CASE STUDY ON SEDIMENT MANAGEMENT AND WETLAND CONSERVATION AT YELLOW RIVER MOUTH

IRTCES Report -2006-2-01

INTERNATIONAL RESEARCH AND TRAINING CENTER ON EROSION AND SEDIMENTATION

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EDITORS:

Mr. Hu Chunhong, Secretary General, IRTCES, China
Mr. Wang Yangui, IRTCES, China
Mrs. Zhang Yanjing, IRTCES, China
Mrs. Shi Hongling, IRTCES, China
Mrs. Tong Yuling, IRTCES, China
Mr. Liu Cheng, IRTCES, China
Mrs. Fan Zhao, IRTCES, China
Mr. R. Jayakumar, Programme Specialist, UNESCO Office Beijing
Mr. Zhou Zhide, IRTCES, China

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Contents

1. Introduction

The modern Yellow River delta was formed after the levee break at Tongwaxiang and the flood water captured the Daqing River channel in 1855. Since then the river shifted its channel ten times with apex at Ninghai, nine times of which took place in the delta area below Ninghai. The modern Yellow River delta covers the fan area as far north as the Tao’er River and south to the Zhimaigou River, with an area over 6000 km^2 and a coastal line of 350 km. Photo.1.1 is the satellite image of the Yellow River mouth. The river mouth delta has actually existed for over 100 years. It is located between 118°30′---119°15′ of East longitude and 37°10′---38°05′of North latitude.

The fluvial processes of the Yellow River mouth are affected by river and ocean dynamics, i.e., the condition of incoming water and sediment; the hydrodynamic characteristics of tide, waves and sea current; and the boundary condition of the river mouth. The Yellow River is well-known for its deficient water flow and abundant sediment load. The average annual runoff at the Lijin station is 33.2 billion m^3, the average annual sediment load is 0.823 billion t (Hu, et al., 2005). The ocean dynamics are relatively weak, the velocity of the tidal current is about 1 m/s, the average tidal range is 0.61-1.13 m, and the tidal reach length is only 15-30 km (Hu, et al., 1996). A great amount of the incoming sediment load deposit in the river mouth, extending the river-mouth bar further offshore. 64 % of the incoming sediment deposit on the delta area, among which 24% deposit on the area above the zero elevation contour, 36% is transported to the deep sea. Therefore, the Yellow River mouth has a strong function of land creation.

Photo 1.1 Satellite image of the Yellow River mouth, August, 1996

A 1500 km^2 national natural reserve in the delta declared in 1992 consists of two wet lands created by the Yellow River and accommodates many migration birds. Accordingly, sustainable development of the delta requires stabilization of the Yellow River channel, long-term strategies of water resources development, flood risk analysis and control measures, and development of the wet land nature reserve.

2. Sedimentation in the Yellow River Mouth

2.1 Basic Characteristics of Water and Sediment

2.1.1 Changes in Runoff and Sediment load

The variation of annual runoff and annual sediment load at Lijin station, which is the Yellow River’s last gauging station entering the sea, in the period of 1950 to 2000 is listed in Table 2.1. After 1990, the amount of water and sediment load substantially decreased.

Table 2.1 Characteristic values of annual runoff and annual sediment load at Lijin

Time (year)	Average annual runoff (10^9 m^3)	Average annual sediment load (10^9 t)	Average sediment concentration(kg m^{-3})
1950-1959	463.7	13.15	28.40
1960-1969	512.9	11.00	21.4
1970-1979	304.4	8.88	29.2
1980-1989	290.7	6.46	22.2
1990-2000	122.8	3.47	28.3
1950-2000	334.7	8.49	25.4

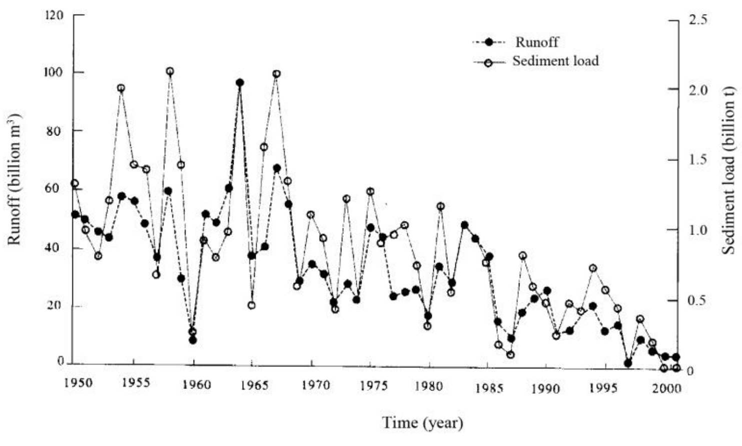

Fig.2.1 Changes in average annual runoffs and average annual sediment loads during 1950~2001 at Lijin gauging station

Changes in average annual runoff and average annual sediment loads at Lijin station during 1950~2001 are shown in Fig.2.1. Since 1950, the annual incoming runoffs and sediment loads of the river mouth have been in three different stages and reduced stage by stage, i.e. 1950~1968, 1969~1985 and 1986~2001, respectively, which can be seen clearly from Fig.2.1. During the period of 1986~2001, the average annual incoming runoff and sediment loads were 13.77 billion m^3 and 0.351 billion t, respectively, which were only 27.4 ％ of 50.15 billion m^3 and 28.4％ of 1.237 billion t in the first stage of 1950~1968. During the recent five years of 1997~2001, the average annual incoming runoff and average annual sediment load reduced to 11.1％ and 9.8％ of those in the first stage.

Tables 2.2 and 2.3 present runoffs and sediment loads transported to the delta in recent decades. The average annual runoffs and average annual sediment loads released to the lower reaches of the Yellow River in the recent decade were 11.3 billion m^3 and 0.36 billion tons less than the long-term average values, and those to the delta were 23 billion m^3 and 0.5 billion tons less than the long-term average values. The main causes for the remarkable reductions are attributed to the soil conservation projects in the upper and middle reaches, increasing water and sediment diversion, and sedimentation in the lower reaches.

Table 2.2 Runoff and sediment load released to the lower reaches of the Yellow River

(Gauging Station: Sanmenxia, Heishiguan, Wushe)

Year	Runoff (10^9m^3)		Sediment load (10^9t)		Maxinum discharge at Huayuankou (m^3/s)	Water and Sediment features
	Year round	Flood season	Year round	Flood season		
1986	31.5	13.4	0.414	0.374	4260	Dry and less sediment
1987	22.1	8.75	0.289	0.269	4800	Dry and less sediment
1988	34.6	21.2	1.55	1.54	7000	Dry and plentiful sediment
1989	40.0	21.6	0.806	0.756	6100	Mid water and less sediment
1990	36.7	14.2	0.724	0.666	4440	Dry and less sediment
1991	24.9	6.06	0.486	0.249	3180	Dry and less sediment
1992	25.6	13.6	1.11	1.06	6260	Dry and less sediment
1993	31.6	14.8	0.608	0.563	4280	Dry and less sediment
1994	29.7	14.0	1.23	1.21	6260	Dry and middle sediment
1950-1987 Average	42.0	23.4	1.162	1.019		
1986-1994 Average	30.74	14.18	0.802	0.743		

Note: "Year-round" is from November last year to October this year. "Flood season" is from July to October.

Table 2.3 Runoff and sediment load at Lijin

Year	Water(10^9m^3)		Sediment 1oad(10^9t)	
	Flood season	Year-round	Flood season	Year-round
1986	8.71	13.69	0.153	0.166
1987	5.06	9.9	0.077	0.089
1988	15.25	22.65	0.803	0.857
1989	14.44	28.63	0.528	0.654
1990	13.03	23.94	0.351	0.537
1991	3.90	5.42	0.080	0.083
1992	9.47	15.21	0.448	0.487
1993	12.30	18.59	0.371	0.484
Long-term average (1950-1987)	24.0	40.4	0.850	0.100

The Xiaolangdi Reservoir is located 900 km upstream of the delta and it is the most downstream gorge-type reservoir of the Yellow River. The multi-purpose reservoir is mainly for flood control and sediment retention to slow down the channel siltation of the lower reaches. The active storage capacity of the reservoir is 4.8 billion m^3 and the storage capacity for trapping sediment is 7.5 billion m^3 with which 9.75 billion tons of sediment can be trapped. The reservoir operated in such a way that floods with a discharge larger than 800 m^3/s and smaller than 3000 m^3/s are detended and then released to form floods with discharges larger than 3000 m^3/s. In the first 8 years of operation, coarse sediment will be trapped and clear water will be released to the lower reaches. About 0.3 billion tons of sediment in the lower reaches will be scoured by the released clear water and transported to the delta. Most of the sediment load to the delta will be transported in wet years and concentrated in flood seasons.

The average annual sediment deposition in the lower reaches of the Yellow River in the period of 1984-1994 was 0.3 billion tons, about the same as the long-term average. Nevertheless, the percentage of deposited sediment in the total load was 40%, much higher than the long-term average value, 25 %, because the annual load in the period was much less than the long term average. The channel in lower reaches behaved like a sediment storage basin. About 70 % of sediment load released to the lower reaches deposited in the river channel in dry years, such as 1987 and 1991, and was scoured and transported to the delta in the successive wet years. It is predicted that such phenomena will occur more often. Sediment siltation resulted in channel shrinkage in the lower reaches and the bankful discharge reduced remarkably. Therefore, a flood of only 7600 m^3/s in 1996 chalked up a highest stage inundated farmland and villages on the floodplain and claimed great economic losses and lives.

2.1.2 Dynamic Characteristics of the Estuary

(1) Tide

Tide in the Yellow River delta is very complicated. After entering into the Bohai Bay, due to the deflection effect of earth rotation and topography, one branch of the ocean tide moves around to the Eastern Bay revolving left, forming an amphidromic point at the southwest part of the Liaodong Bay, another branch moves toward the west via the Bohai Bay, counter-clockwise advancing eastwardly, forming an amphidromic point at the Stake-5 near the Yellow River mouth; in the amphidromic point area the amplitude of mean lunar semidiurnal constituent is close to zero, where the tide difference is the minimum and the tidal current velocity is the maximum. There exist many types of tide in the Yellow River delta, which can be classified into semi-diurnal tide and diurnal tide, etc. The Yellow River mouth belongs to the weak tide river mouth, the distribution of its tidal range appears as a saddle, the average tidal range is 0.73~1.77 m, which is 1.1~1.5 m at the present Qinshuigou mouth as shown in Fig.2.2.

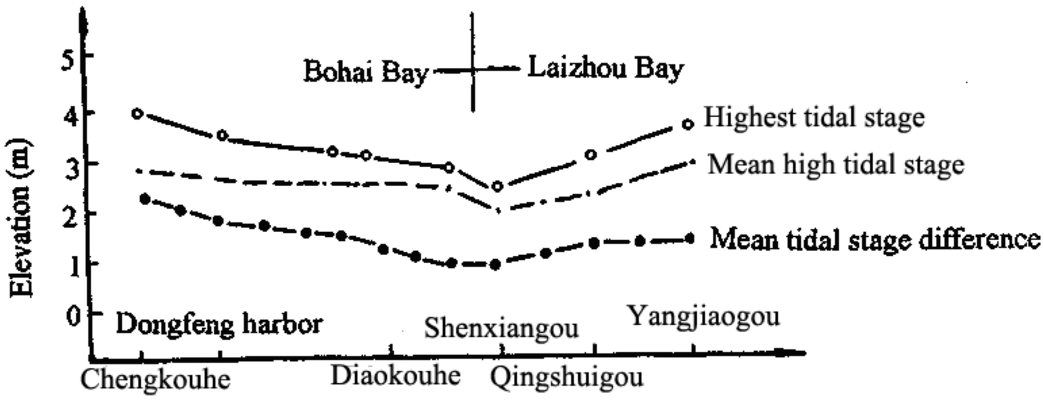

Fig.2.2 Tidal stages along the coast

(2) Tidal Current

The tidal current in the whole sea area is gyrating current; in the middle area of the Bohai Bay, the ellipticity of the tidal current ellipse is 0.3. due to the restriction of the Yellow River delta on circumrotation of tidal current, the tidal current ellipse becomes more oblate, the ratio of the short axis length to the long axis length is less than 0.1, i.e., the tidal current becomes a to-and-fro current. Under normal conditions, the long axis of tidal current ellipse along the delta coast is parallel to the coast, and the direction of tidal current is nearly vertical to the coast at the two bay crests. The velocity distribution of the Yellow River mouth after the Yellow River shifted its channel to Qinshuigou channel is shown in Fig.2.3. There exit two high velocity areas, one lies in the Shenxian Gou mouth, the other lies in Qinshuigou mouth, both constitute its own close radiation area. The variation of maximum velocity outside Qinshuigou is most remarkable among the two high velocity areas owing to the ceaseless extension of the Yellow River mouth. The measured maximum velocity was 2.2m/s. Residual current velocity along the coast outside the Yellow River mouth is generally 0.1~0.3 m/s, and the height of sea wave is 1.5~5.7 m.

