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Sedimentation in muddy estuaries and management of river flow

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Abstract During past years, many estuary barriers have been completed along the shore of the Haihe River catchment in China, where the sediment of about 20 estuaries comes from both the rivers and the sea. A result is deposition in the estuaries. This paper analyzes the behavior of sedimentation in muddy estuaries and shows the changes of hydraulic conditions caused by the construction of tidal barriers. Experience shows that the deficiency of water in channels is the key cause of channel deposition. Consequently, this paper analyzes the channel flow that empties into the sea, and it demonstrates the strategic measures of re-allocation of runoff in channels. It is suggested that a small number of channels can meet the need for equilibrium in sediment transport through the diversion of water from south to north in China to increase the flow in channels.

PHYSIOGRAPHIC FEATURES OF THE HAIHE RIVER

The Haihe River, the largest water system in north China, is formed by five large rivers and about 300 tributaries (Fig. 1). It has a length of 1090 km and drains an area of nearly 320 000 km^2, in which the annual precipitation is about 560 mm and the annual runoff depth is 90 mm. Nearly 70% of annual precipitation occurs in the Haihe River catchment during the summer monsoon season from June into August; often little or no rainfall occurs for extended periods even during the rainy season.

About 130 000 km^2, or 68.4% of the mountainous area in the Haihe River catchment, has been affected by soil erosion. The annual sediment discharge from the area averages about 175 million tons, second only to that of the Yellow River catchment. In 1963 the Haihe River catchment was subject to a flood without parallel in history. In the following decade, comprehensive measures were taken to control the river, which resulted in the discharge of flood waters to the sea in a single, concentrated channel rather than in many smaller channels. Since then, many estuary barriers have been completed along the shore to prevent the intrusion of salty water and tidal backflow, where the sediment of about 20 estuaries comes from both the rivers and the sea. This change causes deposition in the estuaries for several reasons, particularly the decrease of discharge in many channels.

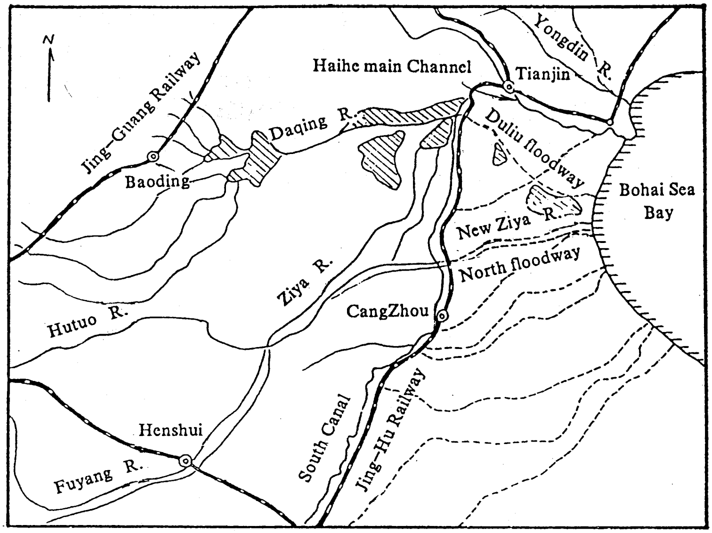

Fig. 1 Map of part of the Haihe River catchment; dotted lines show floodways and cross-hatching indicates depression areas or detention basins.

CHANGES OF DYNAMIC CONDITIONS OF THE ESTUARINE AREA CAUSED BY THE ERECTION OF THE BARRAGE

Because a large number of tidal barriers were constructed at small and medium estuaries in the coastal regions, serious sedimentation occurred. In estuaries with sediment coming from the sea, sedimentation mainly took place in the channel downstream of the barriers; where the sediment of estuaries comes from both a river and the sea, channel sedimentation took place both upstream and downstream of the barriers. For example, two barriers on the Ziya flood way, with gate discharge capacities of 250 and 300 $m^3 s^{-1}$, were built in 1967. Owing to deposition, in 1974 there were 3 460 000 m^3 of sediment in the short channels downstream of the barriers, and the maximum depth of deposition reached 5.7 m; about 80% of the conveyance was lost by sedimentation. Generally, the tidal barriers must be closed for much of each year because water in the river is deficient. Among the constructed 20 tidal barriers, 18 caused extensive siltation and the barriers constructed at the Douhe River caused complete silting twice.

Based on the analysis of observed data and the transport characteristics of sediment-laden tidal flow, it is well known that reasons for deposition downstream of the barrier are the deformation of waves during tides and non-equilibrium sediment transport in flood and ebb periods induced by the construction of a barrier. Generally, change of dynamic conditions caused by construction of tidal barriers in estuaries occurs in three aspects (Luo & Gu, 1980). First is the decrease of runoff in upper reaches. Before construction of the barriers, the total annual runoff to the sea was about 8.428 billion m^3. From 1960 into 1969, the runoff was reduced to 3.165 billion m^3, and from 1970 through 1976 it decreased to 0.710 billion m^3; in 1966, 1967 and 1970 runoff did not reach the sea. Analysis of data shows that if the sediment supply and the channel cross-section remain unchanged, the required discharge release, to maintain an equilibrium condition of no scour or siltation, must be increased. The increased releases would inevitably lead to sedimentation of the channel downstream of the barrier.

