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EVOLUTION OF THE YELLOW RIVER ESTUARY AND ITS SEDIMENTATION PROBLEMS

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Abstract: This paper outlines the general situation of the Yellow River Estuary and summarizes the evolutional characteristics and laws of this estuary. Based on field data, characteristics of flow and sediment load and the evolutional status of the Qingshuigou path are analyzed. Measures for treating sediment in the estuary are evaluated and discussed. This paper points out that the threats of flood and storm surge are still severe, the contradiction between demand and supply of water resources is becoming increasingly acute, and the ecological environment is worsening in the estuary. These are the three major problems existed in the process of harnessing and development of the Yellow River Estuary and must be paid ample attention to.

Key words: Evolution, Sediment, Harnessing, The Yellow River Estuary

1. GENERAL SITUATION OF THE YELLOW RIVER ESTUARY

The Yellow River estuary has been located at the northeast of Shandong province and south side of Bohai Sea since 1855. It connects the developed areas of Bejing and Tianjin with the Shandong peninsula. The Yellow River Estuary is one of the three major estuaries in China.

1.1 EVOLUTION OUTLINES OF THE YELLOW RIVER ESTUARY

The Yellow River Estuary, a weak tide and strong accretion continental estuary, is located between the Gulf of Laizhou and the Gulf of Bohai. It covers the area between 118°10′E to 119°15′E and 37°15′N to 38°10 N′. The estuary was formed gradually after the embankment breach of the Lower Yellow River at Tongwaxiang (about 580 km to the river mouth at then) in 1855. The estuary, considering Ninghai as its vertex generally, covers a fan-shaped area of 6,000 km^2. It starts from the mouth of the Taoer river at north and ends at the mouth of Zhimaigou at south. All the wandering and diversion paths had been taken after 1855 is included in this area basically. To protect the industry and agriculture in the estuary region, vertex of diversion path has been moved to Yuwa at downstream in the last 50 odds years. Range of wandering and diversion has been then restricted to the area between Chezi Channel at north and Songchunrong Channel at south, and the estuary area is reduced to about 2,400 km^2 (see Fig. 1).

Due to huge amount of sediment coming from upstream, the Yellow River Estuary has long been maintained at a state of deposition, extension, wandering and diversion. Since 1855, river course in the estuary has diverted nine times. Among them, six times of the diversion had occurred during 1889 to 1953 and vertex of the estuary was at Ninghai then. Since 1953, three times of major diversion have taken place and vertex of the estuary has moved to Yuwa. Evolution of the Yellow River Estuary has undergone several major phases since 1855 as follows.