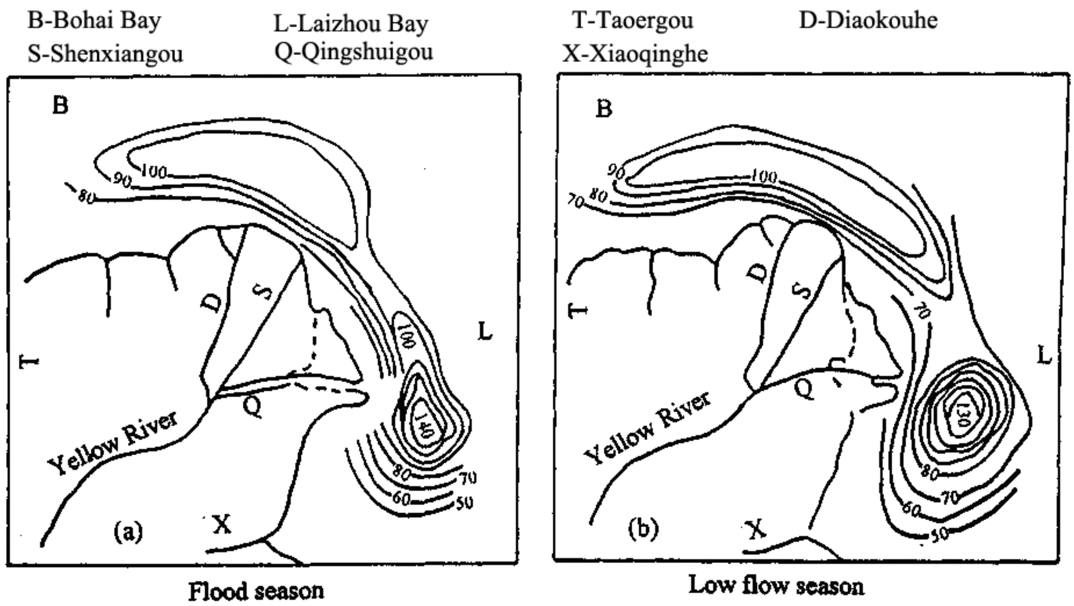

Fig. 2.3 Sea current velocity contour near the river mouth (Unit: cm/s)

(3) Sediment Carrying Capacity of Sea Current

According to the measured data, the distribution of siltation in the Qingshuigou channel and the sediment load transported by the sea current during the period of 1976~1995 are listed in Table 2.5. It can be seen that despite the total amount of runoff and sediment load, the siltation amount in the tail channel and littoral area, and the sediment transport rate to the deep sea were different during different periods, the annual sediment amount transported by sea current was basically kept at about 0.2~0.24 billion t, which showed that the action of sea current on sediment transport was relatively steady.

Table 2.5 Distribution of siltation in the Qingshuigou channel and sediment amount transported by sea current during the periods of 1976~1995（Unit：billion t）

Periods	Sediment load at Lijin station	Siltation on floodplains	Siltation in the channel	Siltation in the littoral area	Sediment amount transported by sea current		
					Total amount	Sediment transport rate (%)	Average annual amount
June.1976~Sept.1985	7.964	1.378	0.024	4.611	1.951	24.5	0.211
Oct.1985~Sept.1989	1.767		0.079	1.179	0.828	46.9	0.207
Oct.1989~Dec.1992	1.272		0.048	0.466	0.758	59.6	0.237
Jan.1993~Oct.1995	1.565		0.062	0.482	0.702	44.8	0.234
Jun.1976~Dec.1992	11.003	1.378	0.151	6.256	3.537	32.1	0.214
Oct.1985~Oct.1995	4.604		0.189	2.127	2.288	49.7	0.229
Jun.1976~Oct.1995	12.568	1.378	0.213	6.738	4.239	33.7	0.219

2.1.3 Prediction of Variation of Flow and Sediment Load

According to the measured data，reductions in incoming runoff and sediment load is not mainly caused by rainfall, for the decrease of rainfall in recent years was only about 10 percent. The main factors affecting the incoming runoff and sediment load were ① hydraulic engineering works and soil and water conservation works in the upper and middle watersheds；② the impoundment of Xiaolangdi Reservoir；③ Siltation in the Lower Yellow River and diversion of water and sediment；④ Siltation in the estuarine reach below Lijin and utilization of water and sediment；and ⑤ Diversion Projects from the South to the North. It can be predicted that along with the development of social economy and the construction of hydraulic engineering works and soil and water conservation works in the upper and middle watersheds, the incoming runoff and sediment load will be further reduced.

2.2. Changes of the flow path in the Yellow River Delta

The Yellow River transports 0.8~1 billion tons of sediment to the delta and created land at rate of 20 km^2/year. Historically, the river in the delta behaved in the routine of "high flood - dike broken - shift of channel - flowing in a new channel and created new land". Major shifts of the flow path have occurred 10 times since 1855 and minor shifts over 50 times. Table 2.6 presents the ten major shifts of the flow path and Fig.2.4 shows these channels.

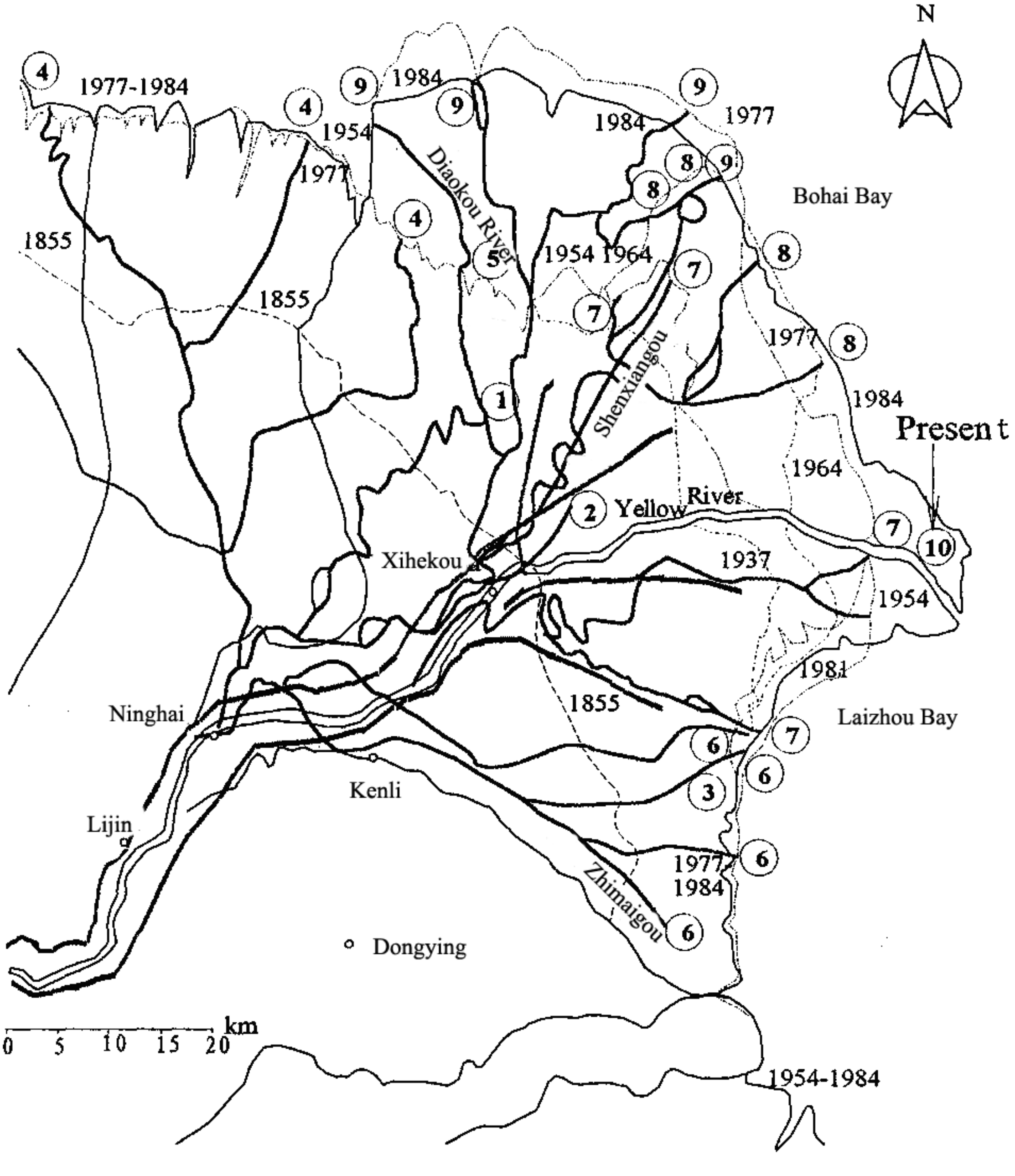

Fig. 2.4 The modern Yellow River Delta and shifts of the river channel

Table 2.6 Shifts of the flow path

No.	Year	Position of diversion	Position of river mouth	Useful life (year)	Time of actual streaming (year)	Trigger of channel shift
1	Aug., 1855	Tongwaxiang	Xiaoshenmiao	34	19	Dike broken by flood
2	Apr., 1889	Hanjiayuan	Maoshituo	8	6	Dike broken by ice jam flood
3	Jun., 1897	Lingzhizhuang	Shiwangkou	7	5.5	Dike broken by flood
4	Jul., 1904	Yianwuo	Laoyazhui	22	17.5	Dike broken by ice jam flood
5	Jul., 1926	Balizhuang	Diaokouhe	3	3	Dike broken by flood
6	Sep., 1929	Jijiazhuang	Nanwanghe	5	4	Artificially dike broken
7	Sep., 1934	Yihaoba	Laoshenxiangou Tianshuigou Songchunronggou	20	9	
8	Jul., 1953	Xiaokouzhi	Shenxiangou	10.5	10.5	Human controlled cut off and channel shift
9	Jan., 1964	Luojiawuzlii	Diaokouhe	12.5	12.5	Human controlled channel shift to control ice jam flood
10	May, 1976	Xihekou	Qingshuigou			Human controlled channel shift

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2.2.1 Historical Changes of the Flow Path

The first shift of the Yellow River delta is referred to as the big shift caused by the levee break at Tongwaxiang and the flood water captured the Daqing River channel in 1855. Until 1884 the flow path was stable because little sediment was transported to the mouth area.

During the period of 1884~1910, as dikes had been gradually completely constructed, more sediment was transported to the mouth area, the new channel and floodplain were formed, the tail channel extended and aggraded, and the water level rose. During this period the channel was unstable, and four shifts occurred. The second shift happened in April of 1889, the channel shifted to the south；The third shift happened in June of 1897, the channel further shifted to the south, entering the Laizhou Bay；The fourth shift happened in July of 1904, the channel abruptly shifted back to the Bohai Bay on the left side.

During the period of 1910～1949，the evolution of the tail channel became slow, and three shifts occurred in July 1926, Sept. 1929 and Sept.1934, respectively. All the three shifts concentrated in the middle-south of the delta.

2.2.2 Changes of the Flow Path in Recent Decades

In recent decades, the river channel was artificially shifted four times: to the Shenxiangou channel in 1953, to the Diaokouhe channel in 1964, to the Qingshuigou channel in 1976, and to the Fork channel in 1996.

Fig. 2.4 shows the Shenxiangou, Diaokouhe and Qingshuigou channels and the current Yellow River delta. Economic development of the area and evolution of the current delta were closely related to the development of the river channels.

(1) The Shenxiangou Channel

As shown in Fig.2.4, the river flowed through the Tianshuigou channel, Songchunrong channel and Shenxiangou channel before 1953. The Tianshuigou channel was the main stream, which was located not far from the present Qingshuigou channel. Some 10% and 30% of the discharge flowed through the Song-chun-rong and the Shenxiangou channels, respectively. For long-term use and sediment deposition, the Tianshuigou channel became too long, high and twisted. The discharge into the Shenxiangou channel increased from 30% to 70%. In the spring of 1953, the Shenxiangou channel bed was lower than the Tianshuigou channel bed by 0.71m near Xihekou. In July 1953, a pilot channel was dug to connect the two channels for releasing flood. All flood discharges flowed through the Shenxiangou channel into the sea. Because the length of the channel was shortened by 11 km and the bed elevation was lower, retrogressive erosion occurred. The stage at Qianzuo dropped 1.5 m at a discharge of 3,000 m^3/s. Considerable scouring affected 170 km of channel bed. Successive floods occurred after the flow was merged, which resulted in erosion and stabilization of the channel. Although the annual sediment load to the delta was over 1.24 billion tons in the 1950s, the Shenxiangou channel bed was not much silted up due to the bed scour during high floods. In 1960, the channel was only 7 km longer than the Tianshuigou channel. In the period of 1960-1963, the Sanmenxia Reservoir impounded water and trapped 5 billion tons of sediment. Therefore, the sediment transported to the delta was remarkably reduced.

(2) The Diaokouhe Channel

Since 1960, the flood stage at the delta has risen gradually. Ice floods occurred in December 1963 and the stage rose sharply which threatened the oil field. The dike at 1100 m downstream from the Luojiawuzi gauging station was artificially broken by explosion and the flood was diverted into the Diaokouhe Channel. The channel length was shortened from 58 km to 26 km. In the early period after the shift of the channel, water overflowed in a 10 km wide channel and the river mouth was unstable. Then several fork channels developed. Two years later, the main stream moved to the east fork and the flows gradually merged. In the period, the channel bed silted up by 2 m and the mouth extended by 13 km. The stage was high so that somebody suggested shifting the channel again. A high flood occurred in September 1967 and the flood scoured the channel. Thus, a straight and stable channel was formed. By 1972, the channel had extended 30 km. In 1972 and 1974, high floods coincided with wind storms and the stage near the mouth rose sharply, as shown in Fig 2.6. In 1976, the channel length (from Luojiawuzi to the mouth) was 59 km and in May the river was then artificially shifted to the Qingshuigou channel.

The year of 1964 was wet with 101 days of flow discharge over 5,000 m^3/s. The sediment concentration in that year was low; the average concentration in the flood season was only 28 kg/m^3. Nevertheless, no retrogressive erosion occurred in the Diaokouhe channel in the period, though the flow conditions were favorable, because the bed elevation at several locations was high and there were cohesive silt bars which resisted scouring. Moreover, the Diaokouhe channel was covered with weeds which resisted scouring. The annual sediment load was 1.08 billion tons in 14 years of the Diaokouhe channel period. The operating regime of the Sanmenxia Reservoir was changed in the period and a huge amount of sediment were released, which deposited on the river bed of the Shandong section. The water stages at a discharge of 3,000 m^3/s rose by 1.97 m at Aishan, 2.32 m at Luokou, 1.36 m at Lijin, 0.95 m at Yihaoba and 0.62 m at Xihekou. The extended length of the channel was 12 km longer than that of the Shenxiangou channel.

