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Variability of sediment load and its impacts on the Yellow River

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Abstract Variation of runoff and sediment load in the main Yellow River is reported in this paper. Reduction of sediment load, variation of its seasonal distribution, the compatibility of water and sediment runoff and attenuation of peak flow in the past two decades are described and analysed using hydrologic and soil conservation methods. It is found that besides natural variation due to less rainfall, human activities, including soil conservation and construction of large reservoirs, play an important role. Preliminary results of a study of the variability of the river flow and the response of the alluvial reaches to these variations are presented. The methods used in evaluation of the variability are also discussed.

INTRODUCTION

In an effort of taming the Yellow River and developing its water and sediment resources, a large amount of work was done in the past four decades which promoted economic development and also induced variation of both the water and sediment runoff. Long has described the erosion, sediment transport and deposition process in the whole basin (Long, 1986). Problems of floods and sediment were explained by various authors in the proceedings (Brush, 1989). This paper will discuss the variation of sediment load and its impacts on sedimentation observed in recent decades. Present status of harnessment work is illustrated briefly in Fig. 1 (Yellow River Conservation Commission, 1987).

VARIATION OF WATER AND SEDIMENT IN THE YELLOW RIVER BASIN

Annual runoff

A tendency for reduction of annual water and sediment runoff has been observed for two recent decades. Average annual water runoff and sediment load above Sanmenxia were 45.6 billion m^3 and 1.75 billions tonnes respectively from the 1930s to the 1960s. It had reduced to 36.0 and 1.36 respectively in the 1970s and 36.4 and 0.78 respectively in the 1980s. In the 1980s, not only was the amount of sediment load reduced but also the

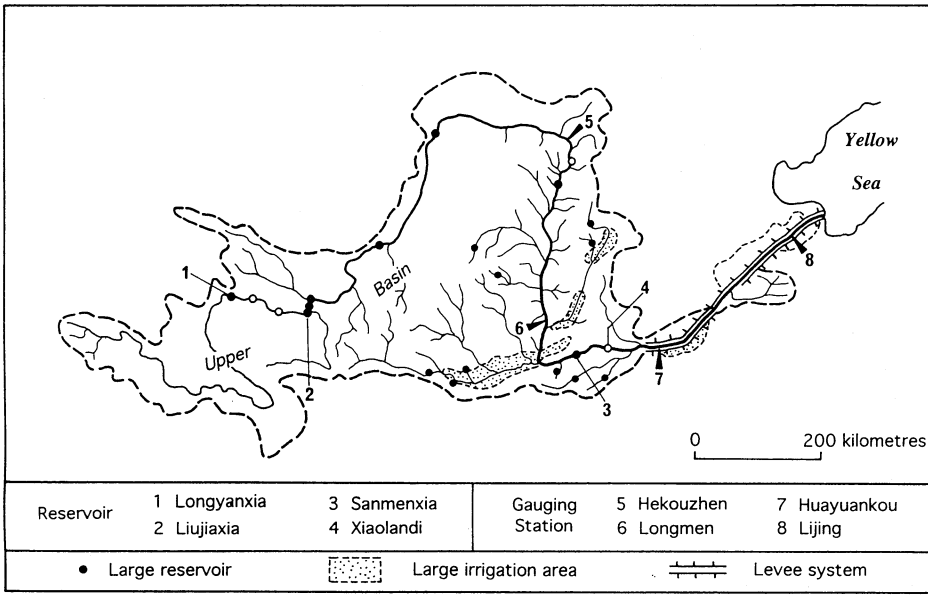

Fig. 1 The Yellow River basin.

percent of coarse sediment greater than 0.05 mm had reduced from 31% to 24% (IRTCES, 1993).

Seasonal distribution

Since the commencement of operation of the Liujiaxia Reservoir, one of the large reservoirs on the main stem of the upper Yellow River in 1968, the percentage of runoff in the nonflood season had raised from the original 40% to 47% and it was further raised to more than 50% after the impoundment of Longyanxia Reservoir in 1986. Since 1974, sediment-free water was released from the Sanmenxia Reservoir during the nonflood season and the whole year's sediment load was imposed on the lower reaches in the flood season causing great changes in the seasonal distribution of the sediment load.

Floods

Floods entering the Sanmenxia Reservoir are composed of floods originated from the upper and middle basin. The upper basin usually has a relatively large volume discharge and far less sediment concentration serving in general as the baseflow while the middle basin has a high peak flow and is heavily sediment laden. Due to regulation in the upper reservoirs, the flood volume would be reduced in most cases leading to an increase in sediment concentration.