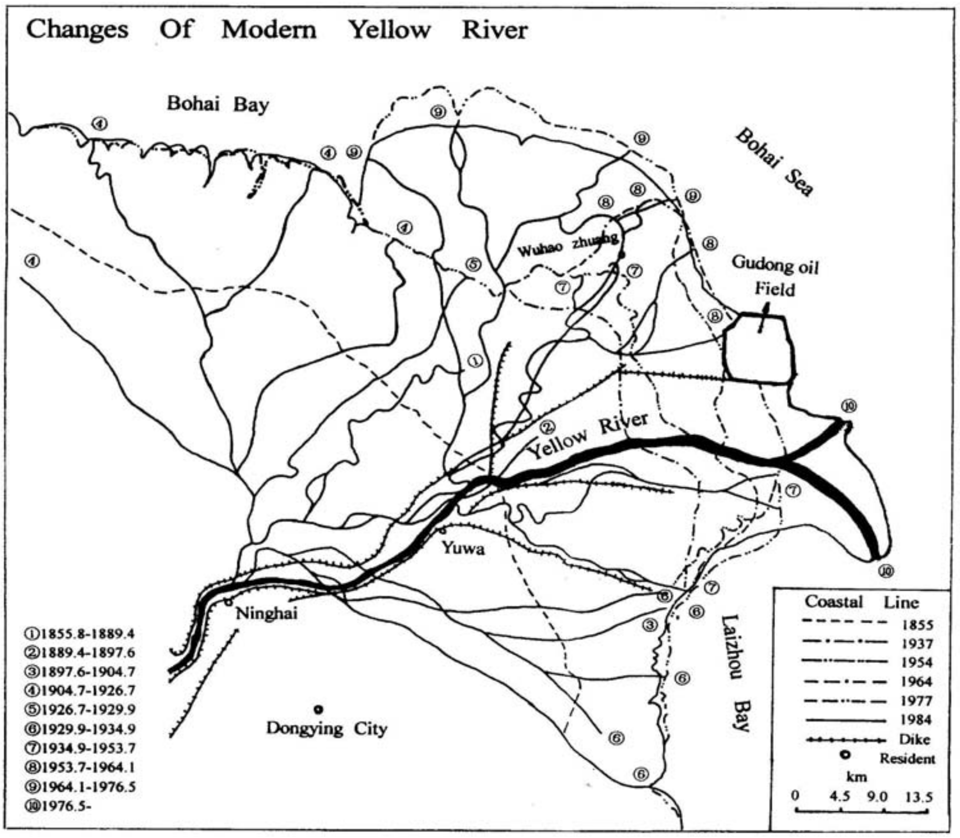

Fig. 1 Evolution of the Yellow River Estuary

From 1855 to 1889, sediment being transported to the estuary was few and the river mouth was relatively stable. After 1872, embankments had been constructed gradually at downstream of Dongbatou (where the 1855 breach occurred). By 1885, embankments from Dongbatou to Ninghai were completed at both sides of the river. With perfection of embankments, more sediment was transported to the estuary. Problems of deposition and channel extension had appeared gradually.

From 1889 to 1949, river at downstream of Ninghai had varied naturally. During this period of time, mankind activities had increased gradually. However, dikes at downstream of Ninghai was only about 20 km long, river course wandered and diverted frequently and major course diversions were recorded by six times.

After the founding of New China in 1949, development of the Yellow River Estuary has brought forward the requirements for flood control in this region. Especially when oil drilling industry born in the estuary in 1961, a series of measures with main considerations on flood and ice flood controls have been taken, thus to protect the industry and agriculture business in this region. These measures include heightening embankments, reinforcing dikes, and enlarging river sections where ice jam occurred. To protect development of oil field in the estuary, the last three manmade diversions were well planned. Namely, they were the Shenxiangou path diversion in July 1953, the Diaokouhe path diversion in January 1964 and the Qingshuigou path diversion in May 1976. Diversion locations were all selected at places downstream of Yuwa.

To fully utilize the nature of aggradation of sediment and achieve on-land-drilling of sea oil field, a diversion was made at Qing-8 section before the flood season of 1996. This diversion reduced the river length by 16 km and has caused retrogressive erosion in the estuary.

1.2 GEOGRAPHICAL CONDITIONS

1.2.1 Topographical features

Landform of the Yellow River Delta is high at Southwest and low at Northeast. Defeated river courses become to ridges and areas between these ridges are low land. Ground elevations of these lands are generally between 2 and 9 m above sea level and their surface slopes vary from 1/8,000 to 1/12,000.

1.2.2 Climate features

The Yellow River Delta is in the warm temperature zone and its climate is semi-humid and semi-arid with continental monsoon wind. Due to bordering on the Bohai Sea, it has also clear features of ocean climate. Long term annual average temperature is 12.5℃ with extreme high at 41℃ and extreme low at –22℃. Annual average precipitation is 537 mm and about 74% of them are concentrated in the period of June to September. The illumination time is 2,724 hours yearly. Annual average evaporation from water surface is 1,846 mm with maximum at 2,119 mm and minimum at 1,603 mm.

1.2.3 River system

There are several rivers in the Yellow River Delta region. The Yellow River is the largest one among them. According to hydrological records of 1950 to 2000, annual average runoff was about 33.5 billion m^3 at Lijin hydrological station and sediment load was about 849 million t annually. Besides the Yellow River, there are 20 more streams in the delta and they all flow into the sea directly. Streams on the south side of the Yellow River flow from west to east and enter into the Gulf of Laizhou. Streams on the north side of the Yellow River flow from south to north and join the Bohai Sea.

1.2.4 Tides and storm surge

Tide at the Yellow River Estuary is weak and tidal range is small. Tidal reach and tidal current limit are both short. The former is about 20 km generally. Affected by topographical features of seabed and shallow water of the Bohai Sea, incident wave and refracted wave meet at a place near Shenxiangou after tidal wave enters the Bohai Sea and then forms a standing wave. An amphidromic point appears there. Irregular diurnal tides happen only near Shenxiangou and irregular semi-diurnal tides are observed at other places. Durations of flood and ebb are different in the coast. Usually, it is about 5h for flood tide and 7h for ebb tide. The smallest tidal range occurs near the amphidromic point and increases gradually toward both sides. Average tidal range varies from 0.37 to 1.77 m.