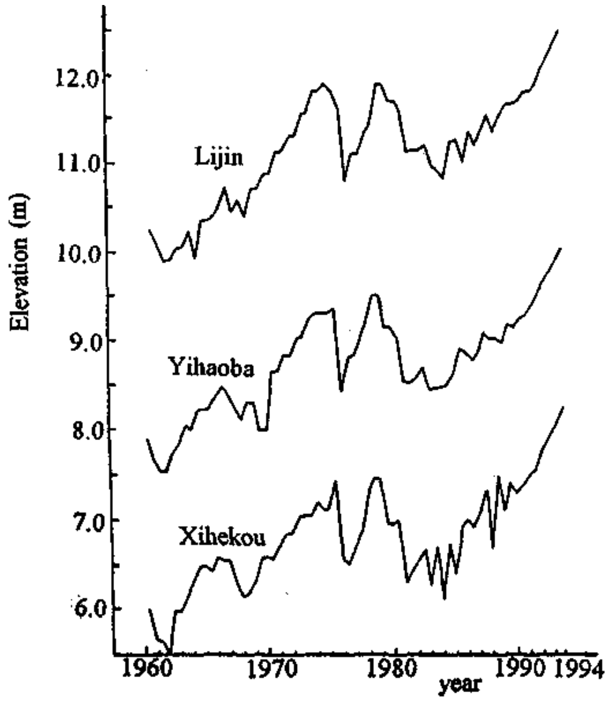

Fig. 2.5 Variation of water stages at Lijin, Yihaoba and Xihekou

(3) The Qingshuigou Channel

In 1975, a flood of 6,500 m^3/s occurred and the stage at Xihekou was close to the critical stage of 8.52 m (in the Yellow Sea system) (the critical stage was increased to 10.52 m after the dikes were raised by 2 m in 1983). Therefore, the river was artificially shifted to the Qingshuigou channel in May of 1976. Before the shift, dikes along the new channel were built and a pilot channel was dug. The original length of the Qingshuigou was 37 km less than the Diaokouhe channel. In the early Qingshuigou channel period, the river flowed through the pilot channel and bifurcated into two fork channels at Qing-3. Later, the flow merged to the south fork. The width of the river was 2~3 km and the water flow was shallow and unstable. The original length of the channel from Xihekou to the mouth was 38 km. Five years later, the channel became stable, straight and deep and the river mouth was unimpeded. The channel length was 45 km. Since then the channel upstream of Qing-7 has been stabilized and the channel downstream of Qing-7 extended.

In the early Qingshuigou channel period, the stage in the area fell apparently because the elevation of Qingshuigou was lower than the Diaokouhe channel bed by l~2 m and the energy slope was steep. In the flood season of 1976, the stage at Lijin dropped by 0.9 m, and at Liujiayuan (30 km upstream of Lijin) by 0.3 m. Until 1979, the stage in the flow path remained lower than the 1975 level. In 1980, a high flood resulted in serious bed scour and made the channel bed and stage much deeper. Until 1989, the stage remained below the historic high level, as shown in Fig. 2.5. The water and sediment load changed considerably and new river training engineering projects were started since 1989. The evolution of the Qingshuigou channel and variation of water stage began to exhibit new characteristics.

In 1973, the State Flood Control Headquarters decided to strengthen the 900 km long dikes of the lower reaches of the Yellow River to reduce the threat of flood in 10 years. The project was finished in 1990 and the dikes were raised by 2 m. The improvement allowed continuous use of the Qingshuigou channel.

(4) The Fork Channel

Before the flood season of 1996, the artificial channel shift to the Fork channel at C.S.Qing-8 was implemented, the river channel length below Xihekou was 49 km, being 16km shorter than that before the channel shift to the Fork channel. Due to rather great amount of incoming water and sediment at the same year of the diversion, the naught isobath near the river mouth during the flood season moved 5.5 km to the sea. Hereafter, owing to continuous low water amount and sediment load, the position of the naught isobath changed a little. Until 1999, the river channel length below Xihekou was basically 56 km. After the operation of Xiaolangdi Reservoir in 2000, the river-mouth bar deposited forward or eroded backward, the river channel length basically kept unchanged, the water level at the same discharge dropped obviously compared with that before the channel shift to the Fork channel.

2.3 Sediment Deposition

2.3.1 Deposition in the Tail Channel

(1) Deposition and extension of the tail channel

The Yellow River mouth area, being the main sediment deposit area, is formed during the frequent shifting and diversion of river course. The flow path to the sea has experienced ten great shifting since 1855, as shown in Fig.2.4. The fluvial processes of the Yellow River mouth have been undergone three great artificial diversions and one artificially forking since 1953. Table 2.7 presents its extension and formation of land, indicating the tail channel kept in continuous deposition and extension.

Table 2.7 Extension and land formation of recent river mouth

Flow route	Period	Life-span of the channel (Year)	Sediment load (Billion ton)	Area of land formation (km^2)	Extension length (km)
Shenxiangou	1954~1963	9	11.625	412.0	15.8
Diaokouhe	Jan.1964~Sept.1973	10	11.309	506.9	17.6
Qingshuigou	Jun.1976~Oct.1991	16	10.647	586.9	17.7

The length of tail channel below Ninghai basically had been about 60 km before diversion to Shenxiangou in 1953, it began to increase after 1953, and the coastline of the delta formed during recent diversions in 1953, 1964 and 1976 extended to sea for about an average distance of 20 km. The shortened lengths of flow path of Shenxiangou, Diaokouhe, Qingshuigou and the Fork channel at the beginning of diversion were 11 km, 12 km, 38 km and 16 km, respectively, and the extended length of these flow routes at the end of diversion were 7 km, 12 km, 38 km and 7 km, respectively. The river channel length during the recent diversions has undergone shortening at the initial stages of diversions and deposition and extenion at the later stages of diversions.

2.3.2 Deposition of the Mouth Bar

(1) Evolution of the mouth bar in plane configuration

Under the joint action of stream flow and sediment load and ocean dynamics, the plane configuration of the mouth bar appears complicated. At the early stage of the flow route, no mouth bar exists, sediment deposits and the mouth bar gradually develops over time. For some periods, when ocean dynamics is stronger than stream flow, the inner mouth shoal and sand bank develop rather quickly as shown in Fig. 2.6

(a). When ocean dynamics is weaker than the stream flow, it develops rather quickly outside the river mouth as shown in Fig. 2.6 (b). When the flow route enters the sea at a relatively stable locality, the shoal and sand bank inside and outside the river mouth connect and change into one single body, form into the mushroom shape as shown in Fig.2.6 (c). The evolution of the mouth bar behaves deposition mode of the old one and the new one overlapping and interlacing with each other, moving back and forward, mainly advancing, which results in transverse and longitudinal extension of the shoal head, and becomes the basic conditions for land formation of the river mouth and coast line extension.

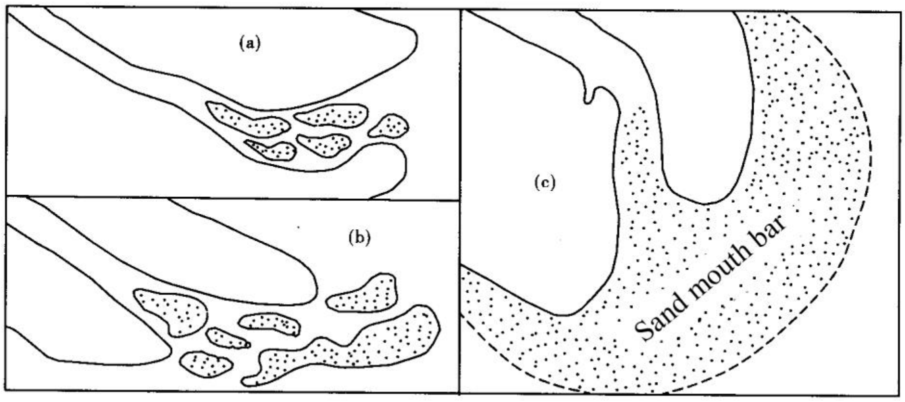

Fig.2.6 Plane configuration of the mouth bar

(2) Evolution of the mouth bar in longitudinal configuration

The longitudinal profiles of the mouth bar in the periods of 1984~1995 and 1996~1999 are shown in Fig.2.7. The longitudinal profiles of the mouth bar are mainly composed by the reverse slope section of upper reach, the top slope section and the steep slope section. The top slope section forms the erosion datum base of the river channel outlet. The deposition elevation of the top slope section is closely related to the condition of incoming runoff and sediment load, and it aggrades quickly when the incoming runoff and sediment load is large. At the early stage of channel shift to Qingshuigou channel implemented in 1976, the incoming runoff and sediment load was rather large, the mouth bar developed quite rapidly, the elevation of top slope section quickly rose to a steady elevation. After 1984, the rise of the mouth bar was rather small; since channel shift to the Fork channel in 1996, due to the low runoff and sediment load, the mouth bar has almost not been developed. The range of the reverse slope section is 0.3~4.4 km, the elevation difference between the toe and top of the slope, i.e., the height of the mouth bar is 0.25~1.75 m, with an average value of 1.07 m. The slope gradient of reverse slope section is -1/5000~1/100. The elevation of the mouth bar ridge peak is -0.8 m~0.05 m, its average value is -0.5 m. The width of top slope section is 0.9~4.8 km, its average value is 2.46 m. The width of mouth bar toe is 2~7.2 km, its average value is 4.7 km. The steep slope section of the lower reach has a range of 0.2~1.3 km, its average range is 0.5 km, its slope gradient is 1/400~1/100, and its average slope gradient is about 1/230. The steep slope section connects with the sea area.

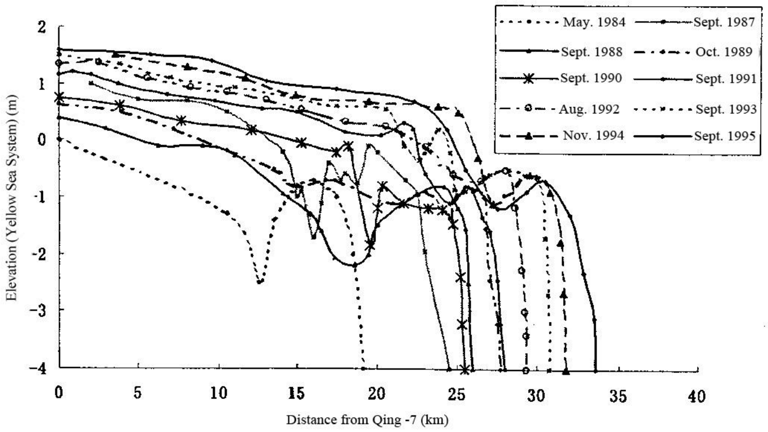

Fig.2.7(a) Longitudinal profile of the mouth bar before Qing-8 forking

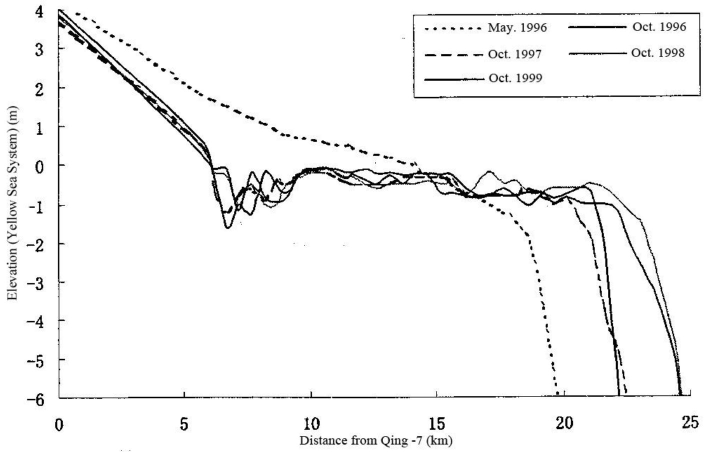

Fig.2.7(b) Longitudinal profile of the mouth bar after Qing-8 forking

(3) Vertical rise and fall of the mouth bar

Vertical rise and fall of the mouth bar is affected by conditions of the incoming runoff and sediment load, stability duration of the river mouth, ocean dynamics, and the variation of sea level, etc. The variation amplitude of mouth bar elevation is restricted by the sea level. In the period of May.1984~ Sept.1995, the average elevation of the mouth bar section was -0.80~-0.10 m; the elevation of the mouth bar ridge peak was -0.70~-0.10 m. After changing the fork channel at Qing-8, the variation amplitude of the mouth bar ridge peak was -0.7~-0.90 m, which was smaller than that before changing the fork channel at Qing-8, and the average elevation of the mouth bar was reduced by about 0.5 m.

(4) Changes of the mouth bar in cross-section

Changes of the mouth bar in cross-section are referred to as the evolution of the mouth bar along the direction perpendicular to the river channel. Fig.2.8 shows changes in the cross-section of the mouth bar in the period of Sept. 1988~Sept.1995 along the axis y=20702500. It can be seen from Fig.2.8 the evolution pattern of the mouth bar is the extension to the left and right sides and aggrades forming the land. The cross-sectional extension of the mouth bar is caused by the action of tide and alteration of stream flow direction.

