Sediment transport in the Yangtze basin

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Abstract Temporal and spatial variations of suspended and bed load at the main stations on the stem stream of Yangtze River have been analysed using 40 years of data. Above Yichang, the Yangtze River is a mountainous river with a close relationship between sediment yield and sediment transport, and the suspended sediment load increased downstream. Below Yichang, it flows on to an alluvial plain and the sediment concentration and load decreased downstream. In the Yangtze basin, the sediment source is concentrated and the sediment delivery ratio is small. Sediment transport is reduced by the human activities. Variations of sediment concentration and load are irregular and no systematic change was found for the 40 years of record.

INTRODUCTION

The Yangtze River is the longest river in China. It is 6300 km long and has a basin area of 1.8 million km^2 and is rich in water resources. At Datong Station, a control station on the downstream Yangtze, the long-term mean annual runoff is 915 billion m^3, sediment concentration is 0.53 kg m^{-3} and sediment load is 472 Mt (Xiang *et al.*, 1990). While sediment concentration is low on Yangtze River, there is a large discharge and the absolute value of annual sediment transport is still large. This large amount of sediment being transported results in some problems with flood control, power generation, navigation and water supply for industry and agriculture.

For comprehensive utilization and planning, engineering construction and river regulation in the Yangtze basin, a great number of sediment observations (including sediment yield, transportation and deposition) have been made by the Hydrology Bureau, Yangtze Water Resources Commission including systematic data processing, analysis, and interpretation (Xiang & Zhou, 1993). This paper describes the characteristics of sediment transport in the Yangtze River.

TRANSPORT OF SUSPENDED LOAD

Suspended sediment load

The distribution of control stations on the main Yangtze and its tributaries are shown in Fig. 1. In the main Yangtze, the long-term mean annual suspended sediment load at Zhimenda Station on the Jinsha River on the upstream Yangtze is 9.71 Mt increasing to 530 Mt at Yichang Station. Below Yichang it decreases to 472 Mt at Datong Station, a downstream control. For the tributaries on the Jialing River, Beibei Station has the

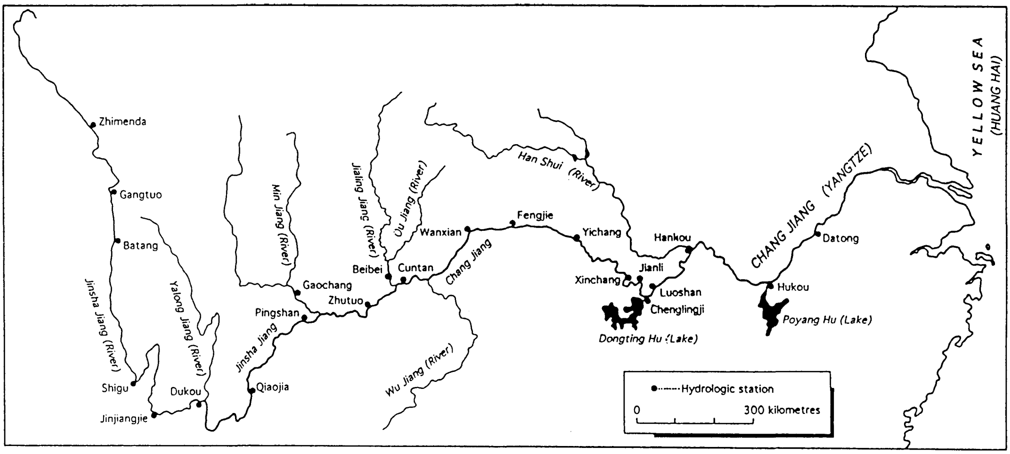

Fig. 1 The Yangtze River and its tributaries showing the major control stations.

highest load of 14.3 Mt followed by Gaochang Station on the Minjiang River with 5.07 Mt. In the other major tributaries those with high loads are the Wujiang River with 32.2 Mt and the Yalong River with 27.5 Mt. Before the construction of Danjiangkou Reservoir, sediment transport at Huangzhuang Station on the Hanjiang River was 124 Mt, and after the construction of the reservoir was 30.1 Mt.