The Bohai Sea is a semi-closed sea. The Yellow River Della is distributed in the south border of the Gulf of Bohai and the west coast of the Gulf of Laizhou. Shoaly land is vast and its slope is small. Water is shallow in the sea. Thus, water volume increases significantly during windstorm under strong action of northeast wind. Especially when wind turns to northeast from southeast, a storm surge may form most likely. According to historical records, storm surges had occurred 60 times during a period of 582 years before the founding of New China. Since 1949, large storm surges have been recorded by 6 times and 4 of them were extremely large. During August 18 to 20 of 1997, extreme storm surge happened in the Yellow River Delta. Tidal level was measured at 3.26 m in Port Dongfeng of Wuli County and the maximum wave height was 4 m. Economic loss caused by this storm surge was estimated as 2.6 billion RMB and the damage was the most severe one among all the storm surges recorded in history.

1.2.5 Wet land and natural reserve

Wetland area in the Yellow River Delta is about 3,500 km^2. Among them, about 2,000 km^2 is in the supper-tidal zone and 1,500 km^2 is in the inter-tidal region. Wetland is distributed in the defeated rivers, present channel and newly deposited land. By their locations, wetlands of the Yellow River Delta are classified as inter-stream wetland and newly born wetland near the coast. According to scientific investigation, there are about 1,921 kinds of wild animal in the delta area. Among them, 641 kinds are aquatic fauna and 269 kinds are birds. There are 12,000 ha of locust tree planted in the estuary, which is the largest manmade forest of its kind in North China Plateau.

2. EVOLUTION CHARACTERISTICS OF THE YELLOW RIVER ESTUARY

2.1 CHARACTERISTICS OF "DEPOSITION, EXTENSION, WANDERING AND DIVERSION"

Sediments carried by the Yellow River deposit in the estuary. Consequentially, the sand spit extents toward coastal areas outside of the river mouth. With the increase of extension, retrogressive sediment depositions are intensified and riverbed is elevated gradually. When riverbed elevates to a certain degree, flow would seek low land area naturally and pick up a new and short course to the sea. Afterwards, the sand spit extents again and the cycle carries on under new conditions. Evolution of the Yellow River Estuary is reflected by the periodic variation of "deposition, extension, wandering and diversion".

2.2 CHARACTERISTICS OF PLANE EVOLUTION

Generally, plane variation of the channel in the Yellow River Estuary undergoes through several stages after each diversion and can be summarized as follow: forking and wandering during early stage after a diversion, forming a single straight channel, meandering, forming fork-river and wandering, forking point moves toward upstream, diversion again. This process can be simplified to three phases. They are the phases of forking and wandering, relatively stable single channel, and forking, wandering and diversion. According to these evolution characteristics, one can predict the development of channel and plan engineering works (see Fig. 2).