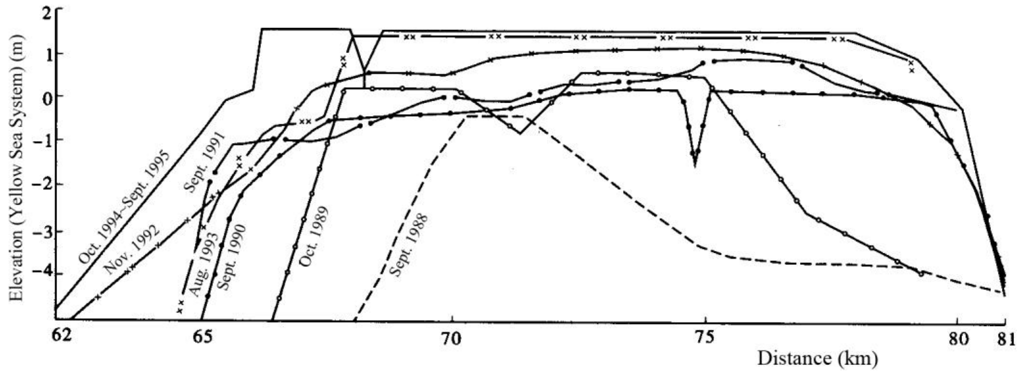

Fig.2.8 Changes of the mouth bar in Cross-section

(5) Silting forward and eroding back of the mouth bar

Except the period of 1989~1990, the front edge of the mouth bar advanced toward the sea (See Fig.2.7). The advancing rate of the mouth bar varied in different periods, but it showed a decreasing tendency.

In 1996, the year of changing the fork channel at Qing-8, the advance distance was rather large, in 1997 the Yellow River dried for 300 days, the shoal head eroded back obviously under the action of ocean dynamics, the isobath of 0 m moved back 1.7 km，the isobath of 2 m back 0.5 km，and the isobath of 12 m was basically stable. In 1998, the incoming runoff and sediment load were large, the shoal head deposited and moved forward, the isobath of 0 m forward 1.7 km，the isobath of 2 m forward 2.4 km，the isobath of 12 m forward 2.2 km. In 1999 and 2000, the incoming runoff and sediment load were small，and the mouth bar eroded back. During the period of 1997~2001, the shoal head silted forward or eroded back according to the incoming sediment loads, and basically kept in homeostasis state.

2.3.3 Silting Forward and Eroding Back of the Coast Line

The remarkable characteristics of the Yellow River mouth is that a large amount of incoming sediment load deposited in the river mouth, making extension of the river mouth and increase in land area. The extension rate of the river mouth to the sea varies with the incoming runoff and sediment load; since 1986 it has been slowed down and eroded back due to the continuous low runoff and sediment loads. According to measured data, the average annual extension rate of Shenxiangou route was 3.45 km/a，Diaokouhe was 2.68 km/a，Qingshuigou was 2.64 km/a during the period of 1976~1987， 1.14 km/a during the period 1988~1994，it was less than 1 km/a in recent years. Since 1855, the newly-generated land area is about 2500 km^2， the average annual land formation area is 22.5 km^2/a，it was 23.6 km^2/a during the period of 1855~1954，24.9 km^2/a during the period of 1954~1976, 14.7 km^2/a during the period of 1976~1992，about 8.6 km^2/a after 1992. Along with the reduction of incoming water and sediment load, the extension rate and land formation rate of the river mouth have been greatly reduced, and some of the coast area was eroded back.

2.3.4 Evolution Trend of the Yellow River Mouth under the New Water and Sediment Conditions

The remarkable changes in the incoming runoff and sediment load have a profound effect on the evolution and regulation of the river mouth, and the aberrance of the water and sediment makes the evolution of the river mouth with following new characteristics.

(1) The tail channel shrank seriously, and its cross-sectional area reduced greatly；

(2) The rate of extension and land formation of the river mouth slowed down，the coast line was eroded back, and the wetland reduced；

(3) The development of the mouth bar slowed down, and its effect on the Lower Yellow River weakened；

(4) Along with the reduction of stream flow and sediment load, sediment from the sea (deposited sediment) resuspended and transported again under the action of ocean dynamics, and the effect of which on the river mouth can not be neglected.

(5) The ecological environment of the river mouth worsens, and the basic flow for maintaining life of the river mouth is seriously insufficient.

3. Strategies for Stabilizing the Flow Path

3.1 Requirement for River Harnessing

Due to deficient water amount and abundant sediment load of the Yellow River and relatively weak ocean dynamics of the Yellow River mouth, a large amount of sediment carried by the Yellow River deposit in the Yellow River mouth, making the shoal extending offshore ceaselessly. The extension of the river mouth leads to ascension of datum level of the channel bed and retrogressive deposition towards the upper reach, and aggravates deposition on bed and rise of water level. When the channel bed aggrades to some extents, floodwater will break the restriction of the channel boundary, seek shortcut to the sea through bottomland. Henceforth, the processes of extension of the shoal head and the aggradation of the channel bed will begin again under new conditions. The fluvial processes of the delta are periodical changes of deposition, extension, aggradation, and forking and shift of the channel. The flow route to the sea has been changed frequently.

The extension of the river mouth and frequent shift of channel lead to aggradation of channel bed and rise of water level, which poses a great threat to flood control and ice jam prevention, influences the production and safety of the Shengli Oil Field, and seriously restricts the social and economic development of the Delta area. Therefore, it is very significant to implement regulation measures to stabilize the flow route and create a stable environment for Shengli Oil Field, for assuring sustainable development of the delta and protecting ecological environment effectively.

The economic development of the delta requires: (1) to harness the river mouth and stabilize the channel for a long term; (2) to utilize sediment carried by the river silting up the off shore oil field near the river mouth; (3) to construct harbors of capacity of 30~50 million tons; and (4) to construct railways along the Yellow River and connect harbors.

3.1.1 Stabilizing the Yellow River Flow Path

(1) The old Diaokouhe channel mouth has been eroded by sea-currents and the coastline is moving back. To stabilize the coastline, the Diaokouhe channel should be re-employed for sediment transport to the old mouth area. After the river shifted from the Diaokouhe channel to the Qingshuigou channel in 1976, the dikes at Luojiawuzi was raised by 2 m which enables the re-use of the Diaokouhe channel. The Dongying and Guangli harbors are playing more and more important role in the economic development of the area. The safety and long-term usage of the harbors must be taken into account in the river harnessing strategies, which means the harbors have to be prevented from sedimentation.

(2) The modern Yellow River delta is rich in oil and gas resources. Many oil fields are located beneath the fan of the channel migration. Any long or medium- term

construction of the oil fields cannot be planned if the channel is not stabilized. The Kendong oil field is located in the offshore area near the river mouth, with oil reserves of 257 million tons and may be developed into an oil field with an annual production of 5 million tons/yr. The water depth in the area is in the range of 1~5 m. By placing the huge volume of sediment transported by the Yellow River in the offshore oil field, Shengli Oil Corp. can be helped to achieve its plan for changing the in-water to on-land drilling operation in that area, so that the cost of oil extraction can be reduced by 3 billion yuan.

(3) Because of frequent shift of the river channel, long-term planning and construction of oil fields, harbors, cities and towns and infrastructures can not be conducted. Only 50% of the land has been used so far.

3.1.2 Flood Control Capability

(1) Because of the heavy sediment load the lower reaches of the Yellow River bed rise at a rate of 0.1~0.15 m/yr. The flood stage in the delta area is 3-4 m higher than the ground. The delta is seriously under the threat of flooding from the Yellow River. The discharge of the 100 year flood is 10,000 m^3/s. Table 3.1 presents the elevations of the dikes and the flood stages for 10,000 m^3/s discharge at a few stations in the delta. The recorded flood stage is still lower than the dike elevation. The completion of the Xiaolangdi Reservoir will slow down the siltation of the lower reaches of the river, and favor stabilization of the flow path. Nevertheless, the stage rise and flood risk to the whole lower reaches of the river have to be taken into account in the flow path stabilization strategies.

Table 3.1 Flood stages and dike elevations at a few stations in the delta

Station	Lijin	Yihaoba	Xihekou
Flood stage [m]*	16.60	13.69	11.12
Dike elevation [m]	17.39	14.82	12.00

* The stage and elevation are in the Dagu System (Value in the Dagu System= Value in the Yellow Sea system + 1.48 m)

(2) Wind and storm tides often occur in the coastal area in spring. In the past 100 years, storm surges with heights over 3.5 m occurred six times, in 1845, 1890, 1938, 1964, 1969, and 1992, respectively. The storm surge induces sea water to flow inland for several tens of kilometers. The stage in the river is often much higher than the ground level because the ground elevation along the coast is only 1~2 m. According to recorded data, the 100 years, 50 years and 10 years storm surge heights are 3.95 m, 3.70 m and 3.10 m, respectively, which threaten the delta seriously. The coastal areas are protected by embankments along the coast line except the southern area. The elevation of the embankments is 4.9 m. To the south of the river there is only poor and weak coastal dike which is not able to protect the land against storm and tidal surges. The system is vulnerable, especially if a wind storm coincides with a rain storm. Therefore, it is important to strengthen the embankments.

3.1.3 Water Resources and Development of Wetland

(1) The Yellow River is the main water resource of the area. In the non-flood season from November to June, the sediment concentration is low and water is diverted from the Yellow River through diversion works and canals, and then is stored in reservoirs and supplied for irrigation, industry and urban use. There are 11 canal headworks on the south bank and 5 canal headworks on the north bank, with a total diversion capacity of 485 m^3/s. In recent years, the Yellow River dried up in spring and the number of dry days increased rapidly. The number of dry days was 123 and

133 days in 1995 and 1996. Diversion of water in winter is affected by ice cover. More and more often water is diverted in summer when the sediment concentration is high. Therefore, how to combine the river training and water resources utilization, how to divert heavily sediment-laden water and protect the canals from siltation, and how to dispose of sediment in reservoirs and canals need to be studied.

(2) There is 4500 km^2 wetland in the Yellow River delta. The State Government has established the National Yellow River Delta Wetland Nature Reserve in 1,500 km^2 of the delta according to the International Wetland Protection Convention which accommodated many redlist species and rare species of birds and other animals. The Nature Reserve is located between the Qingshuigou channel and the Diaokouhe channel. The development of the wetland is closely related to the evolution of the river mouth. Following extending of the river mouth and shift of the channel, new wet lands are created which become new territory of the protected animals and vegetation. Meanwhile, some inland protected areas gradually loss their ecological importance because the river has moved far away. Therefore, the wetland reserve is dynamic and moves with the river mouth. Training of the river mouth must be integrated with the protection of the wetland

Therefore, the main aims of the river mouth harnessing is to stabilize the flow path for at least 100 years, make full use of the coastal area and water and sediment load from the Yellow River, enhance the flood control ability of the delta, provide enough water resources for development of the area and protect the Yellow River Delta Wetland Preserve.

3.2 Ideas and Schemes for Stabilizing the Channel

The useful life of each flow path depends on the speed of the channel extension and effect on the upstream flood stage. The following four measures can extend the useful life: (1) to rise the elevation of the apex of the delta fan; (2) to enhance the sediment transport capacity of sea currents; (3) to make full use of the sediment disposal capacity (or effective volume for dumping sediment) of the bay; and (4) to train and dredge the channel to increase the channel capacity for conveying water and sediment load.

According to the established criteria system for schemes of river harnessing, the following 8 terms can be served as the basis of selection of alternatives for long term development:

(1) Investment - how much money is needed to stabilize the channel, including dredging, dike and pilot channel construction;

(2) Oil production - to favor or disfavor oil production;

(3) Impact on infrastructures - to harm or non-harm the present infrastructures such as harbors, highways and hydraulic works;

(4) Land-use capability - how much land can be used for economic development and how much land is occupied by the river channel;

(5) Effect on upstream reaches - to favor or disfavor flood control of upstream reaches;

(6) Biodiversity - to favor or disfavor biological resources;

(7) Risk - number of people at risk and value of capital at risk;

(8) Environmental effect - if the pollution by dredging and oil extraction is serious for ecology and environment.

Based on the river mouth harnessing experiences in China and abroad and studies of long term development of the delta, river stabilization strategies are suggested with the following 4 ideas: (1) to make full use of the sediment transport capacity of the sea currents and extend the useful life of the Qingshuigou channel as long as possible; (2) to make full use of the Yellow River sediment for land creation, raising the ground elevation of the delta, creation of new wetland, improvement of the soil quality and the Kendong offshore oil field to be turned into land oil field. In the mean time the flood stage must be controlled below the critical stage; (3) to dredge the channel periodically and divert flood to reduce siltation of the channel; and (4) to use the main and branch channels alternatively.

To stabilize the Yellow River for 100 years 6 channels may be used for transportation of flood and sediment, namely the Qingshuigou channel, the Qingshuigou Fork Channel, the Qingshuigou North Branch 1 and 2 channels, the Diaokouhe channel and the Diaokouhe West Fork channel, as shown in Fig. 3.1. The useful life of each channel is calculated based on estimations of incoming sediment load, capacity for sediment disposal of the bay area and extension rate of the channel. Three strategies for stabilizing the Yellow River are proposed based on calculations by the river harnessing experts are as follows.