A second factor is the decrease of tidal discharge. Because tidal discharge and the prism of tidal water in the channel reach are reduced by the barrier, the tidal discharge in the channel close to a barrier is generally decreased. The decrease in discharge in turn reduces the width, depth, and cross-sectional area of the wetted perimeter owing to the close relation between cross-section dimensions and tidal discharge. A third aspect to be considered is deformation of tidal wave. If a barrier is near the river mouth, the tidal wave will change from a progressive wave to a standing wave, resulting in an increase of velocity in the flood period and a decrease of velocity in the ebb period. Consequently, the sediment transport capacity during a flood period is greater than that during an ebb period and sedimentation occurs in the channel downstream of the barrier.

Since 1963 many separate floodways were built to channel floodwaters into the sea, thereby eliminating concentrated discharge. Because total runoff to the sea from the Haihe River catchment is gradually decreasing, however, the distribution of runoff among many floodways leads to a reduced flow in each floodway that is insufficient to maintain an equilibrium cross-section of the constructed floodway. Based on statistical analyses of available data, total runoff to the sea in each decade since the 1950s has decreased by 15%, and greater decreases of runoff have occurred during flood seasons. These decreased runoff rates do not help prevent sedimentation. Figure 2 shows that for similar cross-sections, the equilibrium discharge required to prevent scour or sedimentation is increased by the construction of a barrier. Providing adequate runoff to maintain

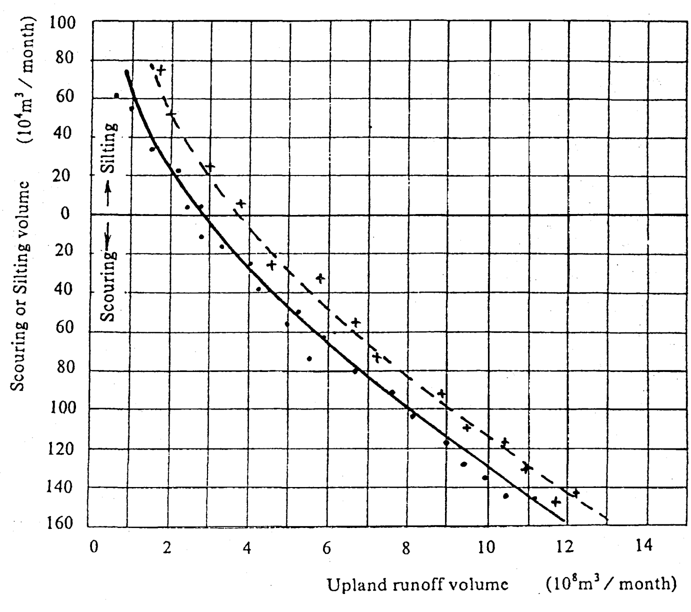

Fig. 2 Graph showing the relation between upland runoff and quantity of scouring or silting in the estuary before and after construction of a tidal barrier (modified from Luo & Gu, 1980). Solid line denotes the relation before barrier construction, dotted line denotes the relation downstream of the barrier, dots are data points for pre-construction, and plus signs are data points for post-construction.

a stable floodway morphology, therefore, may be the most effective measure to prevent deposition of sediment downstream from a barrier. Our experience suggests also that as long as sufficient runoff is available, the agitation caused by dredging may be effective in initiating the lifting and movement of bed material in an aggraded reach by weak flows of ebb tide.

STRATEGIC MEASURES TO SOLVE THE PROBLEM OF DEPOSITION DOWNSTREAM OF A BARRIER

Statistical analyses of data from 1966 through 1981 suggest that the runoff volumes to the sea in floodways are characterized not only by reduced flows but, more seriously, also by dry-wet cycles. In particular, greatly reduced runoff, and even a lack of runoff, may occur in one year or in consecutive years. It is well established that with highly deficient runoff, even no runoff, the deposition of sediment downstream of a barrier may reach to the high-tide level.

With the progress of the economy and society, available water resources can not meet the demands for water use in the upper reach, and it is therefore very difficult to maintain water use limits. For this reason, in recent years the possibility of strategic measures concerning re-allocation of runoff in channels by regulation and diverting water from the Yangtze River to the Haihe River (referring to the diversion in China of water from south to north) are being studied.

Re-allocation of runoff

A strategic management goal is to permit varying amounts of deposition in different river channels. Because runoff volumes in all channels are deficient and do not prevent deposition, it is proposed that regulated runoff be aggregated in a small number of channels in which an equilibrium flow regime can prevent scour or sedimentation. For example, the Haihe River main channel and the Duliu floodway are both short; if we divert runoff from the Ziya floodway and the North floodway to the above two (Fig. 1), assuring them of adequate discharge to maintain a stable flow regime, the situation may be improved.

Diverting water from south to north

The Haihe River catchment has inter-annual and seasonal variation of runoff; the regulation of its local runoff can not satisfy the requirements for equilibrium runoff that is needed to prevent deposition in some channels. According to the analysis of water supply and demand, runoff from the Haihe River catchment is far from adequate to meet the increasing demand for water. A fundamental way to solve the water shortage problem is to divert water from the Yangtze River to the Haihe River. A feasibility study for a large-scale project to divert water from south to north is currently being conducted. The investigations and research carried out during the past 10-12 years have provided a solid base for the early stages of the project. When completed, the water diversion system will discharge water through a long canal from the lower reaches of the Yangtze River in Jiangsu Province, across the Yellow River, to Tianjin City (Fig. 1). The main goal of the project is to ease water shortages in the Haihe River catchment. Upon completion of this large-scale project, an increase of runoff in floodways can be realized.

REFERENCE

Luo Zhaosen & Gu Peiyu (1980) Process of sedimentation and measures of its reduction in estuaries below tidal barriers. In: *Proc. International Symposium on River Sedimentation* vol. 1, 477-486. Beijing, China.