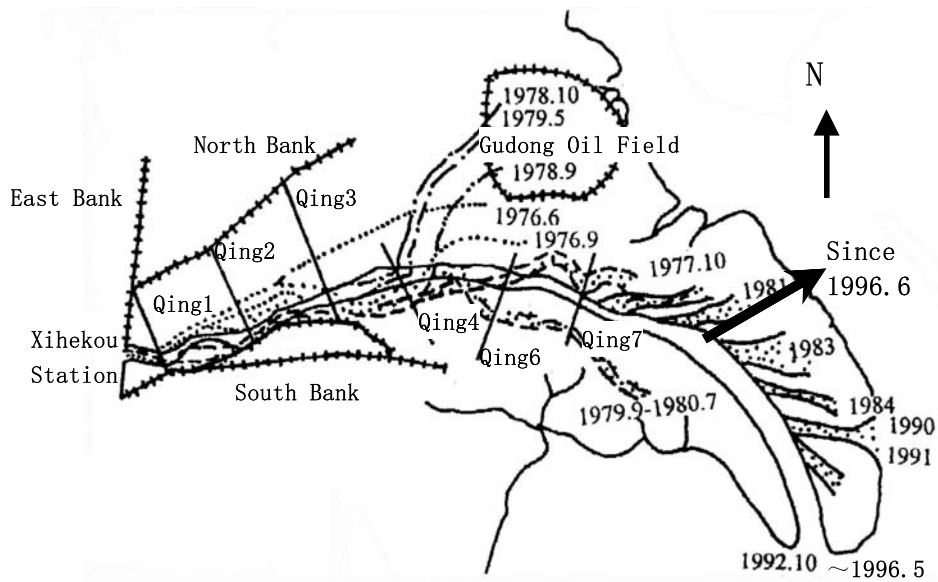

Fig. 2 Plane evolution of the Estuary Channel

2.3 SEDIMENT TRANSPORT IN THE RUNOFF REGION

The characteristics of channel erosion and sediment deposition at reach downstream of Lijin are similar to those at the Lower Yellow River. They are controlled by the conditions of incoming flow and sediment load as well as the boundary conditions of the river. Meantime, with the changes of inflow hydrograph and sediment load, sediment carrying capacity can adjust itself quickly. The characteristics of "more sediments are transported and deposited if more sediment loads come from upstream" and "less sediments are transported and deposited if less sediment loads come from upstream" are observed. Usually, sediment carrying capacity is high in the main channel and low in the flood plain. Different from the Lower Yellow River, variations of erosion and deposition in the estuary are also closely related to evolution of the channel. When channel is diverted, its length would be reduced greatly, thus large degree of erosion could happen during the early stage of a diversion process.

2.4 SEDIMENT TRANSPORT IN THE RUNOFF AND TIDAL REGION

The runoff and tidal region varies within the range of 0 to 20 km. It can be divided into runoff and tidal wave region and runoff and tidal current region. Affected by rapid variations of tide and boundary conditions, this region is the main area where sediment deposits. Variations of sediment transport and deposition are more complicated and intensified in this region. Influenced by many factors, the ratio of sediment being transported to the sea varies greatly during different stages of a course process. The characteristics reflected are evident as follow. In the early stage after diversion, most of the sediments are deposited in the continental and costal regions. In the middle stage, amount of sediment being transported to the sea is relatively large even though barrier bar exists at the river mouth.

2.5 VARIATION OF WATER STAGE

Variation of water stage in the estuary is mainly affected by conditions of incoming flow and sediment load as well as the boundary conditions. The influence mechanism of inflow and sediment load on water stage is simple. It is realized through the process of channel erosion and sediment deposition. Generally, channel is scoured and water stage falls during high flow, sediment deposits and water stage rises during low flow. Water stage falls during flood season and rises in the non-flood season. However, water stage increases during a complete year. The influences of boundary conditions on water stage are mainly concentrated on channel configuration and length of the estuary. When channel becomes narrow and deep, water stage would drop. Increase of estuary length means the relative rising of the control of erosion, in turn it would cause the rising of channel bed and water stage. Its mechanism is similar to the upward extension of backwater due to the progress of front slope of the delta in a reservoir. This relationship is not the reflects of a short period process of erosion and deposition, but the results of long period of process of erosion and deposition.

3. CHARACTERISTICS OF INCOMING FLOW AND SEDIMENT LOAD AND EVOLUTION SITUATION OF THE QINGSHUIGOU PATH

3.1 CHARACTERISTICS OF INCOMING FLOW AND SEDIMENT LOAD

Affected by the variations of precipitation and intensified human activity in the upper and middle reaches of the Yellow River, characteristics of incoming flow and sediment load in the estuary have changed significantly since the 1980's. These changes can be summarized as follows.

Firstly, the amounts of runoff and sediment load have reduced greatly and the proportions of middle and low flow have increased. From 1976 to 2000, annual average runoff and sediment load were 22.16 billion m^3 and 579 million t at the Lijin hydrological station respectively, which were about 49% and 51% of those from 1950 to 1975 (see Fig. 3).

Secondly, with the decrease of runoff and sediment load, peak discharges have also been reduced remarkably. From 1976 to 2000, years with peck discharge greater than 3,000 m^3/s and 6,000 m^3/s had reduced by 31% and 30% compared to the period of 1950 to 1975. Flood peck greater than 8,000 m^3/s did not occur.

Thirdly, the Lower Yellow River dries up frequently. From 1972 to 1998, the estuary had dried up in 22 years. Especially from 1992 to 1998, the Lower Yellow River had dried up every year. On annual average, zero flow was measured for 121 days at the Lijin hydrological station from 1992 to 1998. The worst situation happened in 1997. Zero flow was recorded for 226 days at Lijin station and about 700 km long of river dried up. With the implementation and perfection of integrated flow regulation of the Yellow River, the situation of zero flow has been controlled since 1999.