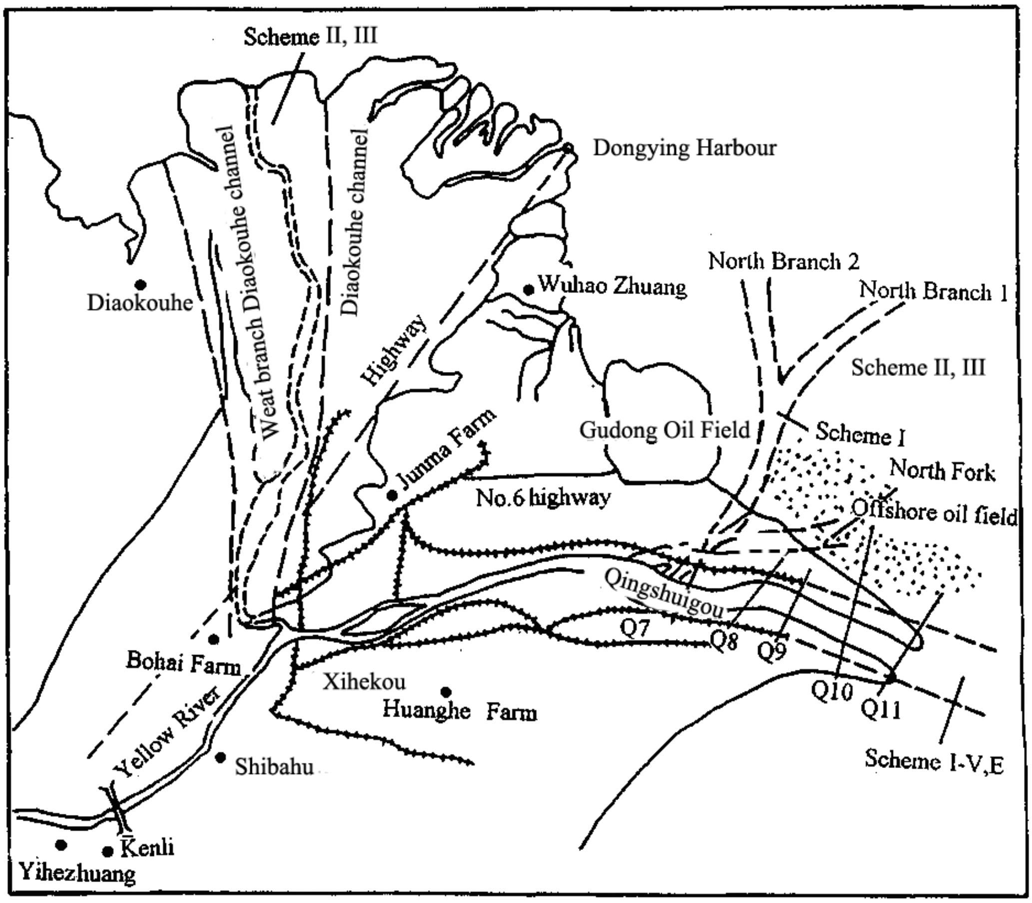

Fig.3.1 Sketch of the river harnessing schemes

Scheme I To use the Qingshuigou channel for 13~28 years and the Qingshuigou Fork channel for 23-28 years, then shift to the North Branch 1 and North Branch 2 with apex at Qing-7, for 25~34 years each. The dikes from Xihekou to Luokou (Jinan) will be raised by 1 m and the channels will have to be dredged during dry seasons with low-ground bulldozers, dipper dredgers and hauling dredgers. The use of the North Branch 2 may be given up if other channels are used as diversion channels while one channel is used as the main channel.

Scheme II To use three Qingshuigou channels, i.e. the Qingshuigou channel, the

Fork Channel, and the North Branch 1 Channel, as the main channel successively and use the Diaokouhe as a diversion channel. The useful life of each channel is 10 years more than those in Scheme I. The Diaokouhe channel is 600 m wide with flood diversion capacity of 3000-4000 m^3/s. The North Branch 2 channel will not be used because it may cause serious siltation of the Dongying Harbor. Desilt all channels alternatively in dry seasons. The dikes upstream of Xihekou are not required to be enhanced in the scheme.

Scheme III To use the Qingshuigou channel and the Diaokouhe channel alternatively. To maintain the channels by utilizing the capability of sea currents and small- scale dredging as an auxiliary measure. The river will flow first through the Qingshuigou channel, the Qingshuigou Fork channel and the Qingshuigou North Branch 1. The useful life of each channel is the same as those in Scheme I. Then the river will be shifted to the Diaokouhe channel and the West Diaokouhe channel. The width of the Diaokouhe channel, or the interval between two embankments is 4 km.

Each scheme involves several times of channel shift. It is estimated that shifts of river from the Qingshuigou Channel to the Fork, Branch 1 and 2 channels costs 380 million RMB Yuan, shift from the Qingshuigou channel to the Diaokouhe channel costs 592 million Yuan and to dig the channel and all necessary equipment cost about 2 billion Yuan. To develop the Diaokouhe channel into a diversion channel costs 592 million Yuan and additional 280 million Yuan is needed to construct gates and clean the channel. To raise the dike by 1 m needs an investment of 810 million Yuan. The channels should be dredged 47 times in 100 years that costs 925 million Yuan. The three schemes are assessed and compared with the 8 criteria and the preliminary results are presented in Table 3.2.

Table 3.2 Preliminary assessment and comparison of the three schemes

Criteria	Scheme I	Scheme II	Scheme III
Investment (RMB Yuan)	380 + 810 + 925million	592 + 280 + 925 + 2000 million	592+2000 +3300 million
Risk	substantial	middle	insignificant
Oil production	favorable	middle	nor-favorable
Impact on infrastructures			
Dongying Harbor	harmful	middle	unharmful
Highways	unharmful	middle	harmful
Hydraulic works	unharmful	middle	harmful
Land-use capability	high	middle	low
Effect on upstream reaches	nor-favorable	middle	favorable
Biodiversity	nor-favorable	favorable	favorable
Environmental effect	detrimental	detrimental	sound

* Note: (1) According to estimations provided by Shengli Oil Corp., if Scheme III is adopted oil production of 465 oil wells will be reduced and some oil wells, oil extraction equipment and infrastructures will be destroyed which cost about 3.3 billion Yuan. If Scheme II is adopted the cost will be 2 billion Yuan.

(2) In the calculation of useful life of each channel and the three schemes, a sea level rise of 0.5 m in100 years was taken into account. Because the riverbed slope is high, the influence of sea level rise is limited and the useful life of each channel is reduced only by 2-4 years.

Table 3.2 shows that each scheme has advantages and disadvantages. Economically, Scheme I is obviously advantageous over the other two schemes. Scheme III is better than Schemes I and II in the points of view of environmental protection and risk reduction. No matter how the schemes are selected the Diaokouhe Channel has to be reserved for possible future use. The dike enhancement has to be considered in the view of the safety of the whole lower reaches. Dike enhancement depends not only on the extension of the river mouth but also on the river channel siltation. If the dike is enhanced because of upstream channel siltation, the bed slope in the delta is consequently increased and the useful life of the flow path is extended. If the upstream channel is dredged the flow path has to be dredged too.

3.3 Mitigation of Deposition in the Channels

3.3.1 Planned Artificial Diversion

A large amount of sediment is transported to the river mouth, causing sedimentation in the river mouth, which extends offshore and forms shoals. As the tail channel ceaselessly extends offshore, resulting in ascension of datum level of the upper reach bed, retrogressive deposition is induced, the tail channel aggrades, the channel configuration becomes meandering, and the channel flood carrying capacity is reduced. If regulation measures are not implemented, the impact of retrogressive deposition will further proceed upstream. Fig. 3.2 shows the relation of channel extension length and retrogressive deposition length during four artificial diversions since 1953, which reveals that the range of retrogressive deposition is directly proportional to the river mouth extension length.

According to the principle of river dynamics, artificial diversion will cause retrogressive erosion to develop upstream from the river mouth, through shortening of the river length and descent of the datum level resulting in a drop in water level and an increase in water and sediment transport capacity. Furthermore, the implemented artificial diversions in the Yellow River mouth have shown distinct effects on restraining deposition in and extension of the river mouth as well as the impact of retrogressive deposition in the upper channel reach. Fig. 3.3 shows the relation between the retrogressive erosion length and the shortened length. It can be seen that the retrogressive erosion length is directly proportional to the shortened length.

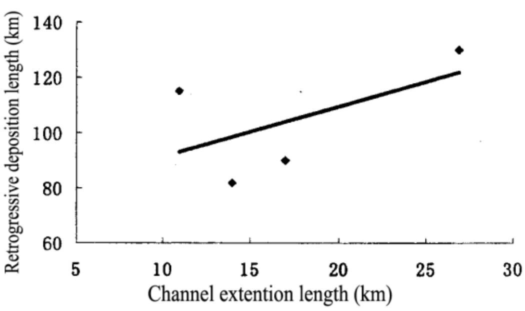

Fig.3.2 Relation between channel extension length and retrogressive deposition length (Zhang, et al. 2005)

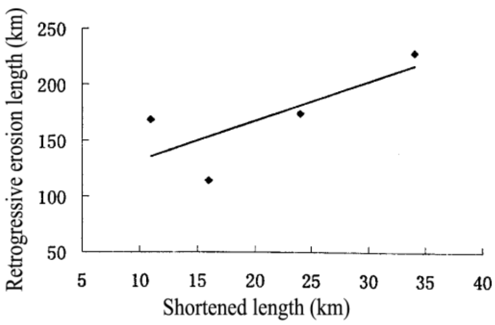

Fig.3.3 Relation between retrogressive erosion length and shortened length (Zhang, et al. 2005)

If the river channel greatly extends, a big decrease occurs in the channel slope, and retrogressive deposition obviously influences the water level at Xihekou, then an artificial diversion could be applied to decrease the deposition in the tail channel.

3.3.2 Channel Regulation

The water flows into the sea in several outlets, the water discharge of each outlets is smaller than 3000 m^3/s, sediment rapidly deposits along the coast. Besides，the frontage below C.S.7 is low and the flow is easy to overflow the bank, a lot of cross channels exist, which provide a precondition for forking and shifting of the tail channel. Channel regulation by cutting river branch and blocking river forks, increasing stability of river channel and sediment transport capacity of trunk stream, making full use of coastal dynamics, lifting deposited sediment on the offshore and transporting it to the deep sea, are one of the effective ways to ensure the stability of the river mouth and decrease the deposition and extension of the river mouth, under the condition that river dynamics for sediment transport gradually weaken. Typical regulation works are double-training dikes, as shown in Fig.3.4. Training dikes are built on the main channel banks in the area of stream flow and tidal wave, being contraction works under the criterion of median flood, mainly used to cut branches and strengthen the main stem, change the boundary condition, make the river channel single and straight, increase the flow velocity of main channel and sediment transport capacity, make the river channel unimpeded into the ocean, control the entrance mouth at the location of deep sea and strong tide.

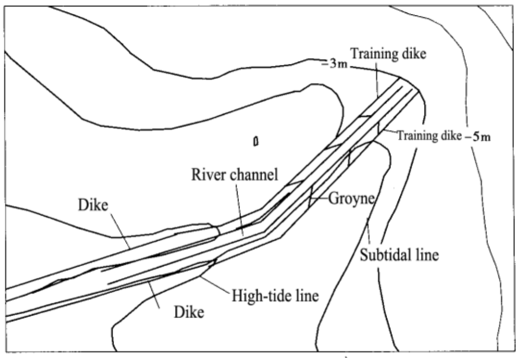

Fig.3.4 Plan view of the double training dikes in the Yellow River mouth

Practices show that if the water flow direction to the sea is perpendicular to the direction of the tidal current, the sediment transport capacity is larger, and the life-span of a flow route is longer, whereas if it is parallel to the direction of tidal current, more sediment may deposit and the life-span of a flow route is shorter. Construction of training dikes with a certain height is necessary to keep the channel entering the sea in a fixed direction.

Tide in the sea near the Yellow River mouth is irregular and semi-diurnal, the flow direction of the rising tide is to the south and the falling tide is to the north, which greatly influences the amount of sediment transported to the sea. A strong current area exists near the river mouth where the maximum velocity is 1.55~2.20 m^3/s and the duration of strong current reaches 15~17 hours each day. According to statistics, the amount of sediment transported to the far sea increases to about 50% after implementing channel regulation measures.

3.3.3 Diversion of Seawater to Scour the River Mouth

Along with development of social economy and extensively increased usage of water, the condition of water and sediment varies, the situation that there is no water for the reservoir to regulate and no big floodwater to scour the deposited sediment may occur. The main channel of the river shrinks seriously, and the pressure of flood prevention increases. Because of sharp decline of incoming water amount, it is difficult to increase sediment transport capacity by the Yellow River itself. By the thought of increasing sediment amount to the sea, a program of diversion of seawater to scour the Yellow River mouth was proposed by some scientists (Lin, et al. 2002), which is to pump sea water from Laizhou Bay to a reservoir near Lijin, then to pour a big discharge at Xihekou to the Yellow River to scour the tail channel, generating streamwise erosion below the pouring point and retrogressive erosion above the pouring point, thus to mitigate aggradtion of the tail channel. The possible formation of density flow of salty turbid water can transport more sediment to the sea. The study of physical model tests and calculations of mathematical model on the effect of diversion of seawater to scour the Yellow River mouth were carried out by some institutions. The physical model tests show that through pouring seawater a fall is formed at the pouring point, increasing the water surface slope, leading to the increase in flow velocity and sediment transport capacity, and causing erosion in the channel. Under the common action of poured seawater and stream flow of the Yellow River, streamwise erosion occurs below Xihekou, the pouring point, and the amount of erosion is gradually reduced longitudinally. The processes of erosion and deposition of channel longitudinal profiles are shown in Fig.3.5.

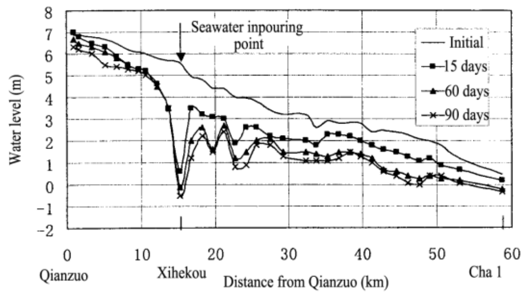

Fig.3.5 Changes in longitudinal profile of the Yellow River mouth after diversion of seawater

According to calculation results by mathematical models, sediment transport rate to the sea increases to a great extent. Pouring seawater discharge of 1000 m^3/s and 1500 m^3/s, the sediment transport rate (inside 10 m isobath) to the sea is 66.1~90%, compared with that of 20~30% under natural condition as listed in Table 3.3.