The Jinsha River and Jialing River are the rivers producing the major sediment yield in the upstream Yangtze accounting for 73-90% of the total sediment. The sediment from the other rivers is small, accounting for only 10-27%. Erosion intensity on the downstream Jinsha River is high, and the long-term mean annual sediment transport exceeds 2000 t km^{-2} $year^{-1}$. Its sediment yield is 57% of the total sediment load of the Jinsha River. The western Han River and the mid-section of the Bailong River are the major sediment contributors on the Jialing River, from which the erosion intensity is high and the mean annual sediment load is greater than 3000 t km^{-2} $year^{-1}$. The discharge of the Western Han River and Bailong River are not high but their sediment concentration is high and sediment yield is generally around 29% of the total load of the Jialing River, but reaches a maximum of 83%. These four rivers account for 83% of the total sediment load of the main Yangtze at Dongting Lake over the period 1951-1987. With the systematic cutoff on the Jing River, the diverted discharge at the Ouchi Mouth has decreased, and in recent years the water and sediment volumes of the Yangtze River entering into the lake have decreased significantly. Consequently, the outflow of sediment from the lake has also decreased from 5.95 Mt (1956-1967) to 3.82 Mt (1973-1984) after cutoff.

Variation of suspended load along the river

The variation of suspended sediment concentration and load on Yangtze River is shown in Fig. 2. In the upper Yangtze, upstream of Yichang, sediment increases with drainage area, however decrease in the mid and lower sections from Yichang to Hankou, due to a large amount of deposition in Dongting Lake. Below Datong, sediment load increases slightly.

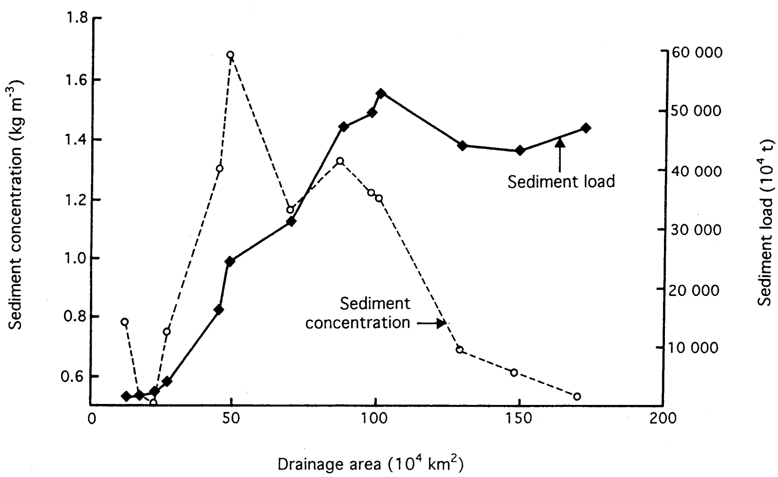

Fig. 2 Suspended sediment concentration and load along the Yangtze stem.

Above Yichang, sediment concentration increases and then decreases, however sediment load continue to increase. Below Yichang, both sediment concentration and load decrease. This is due to by the different characteristics of the river. The Yangtze River above Yichang is a mountainous river with a gravel and bedrock bed, steep slope, high velocity with excess transport capacity and no exchange between suspended and bed load. The load is controlled by erosion of surface soil. Thus, the variation of sediment concentration and load in this reach is closely related to the sediment yield. Downstream of Yichang the Yangtze is an alluvial river. The variations of sediment concentration and load in this section are significantly affected by regulation, storage and deposition of water and sediment in lakes, especially the Dongting Lake. Three quarters of the sediment from the four tributary rivers which flow into Dongting Lake are deposited in the lake resulting in a decrease in downstream sediment. Danjiangkou Reservoir and Poyang Lake also the affect the regulation, storage and deposition of water and sediment.

Intra-annual variation of sediment concentration and load

The variation of sediment concentration and transport runoff throughout the year is determined by the source of sediment. For the Yangtze stem above Yichang, the sediment comes mainly from the erosion of surface soil by precipitation, so the distribution of suspended sediment concentration throughout a year is closely related to the variation of precipitation and runoff throughout the year. The Yangtze River is a flood dominated river, and the major proportion of runoff is concentrated in the flood season, so the variation of annual hydrographs and sedigraphs is similar. However, there are some differences in the low flow season when runoff is derived from ground water, which has low sediment concentrations and results in low loads. Sediment load is the product of runoff and sediment concentration and high loads only occur when there is a coincidence of both, which results in a concentration of load in the flood season.