For sediment management in the Sanmenxia Reservoir, the outlet structures had been reconstructed and its discharge capacity enlarged. The mode of operation has changed from impoundment to only flood detention and then to storing only the relative clear water in the nonflood season and sluicing the muddy during floods (Long & Zhang, 1987). Ratios of attenuation of the peak flow, i.e. the difference of peak discharge observed at inlet and outlet to the peak discharge at the inlet, corresponding to floods with peak flows of 4000-6000, 6000-9000 and greater than 9000 $m^3 s^{-1}$, were 0.27, 0.37, and 0.63 respectively during the period of operation for impoundment (1960-1964), and 0.23, 0.28, 0.44 during the period of flood detention (1965-1973), and reduced further to 0.06, 0.19, and 0.33 for the present operation mode (1974-date), during which, no detention would take place for ordinary floods according to design criteria.

The results of the work done in tributaries towards attenuation of ordinary floods are obvious. Flood and sediment runoff would be greatly reduced during heavy rainstorms provided the rainfall intensity is not excessive. In consequence the number of flood events is greatly reduced.

Compatibility of water and sediment

Compatibility of water and sediment may be expressed by variations of sediment load corresponding to different classes of discharge as shown in Fig. 2, in which, the range of discharge corresponding to maximum sediment load at the outlet station is decreased during the detention period and raised during the latter period.

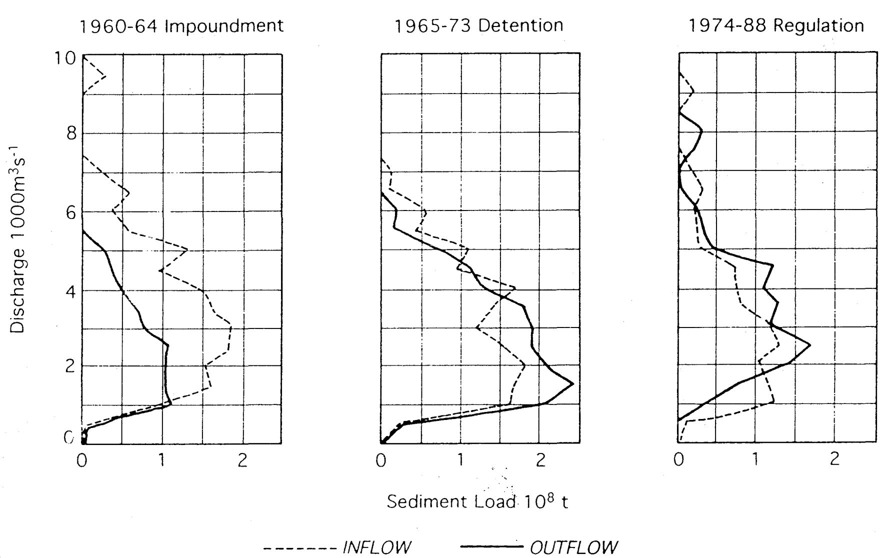

Fig. 2 Sediment load at different discharges.

METHOD OF ANALYSIS

Data base

The earliest gauging station was established in 1919, with the number increasing to form a network in the mid 1950s. Up to 1990, there were 445 gauging stations set up for routine discharge and sediment measurements and more than 2400 raingauging posts. In the past four decades 2685 large, medium and small sized reservoirs were built in the basin. Reservoir surveys were carried out once in a year, or intermittently for large and medium size reservoirs on the main stem and tributaries. Reconnaissance surveys by simplified methods were conducted once every several years for small reservoirs scattered in the basin. Sediment loads withdrawn at large irrigation intakes were directly monitored but were estimated from recorded water data for numerous small intakes.

Since the mid 1950s, reductions of water and sediment by soil conservation measures were studied by several experiment stations located in the loess area. Runoff process was studied in detail at experimental plots in Chaba Gully from 1958 through 1970. Accelerated erosion by human activities in typical areas was investigated only by reconnaissance surveys.

These serve as the data base for the study of the variation of water and sediment in the whole basin.

Methods

With the special funding provided by the Government, IRTCES has organized a number of scientists and engineers within various disciplines to study the variability of water and sediment in the Yellow River basin (IRTCES, 1993). Methods used in these studies are briefly introduced as follows:

Hydrological method Rainfall-runoff-sediment relations established by data observed in periods when human activities were not intensive were used to predict the probable output in the later periods with various measures in existence. Tributary basins are subdivided into physiographic units, base flow was deducted, rainfall intensity was considered in the choice of rainfall index and a relatively stable relationship between water runoff and sediment load was used in establishing the correlations. Although the structure of the formulas is more or less empirical, through verification, the coefficient of correlation of most formulae is, in general, exceeding 0.9 used for computing monthly or yearly runoff as well as sediment load. The analysis was carried for each of the large tributaries. Analysis in one of the tributaries was explained by Zhao (Zhao, 1992). Models used to predict sediment yield in a flood event adopted a unit hydrograph concept or correlating the sediment yield with geographic and geomorphic factors were also proposed, but more verification is needed to extend its application.