Table 3.3 Accumulation and propagation of sediment on the Yellow River mouth after pouring seawater

Series	Pouring discharge (m^3/s)	Discharge (m^3/s)	Sediment Con. (kg/m^3)	Total water amount (10^9m^3)	Total sediment load (10^9m^3)	Sedimentation (10^9m^3)	Sediment transport rate (%)	Deposition area (km^2)
1	0	1000.8	12.14	0.432	0.004	0.0031	22.9	81.3
	1000 m^3/s	1899.3	11.31	0.821	0.007	0.0016	77.8	56.3
	1500 m^3/s	2386.2	10.98	1.031	0.008	0.0009	90.0	56.3
2	0	1496.4	18.87	0.646	0.009	0.0063	33.1	143.8
	1000 m^3/s	2364.7	19.84	1.022	0.015	0.0053	66.1	143.8
	1500 m^3/s	2820.1	20.31	1.218	0.019	0.0038	80.2	131.3

Pouring seawater into the Yellow River produces high concentrated turbid flow, under proper conditions density flow may be generated, due to density difference between turbid flow and seawater. The occurring of density flow will increase sediment transport capacity, and transport more sediment load into the sea. According to calculation result by the 2-D mathematical model, density flow can increase the sediment transport rate in the river mouth by over 20%.

Analysis of diversion plans in the model considered two typical years selected from a ten-year series after construction of Xiaolangdi Reservoir, in which one is a low flow and low sediment load year, and the other is a medium flow and high sediment load year. The results show that diverting seawater under a medium flow and high sediment condition can have a more distinct effect on reducing sedimentation and increasing the sediment transport rate to the far sea. Therefore, in order to have a good efficiency, it is better to implement pouring seawater under the condition of relatively large amount of incoming water and sediment.

Based on physical model tests and mathematical calculations involving different design alternatives, a plan of building a 23 km long channel from the Xiaodao River of Laizhou Bay to Xihekou, and diverting a seawater discharge of 1000 m^3/s by pumping into the Yellow River is recommended. Due to the increase in flow and decrease in sediment concentration, the equilibrium channel bed slope below Xihekou approximately decreases from 1 to $0.6^{0}/_{000}$, and the water level under the same discharge drops 2～3 m. Several purposes can be achieved by the seawater diversion plan. However, two primary problems exist for diversion of seawater. One problem is that the investment and operational costs are high and the other is that it may cause ecological problems, which needs to be further studied.

3.3.4 Dredging in the River Mouth and Utilization of the Dredged Sediment

Along with the decrease in the incoming water amount from the Yellow River, the dynamics of stream flow for sediment transport in the river mouth have further reduced, and dredging becomes one of the important measures for river regulation. Dredging can keep the river mouth unimpeded, which aids the discharge of flood water and the transport of sediment to the sea, at the same time, dredging can generate retrogressive erosion owing to the degradation of the bed and reduce deposition in the channel.

Nevertheless, problems have to be solved before dredging can be applied as a main strategy for river training. One is how to avoid or reduce resiltation in the dredged channel; another is how to identify dredging efficiency at different places; and the last one is how to dispose of dredged sediment to prevent it from becoming a source of pollution.

The dredging effect depends on many factors due to dramatic fluvial changes of the river mouth over time, and among which resiltation is the most important factor. The result of a generalized physical model test (Cao, et al, 2003) on the dredging effect of the river-mouth bar shows that flow velocity is increased because water current becomes more centralized after dredging. The flow velocity in the dredged area increases 10～20%, at the same time, the water level in the tail channel drops, and the water surface slope increases. With resiltation in the dredged area, the increase in flow velocity and water surface slope gradually decreases. The resiltation in the dredged area largely depends on the condition of the incoming flow and sediment load. As data listed in Table 3.4, the amount of resiltation is larger when the water discharge is less than 2000 m^3/s, and it is smaller when the discharge is 3000 m^3/s, due to erosion in the tail channel. Therefore, under continuous low water flows, attention should be paid to resiltation in the dredged area.

Table 3.4 Resiltation in the dredged channel of the Yellow River mouth (Cao, et al, 2003)

Discharge (m^3/s)	Sediment concentration (kg/m^3)	Duration (d)	Amount of siltation (10^6 m^3)	Ratio of siltation (%)
1000	15	25	1.85	48.7
2000	30	13	1.22	32.1
3000	40	8	0.98	25.8

The timing of agitation dredging is a very important factor to be considered for river mouth dredging. According to analyses (Zeng, 1998), during large discharges (larger than 2000m^3/s), erosion often occurs in the river channel, whereas during small discharges, deposition occurs more frequently. Therefore, it is feasible to carry out agitation dredging under discharges less than 1,000m^3/s to alleviate deposition in the channel.

The selection of the dredging location is very important to the effectiveness of dredging, and an appropriate location can make the dredged channel link with the upper and lower reaches to improve flow conditions. Otherwise, the aim of clearing the channel is difficult to be achieved. Because the area above the tidal limit is only affected by river flow, therefore, dredging should start from the river-mouth bar.

Dredged sediment can be used for several purposes. Dredged sediment can be disposed on floodplains to raise the floodplain and eliminate big elevation differences among floodplains, which can stabilize floodplains and fix the main channel, prevent floodwater flowing along the dike, change the floodplain into fertile land, and reduce the probability of overflow, all of which are beneficial to production in the floodplain area. Dredged sediment can be used to fill the back of dikes to prevent dangerous situations, such as water seepage, piping, leaks and cracks on the levee, thus enhancing the capability of dikes to protect against floods. Dredged sediment can be used for land creation to prevent intrusion of seawater, water-logging, serious saline-alkali and degradation, and improve the environment, and thus improve the land so that is can be developed and utilized. Dredged sediment can be used to maintain the coastline, aggrading the bottom of the sea dikes; enhancing the strength of the dike to the influence of wind, waves, and sea current; and stabilizing the coast. According to Cheng, for the above-mentioned usage of dredged sediment, 1.3 billon m^3 of sediment will be needed. Supposing the annual amount of dredged sediment is 0.015 billon m^3, 87 years of dredged sediment would be needed.

Dredged sediment can be used to fill the sea and make land. The oil fields within Kendong and Qingdong lie between the inter-tidal zone and –15 m bottom contour; in order to convert offshore oil extraction to land-based oil extraction, over 10 billion m^3 of sediment will be needed. It is obvious that the utilization of dredged sediment has many prospects.

3.4 River Mouth Harnessing Projects

3.4.1 Implemented River Mouth Harnessing Projects

Sedimentation in the river mouth results in extension of the mouth and expanding of the delta. Following the extension the lower reaches of the river aggrades, which poses high and high flood threat. The grand dikes along the river have to be enhanced many times. The rate of sediment deposition in the delta depends on the following four factors: a) the elevation of the apex of the fan; b) energy slope required for transporting sediment; c) sediment transport capacity of sea currents, whether it can carry all fine sediment with diameter $d< 0.01\text{-}0.02$ mm; and d) the length of the coastal line and depth of the neighbor offshore area, or the capacity of the offshore area for disposing sediment. Therefore, elongation of the useful life of a channel may be achieved by: (1) to raise the dikes and elevation of the apex of the delta fan and keep flood stages in the delta and upstream reaches below the critical stage; (2) to utilize flood to transport sediment with low slope; (3) to make full use of the sediment transport capacity of the sea currents to transport fine sediment away from the river mouth and use the sediment disposal capacity of the bay for sediment coarser than 0.025 mm; (4) to dredge the channel periodically for conveying high floods safely through a main channel and diversion channels, and raise the ground elevation of the delta. One or more of the four methods may be adopted to elongate the useful life of a channel and the selection of the methods depends mainly on social and economic factors. Natural shift of channels in the delta is not the best way of sediment disposal. The useful life of a channel can be artificially elongated. Moreover, if the flow has to be switched to other channel it can be artificially shifted to a selected channel and transports sediment to a specified offshore area.

The following measures can be taken to elongate the useful life of channels:

-to dig and dredge channel periodically;

-to build or enhance flood control dikes;

-to build guiding dikes and direct the flow into the sea;

-to protect the dikes and control flow direction with training works.

The four measures were used in the training of the Qingshuigou Channel. The highest flood stage at Luojiawuzi was recorded in 1967. In order to control flood, since Dec. 1967 people dug an 8.7 km long approach channel, dredged the channels non-periodically, enhanced and reinforced the south dike to make it capable to control 11000 m^3/s flood with freeboard of 2.1 m, built a 17.23 km long guiding dike with capability of control 9000 m^3/s flood with 0.8 m freeboard, constructed closure dikes and drainage works to protect the oil fields, etc. For safe shift of the river from the Diaokouhe to Qingshuigou, 37 dangerous sections of dikes were reinforced with 5.52 km long bank revetment in 1976. After the shift of the river, the river swung in the delta. The Shengli oil men, Dongying people and the Yellow River mouth management bureau blocked many branches to concentrate the flow in the main channel, directed the flow in a given direction by building guiding dikes, dredged the channel and dug the mouth bar with various dredgers, utilizing tidal currents to transport sediment into the mid sea, built bank revetment to stabilize the channel. Moreover, people started the First Phase Engineering Project for further stabilization of the channel in 1995.

In the mean time, the Shengli oil men and Dongying people intensified the river mouth harnessing. By 1981, the Qingshuigou channel had been confined in a small area and basically shaped. In 1986, the dike at the north bank was reinforced, the Shunhe highway and the No. 6 highway were constructed, and several dikes and groins for controlling the flow were finished, as shown in Fig.3.6. The channel became single and stable by 1987.

In 1986, the Shengli oil men dug a fork channel at 500 m downstream of Qing-7, which is now called the North Fork channel, in order to protect the Gudong oil field and silt up the Kendong offshore oil field. The length of the Qingshuigou channel from the mouth to Qing-7 was 20 km but the North Fork channel was only 5 km long. The slope of the North Fork channel was 3 times that of the Qingshuigou channel. More than 80 % of the flow was discharged into the sea through the North Fork Channel in 1987, although the year was quite dry. Nevertheless, meanwhile, the Qingshuigou channel was seriously silted up because the sharp reduction of discharge. Many bars developed in the channel and the elevation difference between the floodplain and the main channel reduced. In 1988, the Shengli oil men blocked the North Fork channel.

Since 1988, the river harnessing was intensified with engineering measures, including: (a) blocking spill channels; More than 30 forks were blocked with timber piles and sand bags in order to concentrate the flow in the main channel, (b) building guiding dikes; a 44 km long guiding dike between Qing-7 and Qing-10 was built, with crest elevation equal to the 4,000 m^3/s flood stage which occurred in 1990. The objective of the engineering structure was to constrain stream and enhance the sediment carrying capacity of the flow, (c) dredging. Various dredgers were used to dredge the channel and the mouth bar in 1988. Explosion, excavators, bulldozers and trailer dredgers were employed to clean the channels in the dry season. The total investment for dredging was 20 million yuan. Table 3.5 presents the dredged volume in 1988.

Table 3.5 Dredged Volume of the Qingshuigou Channel in the Period 1988~1992

Year	Dredged volume (million m^3)				
	Branch-blocking	Guiding dikes	Sedimentation control	Additional works	Total
1988	1.39	0.03	1.65	0.26	3.33
1989		0.42	12 km channel was dredged	0.15	0.57
1990	0.15	0.10	Channel was dredged	0.04	0.29
1991	0.19	0.19	20 km channel was dredged	0.06	0.44
1992	0.12	0.23	10 km channel was dredged		0.35
Total	1.85	0.97	1.65	0.51	4.95

Since the river shifted to the Qingshuigou channel, the river mouth has been extending into the sea and the flood stage has been raisen by sediment deposition in the channel . A flood stage at Xihekou was recorded at 10.8 m, which was close to the critical stage of 12 m. The channel was used for 20 years, much longer than the average channel-using period. In order to relax the threat of flooding, to make full use of the sediment resources and the capacity of the bay to dispose sediment, and to silt the offshore oil field which is located at the north of the river mouth, Shengli oil men dug a new channel downstream of Qing-8 and blocked the Qingshuigou channel in 1996. The new channel is called Fork Channel and is shown in Fig.3.1. The project was composed of:

- to dig a pilot channel 150 m wide, 1-1.5 m deep and 5 km long with a slope of 1/5000. The bank slope of the channel was 1:3. The channel connected the north bank of the Qingshuigou channel at 850 m upstream of Qing-8 with an angle of 29°30′ .
- to block the Qingshuigou channel with a 4.1 km long dam of crest width 7 m. The elevation of the crest of the dam was designed according to the 4000 m^3/s flood stage. The front slope of the dam was 1:2 and back slope 1:3.
- to build a 700 m long guiding dike at the right bank of the river to direct the flow into the pilot channel.
- to build a 5.5 km long guiding dike in the new channel.
- to excavate 150 m wide gap on each of 4 old guiding dikes.

The project started on May 11 1995 and finished on 18 July 1996. The No. 1 and 2 floods of the Yellow River arrived at the delta on 22 Aug. 1996. The floods were successfully diverted to the new channel. In the flood season from July to October 1996, 12.88 billion m^3 water and 0.42 billion tons sediment flowed through the new channel and discharged into the sea. The highest flood discharge was 4100 m^3/s. When the flood flowed through the Fork Channel erosion took place and the channel became 3.5-4 m deep and 300-400 m wide. The stage of 2100 m^3/s flood on 5 Aug. was recorded at 5.8 m at Ding-zi-kou, which is located 1 km upstream of Q-6, and at only 5.81 m for a flood of 3860 m^3/s on 26 Aug. due to scour of the channel. Because the new channel was 16 km shorter than the previous one, the energy slope was larger and retrogressive erosion occurred in a section of 30 km long from the river mouth. The shift of channel reduced the flood stage upstream to Lijin. A flood of 3860 m^3/s flowed through Lijin and downstream reaches. The flow was kept in the main channel and no overbank flow occurred. Therefore, the 25000 ha of farmland and 4 oil fields on the floodplains were not inundated. As a comparison, the bankfull discharge at Hua-yuan-kou was only 3000 m^3/s in the meantime. Nevertheless, the blockage of the Qingshuigou channel has been, to a certain extent, destroyed by the flood and need to be reconstructed to prevent stream diversion. The new river mouth has extended 14 km into the sea due to sediment deposition in the new mouth.