In the Yangtze River below Yichang, sediment concentration is also affected by scouring and deposition in the river channel and sedimentation in the lake, as well as precipitation. The minimum concentration occurs in February. The variation of mean monthly concentration along the river is: Yichang 0.042 kg m^{-3}, Xinchang 0.194 kg m^{-3}, Jianli 0.278 kg m^{-3} and Luoshan 0.320 kg m^{-3}. Sediment concentration increases significantly below Yichang.

Inter-annual variation of sediment concentration and load

The inter-annual variation of sediment concentration and load depends on the effect of human activity as well as natural factors, such as precipitation (amount, intensity and regional distribution) and the condition of the underlying surface (geomorphological pattern, lithologic character, soil characteristics). An analysis has been carried out of the inter-annual variation trend for Yichang Station. Other upstream stations on the Yangtze stem are basically similar to Yichang.

Figure 3 shows the hydrographs and sediment concentration and load at Yichang from 1950-1992. The long term mean annual sediment load at Yichang Station is 530 Mt, based on data from the 1950s. The variation of water flow and sediment basically coincide, with some fluctuation in the mean annual value but with no obvious systematic deviation. Based on the existing sediment data, there was no systematic trend of increase or decrease of sediment in the upstream Yangtze. In the early 1980s, the high sediment load is related to natural hydrologic phenomena and was not caused by human activity.

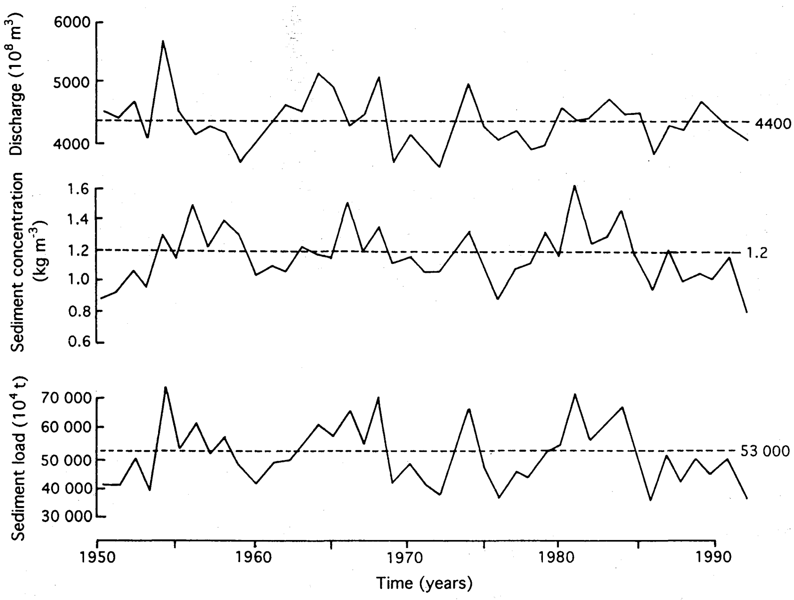

Fig. 3 Discharge, sediment concentration and load for Yichang Station on the Yangtze River.

Grain size distribution of suspended load

The variation of mean annual grain size distribution of suspended load at the control stations on the Yangtze River and its tributaries are described as follows. The grain size at the stations on the Jinsha River is the coarsest, with median grain diameter of 0.045-0.046 mm. This is related to the dry climate, loose surface soil and coarse grained regolith in this region. The median grain diameter at Cuntan is 0.033 mm, finer than all the stations on the Jinsha River. At Yichang it is reduced to 0.029 mm. In the reach from Yichang to Luoshan, a part of the water flow and sediment on the Yangtze stem passes through four river mouths into Dongting Lake where the sediment is deposited. However, due to the effect of systematic cutoff on the lower Jing River, the channel has been scoured. These two factors result in the median grain diameters of suspended sediment at Yichang and Luoshan stations being similar. Below Luoshan, the grain size becomes finer.

