief review of the recent progress in sediment measuring techniques in China. Generally, traditional mechanical device are still predominant ,but great improvements were noted. Modern techniques, in their broad sense, have gradually been applied to this field. For suspended sediment sampling, a variety of time integrating samplers were developed, in which the intake velocity is adjusted either by a collapsible bag or by a pressure chamber. For bed load measurement, assisted by the intercomparison between The HS and TR-2 sampler developed in the United States and the Y78-1 and MB-2 sampler developed in China, a new version of sampler which combines the features of a pressure difference sampler and a flexible bottom sampler is under evaluation showing good performance in preliminary tests.

For size analysis, photosedimentation apparatus has been developed and used for routine analysis in association with the pipet method with greatly improved efficiency and saving of labour in the laboratory operation.

For the hydrographic survey in rivers and reservoirs, a surveying system has been developed in the Yangtze River, in which a laser distance measuring device, mounted on an electronic theodolite is used for positioning and an echo sounder is used for depth measurement. The data are transmitted or interfaced to a portable computer for further processing or for guiding the navigation of the survey vessel along preset courses. Surveying of sandy bars can be performed with no requirement to position stadia rods on the soft surface which is very difficult to walk over without sinking. The system was designed in conformity with the current practice in the hydrographic survey in China and is readily applicable in most rivers in China.

The third aspect is the schedule of taking measurements. In a river basin, hydrometric stations are classified into three categories. The first grade stations are generally key stations playing an important role in controlling the sediment yield from the basin, or in studying the behaviour of the river in response to the modification of flow. In such stations, parameters relevant to sediment transport are observed. Bed load measurements should also be made at some of the stations. The concept of total load can serve as a guide to deciding which items are to be measured. Higher accuracy and frequency of measurements are required than in other stations. Sampling for size analysis is generally required not only for suspended sediment but also for the bed material if it is an alluvial river. In the second grade stations, being representative of particular physiogeographic regions, the required accuracy of taking measurements is lower and measurements may be taken less frequently in the nonflood season during which only a small percentage of the flow takes place. Sampling for grain size analysis is required at some of these stations. In the third grade stations, simplified methods of measurement are usually used and at some part of these stations, measurements are taken only in the flood season.

For sedimentation surveys in rivers, reservoirs and in the estuarine area, cross sections or ranges should be established with a reasonable density. They are surveyed repetitively once, or even twice a year in heavily sediment laden rivers or, once in several years. Topographic surveys are taken in general once every five or ten years. Aerial photos taken once in a while can be used to advantage for studying fluvial processes. Sedimentation surveys are an expensive and laborious task, but by using the surveying system mentioned in the previous paragraph, labor inputs and costs are reduced.

CONCLUDING REMARKS

Movement of sediment in a river basin in the process of sediment yield, transport and deposition is part of the hydrological cycle. The process as a whole is, however, much less studied by hydrologists or scientists. In recent years, sedimentation problems have been gradually looked upon as an important issue to be dealt with in river basin development. Measurements of sediment transport in a river basin provide information on the natural law of sediment movement and, also on the influence of human interference on the process. It is important in rivers with heavy sediment load, and also in rivers where the sediment load is not excessive, to study the whole process and its interrelationships. Sediment monitoring work was developed to provide a sound database for the solution of practical engineering problems and probably will follow the same trend of development in the future. However, the natural law of sediment movement in its process of yield, transport and deposition; the spatial and temporal distribution of sediment load and its future trend, which may be influenced by the global change of climate, as recognized recently by scientists (Osterkamp 1991); the impact of human activities on sediment movement in the era of growing population, etc. represent information which is of major importance to the development of water resources in a river basin. The design of a sediment measurement programme should take into account the above two aspects, and the operation or implementation of the programme may take advantage of recent progress in this field.

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