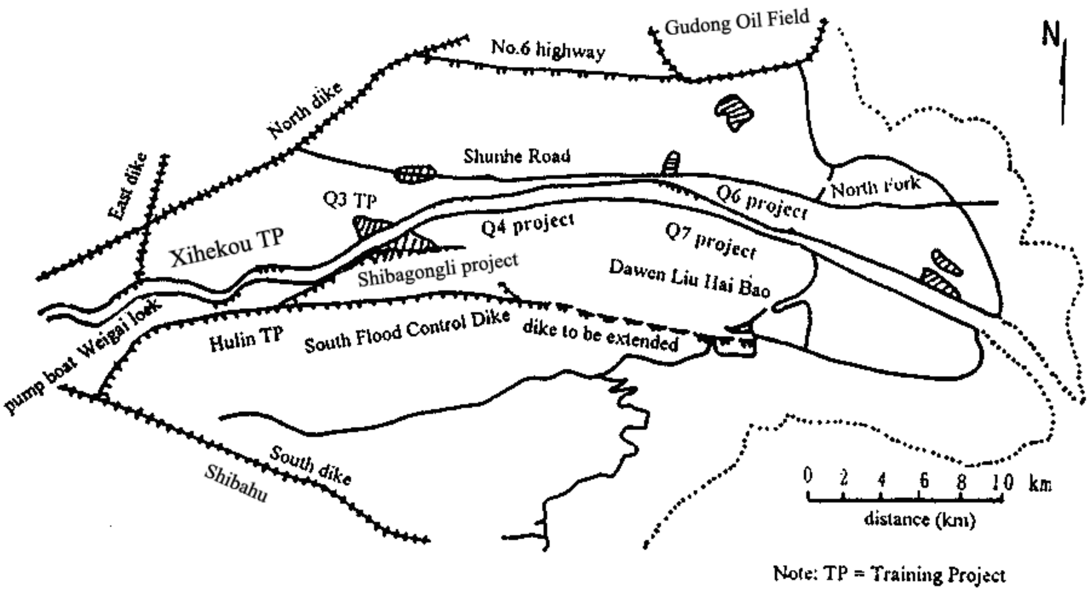

Fig. 3.6 Sketch of the River Training Projects

3.4.2 First Phase Engineering Project

The highest flood discharge for the flow path is set at 10,000 m^3/s, and the highest stage at Xihekou is set at 10.52 m above the sea level. The present embankments along the river provide security against a high level flood spilling over the flood plains but they could not withstand a direct attack by the main flow. The first phase engineering project for strengthening the embankments along the Qingshuigou channel already started in 1995.

The first phase project included a series of engineering works and non-engineering works. The engineering works were:

(1) to extend the north dike along the No.6 highway and strengthen the closing levee of the Gudong Oil Field;

(2) to extend and enhance the south bank dike by 10 km to Qing-7;

(3) to train the river section from Yihe Village to Qing-7 (11.5 km) with groins, protection works and dikes;

(4) to block small forks downstream Qing-7;

(5) to reinforce the north dike of the section from Shenxiangou to Gudong by silting up the land side of the dike to a width of 50-100 m; and

(6) to dig a pilot channel to the North Fork-1 channel. If a high flood occurs which the present channel cannot accommodate, the north fork channel will be opened to reduce the threat to upstream areas. Fig. 3.7 shows the sketch of the project.

Non-engineering works included strengthening the river mouth management institution, setting up a communication system, and the organization of an emergency construction engineering team. The total budget for the first phase project was 369.84 million RMB yuan and it was executed from 1994 to 1998.

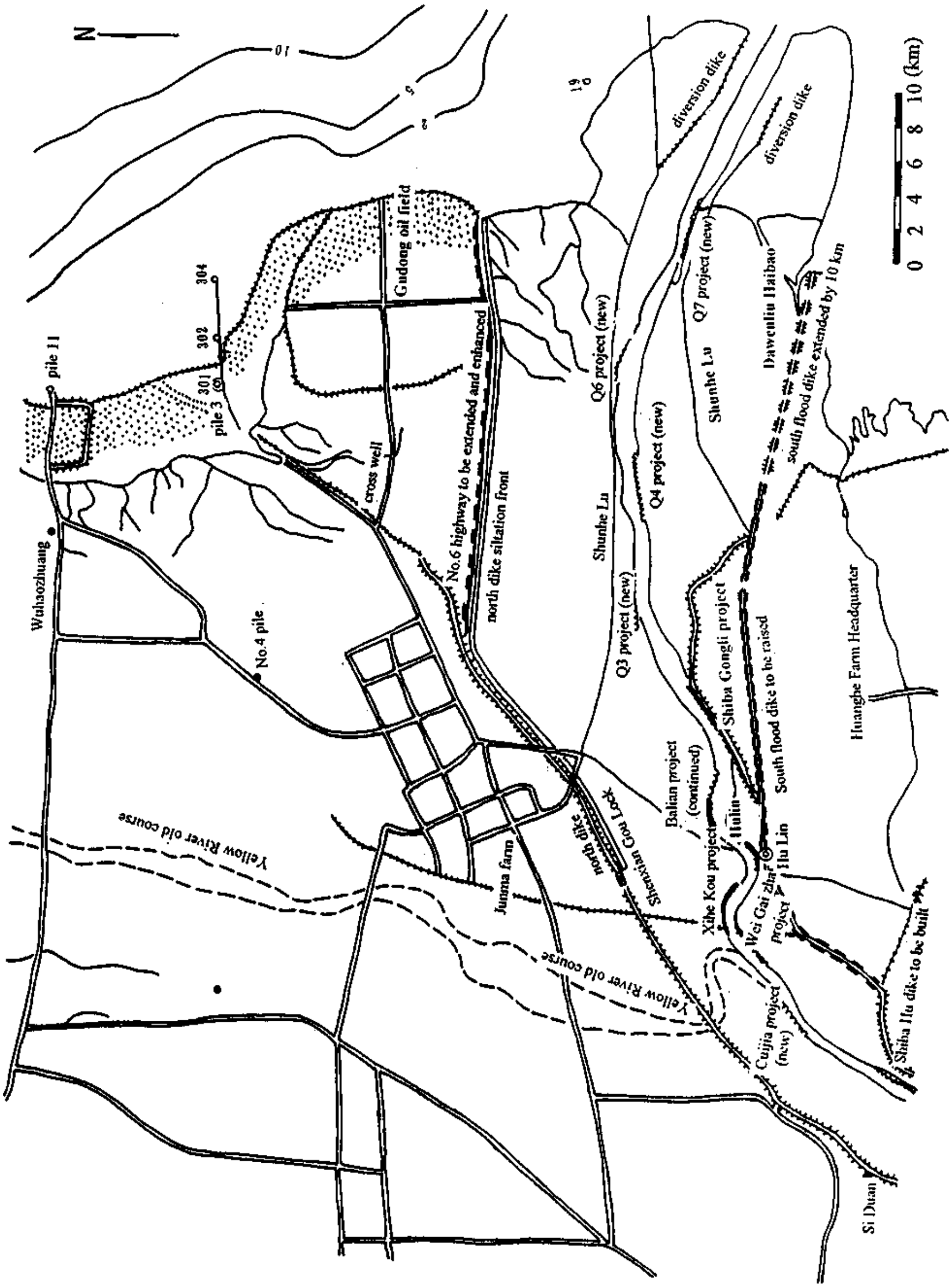

Fig.3.7 Sketch of the First Phase Engineering Project

3.4.3 Effect of River Mouth Harnessing Projects

In order to verify the effect of the river mouth harnessing project, observation and analyses on the effect of the river mouth harnessing project during the period of 1988~1992 were carried out. The observation and analyses results show that the river mouth harnessing project improved the situation of the river mouth and took effect elementarily. The effect of the river mouth harnessing project during the period of 1988~1992 are mainly as follows:

(1) Improving the situation of the tail channel and prolonging the usage life of the Qingshuigou channel

a. The tail channel became single and straight and the extension rate of the channel was slowed down

The annual extension rate of the channel during the period of 1976～1987 was 2.64 km, but during the period of 1988～1992 it was reduced to 1.22 km，0.95 km during the period of 1993～1994 (as listed in Table 3.6). Besides the effect of river mouth harnessing project, the low water inflow and low sediment load during the period of 1988～1992 was also a reason for the reduction of channel extension rate.

Table 3.6 Comparison of channel extension rate during different periods

Time (year)	Channel length below Lijin（km）		Extension rate of channel (km/yr)
	At the beginning	In the end	
1976 ~1987	75	104	2.64
1988 ~1992	104	110.1	1.22
1993 ~1994	110.1	122	0.95

b. The elevation difference between the floodplain and main channel increased and the cross-sections became narrow and deep

Since 1976, the cross-sectional configuration of Qing-1~Qing-10 gradually tended to be narrower and deeper, and the elevation difference between the floodplain and main channel increased, i.e., morphology index $\sqrt{B}/H$ decreased along with time, where *B* is the channel width under the bankful stage, and *H* is the mean water depth corresponding to the channel width. After 1987, due to the river mouth harnessing project and the reduction of the incoming runoff and sediment loads, the reduction rate of $\sqrt{B}/H$ at Qing-1~Qing-8 obviously became larger, indicating that the rate of becoming narrower and deeper increased.

c. The channel slope slightly increased

According to the field data, the channel slope below Lijin during the period 1988~1992 increased from $0.89^{0}/_{000}$ to $0.95^{0}/_{000}$, as listed in Table 3.7.

Table 3.7 Channel slopes below Lijin during the period of 1988~1992

Gauging station	Distance (km)	Before flood season of 1988		Before flood season of 1990		Before flood season of 1992	
		Bed level (m)	Slope ($^{0}/_{000}$)	Bed level (m)	Slope ($^{0}/_{000}$)	Bed level (m)	Slope ($^{0}/_{000}$)
Lijin		11.2		11.48		12.02	
	48.2		0.61		0.67		0.77
Xihekou		8.18		8.24		8.3	
	13.9		1.54		1.46		1.42
Shibagongli		6.04		6.21		6.33	
	26.4		1.18		1.06		1.05
Lijin~Qing-8		3.20		3.40		3.57	
Lijin~Qing-8	88.5		0.89		0.91		0.95

d. The rising speed of the water level was reduced

Table 3.8 lists changes in water level under the same discharge at various gauging stations. The average rise of water level was about 10 cm/yr during the period of 1988~1992, 30 cm/yr during the period of 1987~1988, and 27 cm/yr during the period of 1992~1994, which showed that the average rise of water level during the period of

1988~1992 was obviously smaller than that before and after the year of 1988~1992.

Table 3.8 Changes in water level under the discharge 3000m^3/s at various gauging stations

Time (year)	Average annual rise of water level (m/s)				
	Lijin	Yihaoba	Xihekou	Shibagongli	Dingzilukou
1987 ~1988	0.42		0.20	0.24	
1988 ~1992	0.10	0.11	0.07	0.11	0.13
1992~ 1994	0.28	0.30	0.34	0.25	0.20

In general, the river mouth harnessing projects during the period of 1988 ~1992 took effect in regulating the tail channel. In the meantime, the low runoff and low sediment loads also had some effect on the fluvial processes of the tail channel.

(2) Mitigating hazard of the mouth bar

a. The moving speed of the mouth bar toward the sea reduced

According to the field data, the moving speed of fore-front slope of the mouth bar toward the sea was 1.3 km/yr during the period of 1984~1987, and it was reduced to 1.26 km/yr during the river mouth harnessing projects in 1988~1992. The same result was gotten through analyzing satellite photographs.

b. The streamwise length of the mouth bar shortened

The Yellow River mouth is characterized by a weak tide with a small tidal range and a short tidal reach, thus the streamwise length of the mouth bar is relatively short. Table 3.9 lists the length of the mouth bar. Before 1988 the streamwise length of the mouth bar was usually over 7 km, and after 1988 it was usually less than 6 km, which showed that due to the river mouth harnessing projects, sediment deposition in the mouth bar region was reduced.

Table 3.9 Changes in length of mouth bar

Measured time	Distance from Qing-7 (km)		Streamwise length (km)	Decrease(+) or increase(-) length (km)
	Start point	Terminate point		
May 1984	12.5	17.5	5.0	+ 1.0
Sept.1987	15.8	21.8	6.0	0
Sept.1988	18.6	24.6	6.0	-1.5
Oct.1989	21.5	26.0	4.5	0
Sept.1990	20.5	25.0	4.5	+ 1.0
Aug.1991	20.5	26.0	5.5	-3.4
Aug.1992	26.0	28.1	2.1	

c. The elevation of the sand mouth bar decreased

According to the measured data listed in Table 3.10，the average elevation and the crest elevation in the mouth bar region during the period of the river mouth harnessing projects ceaselessly fluctuated, but the average elevation dropped 0.4 m~0.7 m and the crest elevation dropped 0.1 m~0.7 m compared with that in 1987, which was caused not only by the river mouth harnessing projects, but also by the reduction of the incoming runoffs and sediment loads.