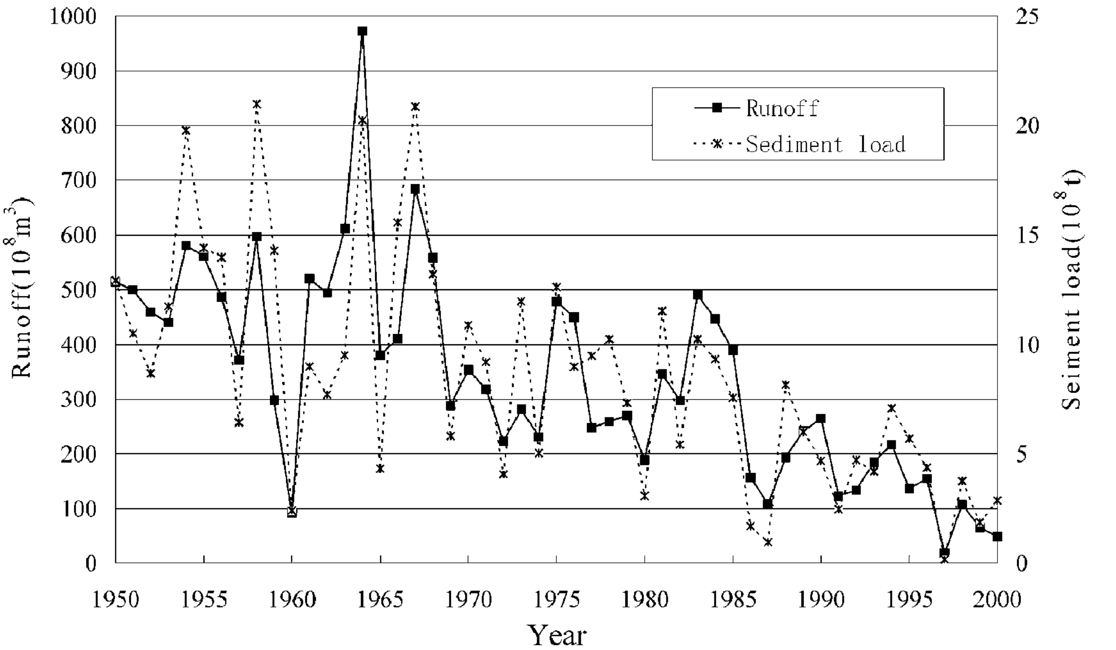

Fig. 3 Variation of runoff and sediment load at Lijin station

3.2 INCREASED INFLUENCE OF HUMAN ACTIVITY AND INTERVENE

Influences of human activity on the Yellow River Estuary are mainly reflected on two aspects. Firstly, the influences of reservoir regulation and water and soil conservation programs carried out in the upper and middle reaches of the river have changed the conditions of inflow and sediment load to the estuary, and thus affected the process and characteristics of estuary evolution. Secondly, various engineering measures have been taken in the estuary thus to guarantee the safety of the estuary and to maintain a relatively stable flow path for a long period of time. Compared to previous flow paths of Shenxiangou and Diaokouhe, quantity, scale, standard of engineering works and measures taken for harnessing the flow path of Qingshuigou are unprecedented. For instance, during 1988 to 1992, training dikes were constructed, jet dredging was experimented at the barrier bar, and fork-channel blockage was carried out. In 1996, the manmade diversion was implemented at Qing-8 section. In 1998, large-scale experiments for dredging channel and reinforcing the lee side of the embankment were conducted.

3.3 NEW CHARACTERISTICS OF EVOLUTION OF THE ESTUARY

Influenced by factors mentioned above, the evolution of the Qingshuigou path appears some new features as follow when compared to the previous flow paths.

3.3.1 Increase of lifetime of flow path

From 1885 to 1976, the Yellow River had taken this estuary as its path to the sea for 87 years. The channel diverted 9 times during this period of time and the average life for each flow path was 9.7 years (The estuary was abandoned due to manmade river diversion at Huayuankou during 1938 to 1947). However, the Qingshuigou path has been used for 26 years and yet it is still vigorous. The lifetime of flow path has increased.

3.3.2 Decrease of sediment deposition in the estuary

Field data indicated that accumulated sediment load at Lijin station was 14.19 billion t from 1976 to 2000. Total amount of sediments deposited in channel at downstream of Lijin was 492 million t that was about 3.47% of sediment load measured at Lijin station during this period. Deposition intensity was 250,000 t/(km • a). During 1964 to 1976, flow took the path of Diaokouhe and deposition intensity was 400,000 t/(km • a). It is obvious that deposition intensity has reduced greatly since 1976 (Fig. 4).