TRANSPORT OF BED LOAD

Transport of gravel bed load

The long term mean annual gravel bed load, $D > 10$ mm, of the upstream Yangtze stem at Cuntan Station is 280×10^5 t. It decreases downstream in the Zhutuo-Cuntan reach, but increases gradually in the reach below Cuntan. The sediment load made up of he large or median grain fraction ($D > 50$ mm) decrease slightly downstream in this reach, while the median or small gravel ($D < 50$ mm) increases. In the upstream Yangtze stem, the gravel bed load becomes finer downstream. The median diameter at Zhutuo is 57 mm, and reduces to 26 mm at Yichang.

The gravel load is related to the velocity so the gravel load is concentrated in the flood season. This is shown by comparing the percentages of bed load transport for the period from May-October to that of the whole year at Cuntan (96.8%), Wanxian (99.7%) and Zhutuo stations (99.8%) respectively. The only exceptional is Fanjie Station, which is located upstream of Qutangjia Gorge, where the proportion is 22.5%. Here, there is a back water effect in the valley during the flood season resulting in low slope and reduced velocity. After the flood season, the back water disappears, the surface slope of the reach and the velocity increase, thus a major portion of the gravel bed load is transported in the low-water season from November to April.

Transport of sand bed load

There is considerable variation in the sand bed load associated with variations in grain size. Before the construction of Gezhoubar Reservoir, the river bed at Yichang Station was mainly sand and the mean annual sand bed load was 8.45 Mt (if the 1-10 mm material is included it was 8.78 Mt). After dam operations commenced the annual sand bed load reduced considerably to 0.32-1.41 Mt for the period 1981-1987 due to a coarsening of the river bed composition. The river bed at Fanjie is mainly gravel but in flood season the back water in Qutangjia Gorge reduces velocity and the bed material becomes finer with an increased proportion of sand with a sand bed load transport of 0.81 Mt. This is significantly smaller than that at Yichang.

The river bed at Cuntan is gravel although 13% is finer than 1.0 mm. As the velocity is low, there is no gravel transport and the overlying gravel protects the sand from transport. The water flow has an effect on the exposed surface sand, transporting it, but it can not be supplemented from the underlying sand so sand transport cannot be maintained. When the velocity is increased (bottom velocity > 1.1 m s^{-1}) the gravel starts moving and underlying sand passes into suspension. In the gravel river bed, sand bed load is generally non-existent, only being found as bed load in some individual verticals close to the shore.

CONCLUSIONS

The main source of sediment in the Yangtze River is from the Jinsha and Jialing Rivers. Most of the sediment is from the reach between the confluence of the Yalong River and Jinsha River down to Pingshan, and also from the Western Han River and Bailon River.

Soil erosion associated with human activity in the Yangtze basin is common resulting in increased sediment concentrations and loads compared with natural conditions. However, there is a reduction in sediment due to water and soil conservation and sedimentation in the reservoir. The amount involved is small and so on the Yangtze stem and its larger tributaries, sediment transport has not been significantly affected. From several decades of data, the variation of sediment concentration and load at the stations on Yangtze stem from year to year is irregular. No systemic trend can be shown.

The Yangtze River above Yichang is a mountainous river with a close relationship between sediment yield and sediment transport. The suspended sediment load increases downstream while concentration both increases and decreases. Below Yichang, the Yangtze flows into an alluvial plain and due to the effects of lake sedimentation and the deposition or scouring of the river channel, the suspended sediment concentration and load reduce downstream.

The variation of grain size distribution of suspended sediment depends on the grain size of the sediment input from the surface of the basin and the deposition or scouring of sediment along the channel. The grain size of suspended sediment on Yangtze stem is coarsest on the Jinsha River and below Pingshan it trends to be finer.

The annual bed load in the upstream Yangtze is 282-324 thousand tonnes. The coarse gravel bed load (D > 50 mm) reduces downstream and the finer gravels (D < 50 mm) increase. The coarse sand and fine gravel (1-10 mm) bed load is insignificant amounting to 8000 t at Cuntan Station.

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