The method can be used to distinguish between the effects of rainfall and that due to human activities. An average result of computation for 20 odd sediment-laden tributaries indicates that in the 1970s, annual reduction of water and sediment was 1.06 billion m^3 and 0.24 billion tonnes respectively, of which, that due to reduced rainfall accounts for 21.8 and 11.4%. This compares with that prior to 1969, and in the 1980s, annual reduction was 1.57 billion m^3 and 0.39 billion tonnes, among which, that due to less rainfall accounts for about 40.0 and 40.3%. It is clear that the harnessment works play an important role in the reduction of sediment load in the basin.

Failure of sediment retention structures might occur during an excessive heavy rain. According to field investigations of four events in between 1966 and 1977, part of the dam body of 30-64% structures was eroded however, deep channels were formed behind the dam and the major part of the desilted land still can be used for cultivation. Eroded sediment would be deposited again along the valley and only a part might enter into the main channel.

Soil conservation methods Sediment retained by different measures are computed separately. Observed or investigated data may be used directly for large and medium sized reservoirs and irrigation intakes. For soil conservation measures and small water conservancy works, reductions of water and sediment were computed by amount of work done by various measures multiplied by the quota of detention which is defined as the amount of sediment retained per unit area of soil conservation measures. The amount of work was obtained by statistics checked by ground surveyed data or remote sensing in some cases and by direct sampling at cross points of grids located one kilometre apart in one tributary. The quota of detention for terraces, reforestation and grass plantation as well as sediment withdrawn for irrigation, was obtained by applying a discount ratio to that obtained in experiment plots or watersheds checked by reconnaissance survey. For gully control measures, Xiong found that the amount of sediment retained by desilting dams varied with time and proposed a formula to account of this effect which has been verified in three tributaries having drainage areas of 3400-14 700 km^2 with fairly satisfactory results (Xiong, 1993). Besides the sediment directly retained by the desilting dams in the control of gully erosion, the down-cutting and widening tendency of the gullies were controlled to some extent by raising local base level in the desilting dams.

In practice, the aforementioned method was used to indicate relative contributions of various measures. In the middle basin above Longmen, the average annual amount of sediment retained by various measures reached 0.38 billion tonnes, 2.8% accounted for irrigation, 25.0% by small reservoirs and 72.2% by various soil conservation measures. Deducting the estimated increase of sediment load caused by mining, road construction and reclamation on steep slopes, the net effect of reduction of sediment load entering the main stem of the Yellow River was nearly 0.3 billion tonnes per year. By another analysis, among the total amount of sediment retained by soil conservation measures 44.2% was retained by desilting dams, and 21.2, 28.2 and 6.4% were by terraces, reforestation and grassing respectively (Gu, 1993).

IMPACT ON SEDIMENTATION IN THE MAIN RIVER

From a large scale macroscopic viewpoint, sedimentation in the lower Yellow River is closely related to the sediment input to the river. However, due to regulation of large reservoirs, the compatibility of water and sediment may be worsened or improved, increasing or reducing the amount of deposition in the lower reaches correspondingly. By adopting the present mode of operation in the Sanmenxia Reservoir, the water and sediment outflow are more compatible with each other which plays an active role in reducing the rate of aggradation in the lower reaches. During the period from 1974 to 1986, an average annual reduction of deposition of nearly 30 million tonnes is estimated by data analysis checked with the result by computation with mathematic models.

The influence of water withdrawn for irrigation was analysed by Qian with the observed data (Qian, 1993). An increase or decrease of sedimentation in the main channel varies with the original status of sedimentation, diversion ratio of both water and sediment and transport characteristics of the main channel. Other things being equal, the amount of increase in deposition due to diversion would be less if the river were in a state of aggradation. For instance for a slightly aggradated reach, if the diversion ratio of sediment was exceeding 2, deposition in the lower reaches might be reduced. By analysis and computation with a mathematic model it is estimated that an average annual increase in deposition due to water withdrawal amounts to nearly 20 million t.

River regulation works may also play a decisive role in the boundary conditions of the main channel. For the transition of the reach from a wide and wandering reach to a narrow and meandering reach in the lower Yellow River near Gaocun, the width depth ratio expressed as w/d corresponding to range of discharge 3000-6000 $m^3 s^{-1}$ varies in average from 1030 to 440 after implementation of river training works.

One of the important impacts of the flood prevention is the possible decrease in flood conveyance capacity of the river channel in the lower reaches due to attenuation of peak flow for ordinary floods and variation of seasonal distribution of the surface runoff. An alluvial river will adjust itself to accommodate the oncoming flow, which has been regulated to some extent in ordinary years. However, large or even extreme floods might still take place which can't be controlled by present works. Keeping an adequate flood conveyance capacity under the varied oncoming flow conditions is still a key problem to be studied.

CONCLUDING REMARKS

The physiogeographic conditions of the Yellow River basin with a drainage area of 752 000 km^2 are quite complicated. Study of the variation of its water and sediment runoff is an important and difficult problem. The results and methodology presented in this paper are preliminary attempts. More accurate and reliable assessments will be made in the coming years to serve for the improvement of river basin planning and betterment of basin management.

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