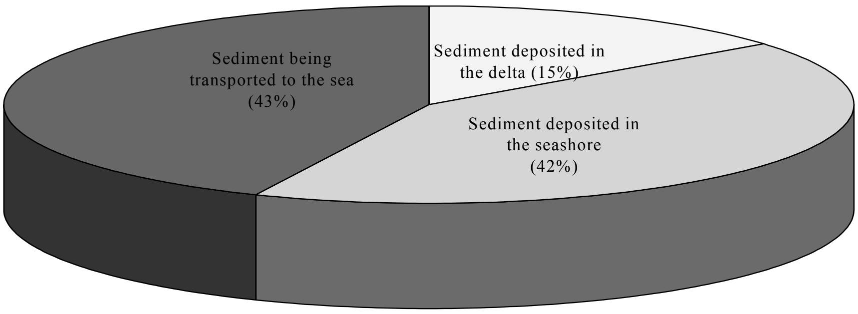

Fig. 4 (a) Distribution of sediment deposition during 1954—1974

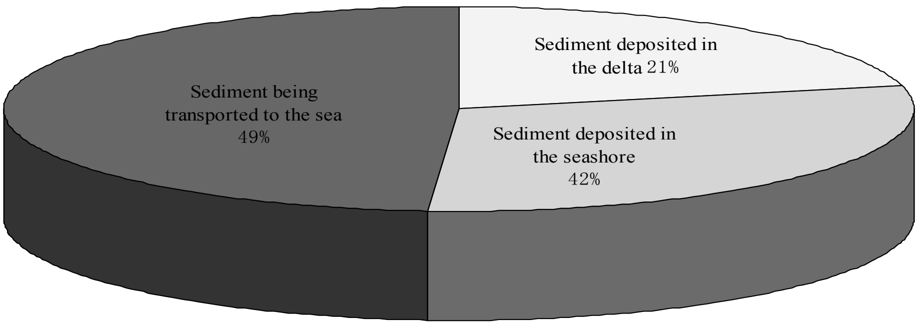

Fig. 4(b) Distribution of sediment deposition during 1976—2000

3.3.3 Contraction of channel and decrease of flood discharging capacity

Since 1986, the Lower Yellow River has undergone a low flow period. Channel in the estuary has contracted due to sediment deposition. Frequent drying up of river has made the situation even worse. Comparing 1995 with 1984, channel cross section areas under normal water stage have reduced by 38% to 25% at Section Qing-1 and Qing-6 respectively. As a result, dominant discharges have reduced greatly. For instance, dominant discharge at Lijin station has reduced from 6,000 m^3/s in 1985 to 3,400 m^3/s in 1997. This leads to enormous high water level during middle and small size floods and more dangerous situations for the estuary. In 1996, the flood discharge was only 4,130 m^3/s at Lijin station. However, water level was closed to that in 1976 for a discharge of 8,020 m^3/s.

3.3.4 Low rising rate of water level

During the late period of a flow path, rising rate of water level in the estuary is usually high. For example, rising rate of water level for the equivalent discharge of 3,000 m^3/s was 0.26 to 0.33 m on annual average (1958—1961) for the Shenxiangou path and 0.15 to 0.38 for the Diaokouhe path. However, it was only 0.10 to 0.13 (1982—1995) for the Qingshuigou path.

3.3.5 Decrease of magnitude of channel wandering and slowing down of channel process

Since 1976, the Qingshuigou path has gone through a compound process of random path (for 2 years), forming the main channel (for 2 years), relatively stable single channel (for 5 years), forming fork-river and wandering (for 2 years), human intervene for extension (for 8 years) and man-made diversion (for 5 years). Since the 1980's, the magnitude of channel wandering has been reduced to 2 to 6 km and even smaller after 1992.

3.3.6 Rapid decrease of coastal line extension

From 1976 to 1992, net area of land made by sediment deposition in the Yellow River Delta was 364 km^2. Annual average rate of land making was 22.8 km^2. Into the 1990's, sediment load entered into the estuary has changed remarkably. From 1990 to 1995 (before the man-made diversion at Section Qing-8), 81 km^2 of land was created by sediment deposition in the delta. Annual average rate of land making in this period was 16.2 km^2. From 1996 to 1998, the average rate was 9.8 km^2/a. Land making rate was only 0.67 km^2/a for the period of 1998 to 2001 due to the influence of the Xiaolangdi Reservoir.

4. MEASURES FOR TREATING SEDIMENT IN THE ESTUARY

One of the key tasks for harnessing the Yellow River Estuary is to solve its sedimentation problem and thus to maintain a stable flow path, to reduce the rising rate of river bed, to increase the life time of flow path, and to guarantee the safety of the delta area. Practical measures that may be taken can be summarized as follows:

- Reducing sediment load being transported to the estuary;
- Increasing the amount of sediment being transported to the coastal region;
- Increasing the sediment disposal area in the delta or heightening the protection works.

Major ideas about treating sediments in the estuary are introduced in the following sections.

4.1 DREDGING CHANNEL AND CONSTRUCTING TRAINING DIKES

From 1988 to 1992, the municipal government of Dongying city and the Shengli Oil Company had conducted a dredging experiment in the estuary. Reported effects of this experiment include improvement of channel, reduction of hazard of the barrier bar, increase of sediment being transported to the deep sea, and mitigation of flood pressure in the estuary (Li, 2002). Li (2002) also concluded that following measures shall be taken in harnessing the Yellow River Estuary.

- Constructing training dikes to restrict flow direction to the sea;
- Applying jet dredging and excavation to improve the river mouth, and using natural force to dredge the river mouth;
- Using engineering measures to stabilize channel for sediment transport and utilizing storm surge and density flow to transport sediment to strong current region;
- Constructing diversion project at Xihekou to divert flow at high water stage thus to mitigate flood pressure. Meanwhile, flow diverted to the Diaokouhe path can scour

the defeated channel and carry sediment to the north body of the Bohai Sea, thus to prevent coastal line erosion.

However, Bao (1999) thought that “dredging” or “training” alone could not achieve the objective of stabilizing flow path in the estuary. Under the circumstance of huge amount of sediment being transported to the estuary, dredging can only push the barrier bars forward but not eliminate them. This is a common law of river dynamics. Constructing training dikes means that flow will be restricted to a narrow and long path. It is infeasible in engineering practice. On the other hand, a very long flow path would accelerate the rising rate of water stage at upstream, which will increase the pressure of flood control and put the security of industry and agriculture of the delta region in danger. Nevertheless, certain amount of training dikes in the estuary can control the flow. Engineering practices in the past have proved that they are effective for increasing the lifetime of a flow path.

4.2 TRANSFER SEAWATER TO SCOUR THE CHANNEL

Transfer seawater to scour riverbed was proposed by academician Lin (1997). In his proposal, seawater will be transferred from the Gulf of Laizhou to the Yellow River at a proper location downstream of Lijin thus to scour riverbed and to lower flood stage. In addition, saline water mixed with turbid flow may form a density current. This density current could carry more sediment to places far from the river mouth and thus to slow down the process of channel extension. When discharge of transferred seawater is large enough, the flow could scour the river mouth directly. This action would be even better when the river dries up. However, this measure has never been practiced. Many problems need to be solved. For example, will the sediment scoured be transported to the sea? How about its influence on ecological environment? How about the economic feasibility to construct and operate such a system?

4.3 BUILD A PROJECT AT XIHEKOU

Li (2001) proposed to build a project at Xihekou. The objective for constructing this project is to regulate and treat flow and sediment load better thus to maintain the coast at dynamic equilibrium and to reduce impactions on the Lower Yellow River due to deposition in the estuary. This will not only create a basic condition for stabilizing the Qingshuigou path but also optimize the comprehensive system of flow and sediment treatment in the estuary. Nevertheless, some problems shall be taken seriously. For example, will sediment deposition be intensified at upstream due to influence of the project? How to solve problems of ice flood in the estuary?

4.4 HARNESSING THE BARRIER BAR

After analyzing the influences of barrier bar on navigation, discharging flood, transporting sediment and discharging ice flood, Zeng (1997) pointed out that the exist of barrier bar will have direct impactions on flood discharging and sediment transport. By analyzing tidal characteristics of the Yellow River Estuary and summarizing domestic and foreign experiences, Zeng (1997) studied various measures for harnessing the barrier bar by using tide and increasing the tidal flow. The ideas of transporting sediment by circulation flow and torrential flow during windstorm were proposed by Xiu (1995). Sun (1995) proposed to use the technique of pulsejet to reduce sediment deposition in the area of barrier bar. However, Wang (2001) thought that the volume of barrier bar is huge and its variation is rapid. At present, it cannot be controlled by manpower. The outcome for harnessing the barrier bar by measures mentioned above is bound to arouse suspicion. Besides, the conditions for carrying out these projects are harsh and all the ideas are lack of demonstration on their feasibilities.

4.5 PLANNED DIVERSION OR FORKING

Retrogressive erosion occurs after each diversion or forking in the Yellow River Estuary. It will cause significant fall of water stage in the estuary. This indicates that through diversion to enlarge the range of sediment deposition would have notable affect on slowing down the rising rate of water stage. The rising rate of water stage is not only decided by the extension of channel length, but also by the range of front line of the delta. For a smaller range of front line of the delta, the extension rate would be larger under the same conditions of flow and sediment load. Therefore, from river harnessing point of view, a large area for sediment deposition is preferred. Man-made diversion of 1976 had made it possible for normal productions of industry and agriculture and as well as steady development of oil industry in the estuary. These harnessing experiences show us the possibility of achieving maximum economic benefit with minimum cost and at the same time guarantee the safety of the delta region.

4.6 HEIGHTENING EMBANKMENT AND REINFORCING PROTECTION DIKES

Heightening embankment and reinforcing protection dikes are passive measures for harnessing the estuary. These measures would increase the possibility of ice flood hazard and the extent of loss. In addition, costs for reconstructing these projects would be doubled and redoubled with increasing the heights of embankment and dikes. From long-term point of view, extension of delta line would affect the whole alluvial plain. Thus, it would be wise not to take these measures. However, to protect key infrastructures in the estuary, to maintain a relatively stable flow path and increase its lifetime, certain amount of protection works are required.

4.7 CHANNEL DREDGING AND EMBANKMENT REINFORCING WORKS

In recent years, some scholars have proposed the measure of channel dredging. By dredging channel, sediment deposition could be reduced, flow regime could be improved, capacity of discharging flood could be increased, and yet at the same time, sediment being dredged can be used to reinforce the embankment. Studies (Hong, 2002) indicated that channel dredging is one of the key measures for reducing sediment deposition in the Shandong reach of the Yellow River and shall be continued. The effect of deposition reduction is relevant to amount of sediment being dredged and geometric size of the dredging pit. Experiment of physical modeling showed that channel morphology (expressed by $\sqrt{B}/H$) shall be controlled between 6 and 9 and bed slope of dredged channel shall not be less than its original slope. Meantime, vicinity at downstream shall be smoothed thus to make a stationary joint for flow. Dredging site shall be selected at transitional reach in the estuary and operated from downstream up. Dredging shall be arranged at the period of March to June and October to December. It is better to dredge the channel during March to June. Since flood season followed will make a better effect for reducing sediment deposition. Nevertheless, wastewater, exhaust gas, noise and dusty being produced are the side effects of this measure. Local desertification and alkalization may also be created.

Various measures and ideas for harnessing the Yellow River Estuary have been discussed. Some of them have been practiced in the past. Some of them are summary of past experiences under new conditions and some of them are just ideas and inferences. The later need to be studied.

5. REMARKS

Harnessing the estuary is an important part of harnessing and development of the Yellow River. Since 1946 especially in the last 20 years, great achievements have been made on harnessing the Yellow River Estuary, which have improved the economic and social development of the estuary. However, flood and storm surge are still threats to the estuary.

The contradiction between water demand and water supply is prominent. Unreasonable use of land resource and deterioration of ecological environment are serious problems.

In March 2003, Forum on Problems and Countermeasures of the Yellow River Estuary was hold in Dongying City. This forum marks the beginning of a new era for harnessing the Yellow River Estuary. Agreements being made on this forum are as follows:

- The Yellow River Estuary is one of the most complicated estuaries in the world. It is also one of the most difficult estuaries to harness. Studies and engineering practices of this estuary are both full of challenge;
- The evolution process of deposition, extension, wandering and diversion is a natural law of the Yellow River Estuary under certain conditions of flow and sediment load;
- Systematic and discriminative concepts shall be established in harnessing the estuary;
- Stabilizing the Qingshuigou path is not only necessary but also feasible;
- Based on knowledge about evolution of the Yellow River Estuary and strategic considerations, the Diaokouhe path shall be reserved;
- Conditions of water resources shall be considered in developing the Yellow River Estuary;
- Management system of the Yellow River Estuary shall be rationalized;
- Research and field monitoring shall be enhanced.

Li (2002) point out that by the year of 2050, sediment load entering the estuary will be 300 to 400 million t on annual average. This estimation was made based on the conditions as follow:

- By the year of 2050, all the soil and water loss areas preferential for harnessing will be harnessed. Sediment load reduced by water resources projects and water and soil conservation works will reach 800 million t;
- By the year of 2020, the first phase of West Route of South-to-North Water Transfer Project will be completed and 4 billion m^3 of water will be transferred to the Yellow River. All the key reservoirs on the master stem of the Yellow River are implemented. Comprehensive regulations of flow and sediment load will be possible by using these reservoirs. On the premise of guaranteeing enough water for ecological environment and sediment transport, water resources of the Yellow River will be fully developed.

With continuous enhancement of the estuary harnessing, it can be predicted that the Yellow River Estuary will take on a new look. Flow path will be relatively stable. Coastal line will be maintained at dynamic equilibrium. Water shortage will be mitigated. Ecological environment condition will be improved.

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