Table 3.10 Changes in elevation of mouth bar

Measured data	Average elevation of mouth bar (m)			Crest elevation of mouth bar (m)		
	Average	Rise(+) Drop(-)	Water depth at low tide	Average	Rise(+) Drop(-)	Water depth at low tide
May.1984	-0.50		0.10	-0.50		0.10
		+ 0.40			+ 0.50	
Sempt.1987	-0.10		-0.30	0		-0.40
		-0.60			-0.70	
Sempt.1988	-0.70		0.30	-0.70		0.30
		0			+ 0.20	
Oct.1989	-0.70		0.30	-0.50		0.10
		-0.10			+ 0.40	
Sempt.1990	-0.80		0.40	-0.10		-0.30
		0			0	
Aug.1991	-0.80		0.40	-0.10		-0.30
		+ 0.30			-0.30'	
Aug.1992	-0.50		0.10	-0.40		0

(3) The sediment amount transported to the far sea increased

The average annual incoming sediment load was 0.861 billion t from June 1976 to Sept. 1985, 17.6％ of which deposited on the land (the channel and floodplain above Dagu datum level), 57.6％ in the delta area，and 24.8％ transported to the far sea. During the period of 1988~1993 about 40％ of the incoming sediment loads deposited in the delta area, and about 40 ％ were transported to the far sea, which was larger than that before 1988.

(4) The flood threat of the river mouth region mitigated

In the past, due to overflowing floodplain during low water, flood disasters occurred frequently. After adopting the river mouth harnessing project from 1988, the channel situation was improved, the river mouth was unimpeded, and it discharged floodwater smoothly. Floods did not overflow in three years and ice floods did not arouse disasters in two years during the period of 1988~1990, and the flood threat was mitigated. Table 3.11 lists the water level during the period.

Table 3.11 Changes in the water level under different discharges during 1988~1992

Time (year)	Daily average discharge (m^3)	Water level(m)			
		Lijin	Yihaoba	Xihekou	Shibagongli
1988	2710	12.86	10.41	8.73	6.59
	2670	12.81	10.29	8.51	6.41
	4090	13.62	11.11	9.11	7.04
	5220	13.89	11.40	9.21	6.94
1989	2210	12.43	9.91	8.24	6.07
	4150	13.63	11.16	9.20	6.93
	2670	12.90	10.20	8.54	6.30
1990	2680	12.94	10.52	8.70	6.72
	3510	13.36	10.87	9.12	6.86

3.4.4 Planned River Mouth Harnessing Projects in the Near Future

The river mouth training in the near future is planned based on the ideas: (1) to raise the elevation of the apex of the delta fan and keep flood stage in the delta area and upstream reaches below the critical stage; (2) to make full use of the sediment transport capacity of the sea currents to transport fine sediment away from the river mouth and use the sediment disposal capacity of the bay for sediment coarser than 0.025 mm; (3) to dredge the channel periodically for conveying high floods safely through a main channel and diversion channels, and raise the ground elevation of the delta.

River training engineering projects under construction and those will be implemented soon are as follows:

(1) Stabilizing the new Fork Channel project which includes reinforcing and elongating the guiding dike of the new channel and maintaining the Qingshuigou channel for flood diversions.

(2) Dredging the river mouth channel for utilizing clear water released from the Xiaolangdi Reservoir to remove coarse sediment in the main channel to floodplain and the offshore oil field.

(3) Operation management of the YRD Wetland Nature Reserve. According to ecological studies, engineering projects including dredging should be implemented to create favorable environment for wetland development and ecology protection.

(4) Other river mouth training projects to match the operation of the Xiao-lang-di Reservoir, including projects to maintain capability of the channel to transport heavily sediment-laden floods released from the Xiaolangdi Reservoir.

3.5 Dredging the River Mouth

Stabilization of the flow path needs a comprehensive training plan and a combination of training measures. Besides reduction of sediment load to the delta by utilizing soil and water conservation works and reservoirs in middle and upper reaches, construction of guiding dikes and embankments, artificial shift of channel and utilization of sea currents for sediment transport, river mouth dredging is an important auxiliary measure.

3.5.1 Purpose and Conditions of Dredging

Sediment deposits in the river mouth and results in a river mouth bar. The Yellow River mouth bar is usually 4-5 km long and 5-8 km wide extending across the river mouth like a sill. The crest of the bar is 1 m higher than the riverbed, which reduces the flow velocity and results in sediment deposition in the channel. Development and decline of the mouth bar induces retrogressive siltation and erosion. The water stage in the whole delta is sensitively affected by the height of the crest of the bar, especially during the flood season and the ice flood period. High development of the mouth bar results in swinging or shifting of the channel. Before the 1980s, high flood events often occurred in the Yellow River that scoured the channel and maintained a high channel capacity. In recent years, however, high flood events were rare, the flood discharge diminished but the sediment concentration was still high. From February to June, the river is often dried up and the channel was shrinking. To stabilize the river channel by preventing the development of mouth bar is a key job and dredging is an effective strategy. Moreover, the channel needs sometimes to be dredged to improve its discharge capacity.

Now, dredging is an auxiliary measure for maintaining the capacity of the channel. In the future, the incoming sediment load will reduce and the sediment diameter will increase, and dredging will be one of the main strategies for stabilizing the flow path.

The functions of dredging are as follows:

(1) to widen and deepen the channels for alternative use of two channels and conveying flood through one main channel and use the other as diversion channel;

(2) to remove coarse sediment larger than 0.025 mm from the main channel to floodplain so to enhance the sediment disposal capacity of the delta;

(3) to raise the elevation of surrounding ground, improve soil quality and create new wetland.

The key to harness the Yellow River is reduction in sedimentation. Principles and measures to achieve this goal depend on the requirements of politics, economics and technology. Historically, the Yellow River channel was dredged many times, but the results were not satisfactory. On the one hand, the annual sediment load was quite high and the dredged channel was silted up soon: on the other hand, dredging was not supported by advanced technology and suffered from lack of experience. Today, the conditions and requirement for dredging are much different. Many river harnessing projects in China and abroad provide rich experience of dredging and the development of technology and dredgers has greatly improved the efficiency of dredging. Furthermore, the development of the Yellow River watershed, implementation of soil and water conservation projects and diversion of water and sediment from the river have changed the distribution of water resources among the seasons. High floods for scouring the channel occur rarely. Economic development of the Yellow River delta, especially the development of the oil fields in the area requires stabilizing the channel with various methods and also provides the economic basis to dredge the channel. Moreover, the annual sediment load has reduced remarkably. The average annual sediment load was 1.02 billion tons in the period of 1951-1986, but was only 0.484 billion tons in the period of 1987-1994. The flow path did not extend in the period of 1994-1995 which proved that the transport capacity of sea currents was equal to the incoming sediment load. This shows that to stabilize the channel by dredging is necessary and feasible.

3.5.2 Methods and Experiences of Dredging in the Yellow River Mouth

Dredging methods applied in the river mouth include mechanical excavation and transportation; agitating with jet; explosion and employing wind and tide current etc. These methods are used to eliminate bars and maintain the channel bed straight and flat. Various dredgers are used: dredge boats; agitating dredgers; dipper dredgers; hauling scrapers; excavators and bulldozers, and trailer dredgers.

-Dredgers used in the delta are bulldozers, hauling scrapers, dredge boats, trailer dredgers and agitating dredgers.

-Dredged locations include central bars, narrow sections (to widen the section), shallow sections (to deepen the channel), mouth bar and eullitoral zones.

-Dredging ways are digging, hauling, agitation with jet, explosion, and so on.

The following presents the experiences of dredging in the Yellow River delta:

(1) The main channel bed of 600 m long at Qing-6 was dug 1.4-2 m deeper and 200 m wider by using hauling scrapers and bulldozers in May and June 1988 when the flow was cut off. Sand and silt barriers were removed and the channel was cleaned up.

(2) Because of diversion of flow to the North Fork channel, the main channel of Qingshuigou was silted up in 1987. In the spring of 1988 the main channel was dug by 1 km long, 200 m wide and 2m deep. Hauling scrapers were used to remove the top layers and the silt underneath was dug with diggers. Then, the first flood of the year washed the channel through and the main stream was then shift back to the main channel.

(3) There appeared a silt bar at Kendong 32# cross section which clogged the river in 1988. It was removed by using diggers and the channel was dug 1-2 m deeper in a 800 m long by 300 m wide section.

(4) In the littoral zone, the channel cannot be excavated by diggers. Submerged bars and silt barriers are removed by employing propellers of boats and ships of agitating dredgers. The re-suspended sediment is transported by the turbulent flowing water. In 1988, the main channel of 300 m long at Qing-10 was widened by 50 m and deepened 2 m in 4 days in this way.

(5) In 1988, a cutter-suction dredger of capacity 350 m^3/h was used to dredge the mouth bar. The bar was dug 2.5 km long, 5 m wide and 2 m deep. In 1990, three cutter-suction dredgers worked in a 950 m long section downstream from Balian and the channel was widened by 50-200 m and deepened by 4 m. Cutter-suction dredgers may widen and deepen the channel, their usage is wide and efficiency is high.

(6) The top layer of the mouth bar is sometimes very compact and hard to remove, and is named "Tie-ban sha" (Steel plate layer) in Chinese. In 1988, various harrow-type dredgers, such as trailing dredgers, drag dredgers, and scraper dredgers were tested but failed. If the dredger was driven downstream, the spikes of the harrow scratched only a few lines on the top surface of the bar. If the dredger was driven upstream, the spikes of the harrow thrusted into the bar and the dredger could not move. In 1989, a dredger with hydraulic guns mounted on the two sides and end of the boat was tested. The speed of jet was 11.3 m/s and the discharge was 8 1/s. The high speed jet destroyed the top layer of the bar and scoured the bar successfully.

(7) The main channel bed of 950 m long near the mouth was widened 50-200 m and deepened 4 m by using dredge boats in 1990.

From the practical experiences, bulldozers and hauling scrapers can be used to dig the 2-4 m deep channel from Xihekou to Qing-10 in spring when the flow is cut off. Dredge boats are able to dredge the channel from Xihekou to the mouth bar in the period from July to December when the water depth is large enough for boats. Trailer dredgers and agitating dredgers can be used to improve the channel capacity in flood seasons when the discharge is between 500 and 2500 m^3/s. In the littoral zone, the channel is dredged during ebb tide because the ebb current may carry the re-suspended sediment into the sea. Explosion is capable of destroying the mouth bar when the water depth is less than 1 m.

3.5.3 Cost of Dredging

(1) Volume of sediment to be dredged

The aim of dredging is to maintain the capacity of the channel high enough for conveying floods. According to flood records, the capacity of the channel downstream of Xihekou should be no less than 3000 m^3/s. The present channel from Xihekou to the mouth is only 500 m wide and about half of the section has to be widened by at least 220 m. The total volume of dredging is then 220 x 2 x 34,000 = 14.97 million m^3. The volume can also be calculated in the following way: in the period of 1988-1994 the average sediment siltation in the section was 0.256 million m^3 /km.a. The total length of the section is 60 km. Therefore, the total volume of about 15 million m^3 deposits has to be dredged annually. Both the results with the two methods are about 15 million m^3.

(2) Specification of dredgers

Specifications of various dredgers are given in Table 3.12.

Table 3.12 Specifications of Various Dredgers

Type		Length (m)	Depth (m)	Width (m)	Draft (m)	Scoop depth (m)	Engine power	Discharge (m^3/s)
Home made	80	17.5	1.2	5.05	0.7	6	240	800
	200	39.5	2.1	7.2	1.4	10	750	2000
	350	54.8	3.1	10.0	1.8	15	1320	3500
Germany OK Com.		61.6	2.65	13.6	2.05	18	750	2200
Holland	IHC Com.	26.9	1.80	6.5	1.25	10	800	2000
		82.0	4.0	13.0	2.65	22	1200	3000

(3) Cost of dredging with different dredgers

The costs of dredging with various dredgers are listed in Table 3.13.

Table 3.13 Costs of dredging with various dredgers

Dredger	Transport distance (m)	Capability (m^3/hour)	Cost (RMB Yuan/ cubic meter)
Digger	150 - 200	30-40	3
Hauling scraper	250 - 300	300	4-5
Dredger boat	800	80	4
Trailer dredger		150	2.5
Explosion		2000 m^3/explosion	5

The total cost for dredging 15 million m^3 is about 50 million RMB Yuan each year.

4. Wetlands and Nature Reserves

Wetlands are unique ecosystems, interact with the terrestrial and aquatic environment. Wetlands play important roles in flood control, runoff adjustment, climate improvement, pollutants assimilation, environment beautification and ecology balance. Wetlands are regarded as the “kidney of the global”, “cradle of life”, “sources of civilization” and “genic database of species”. Therefore, wetlands, taking a same place with forests and seas, are one of the three basic ecosystems in the World Nature Reservation.

4.1 Wetland Types and Distribution in the Yellow River Delta

4.1.1 Wetland Conception

According to the “Convention on Wetland” in Ramsar, Iran, “wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters.” This is a conception for wetland management, with definite limit, legal sanction and easy to manipulate. While in scientific significance, and in physical geography, a wetland is an environment "at the interface between truly terrestrial ecosystems...and truly aquatic systems...making them different from each yet highly dependent on both" (Mitsch & Gosselink, 1986). In essence, wetlands are ecotones. Wetlands are typically highly productive habitats, often hosting considerable biodiversity and endemism.

The United States Army Corps of Engineers (Federal Register 1982) and the(US) EPA (Federal Register 1980) jointly define wetlands as: those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

4.1.2 Wetland Types

The Yellow River Delta possesses the youngest, widest, best saving and largest wetlands in China. The wetland types and areas were studied by many researchers at different conceptions in different years. In general speaking, the Yellow River delta wetlands can be classified by 3 methods.

Firstly, depending on inundation degree, the wetlands in Yellow River Delta can be classified into epilittoral wetland, eulittoral wetland and sublittoral wetland. In the Yellow River Delta, wetland occupies an area of 4500 km^2, of which 2000 km^2 are epilittoral wetland, 1000 km^2 eulittoral wetland and 1500 km^2 sublittoral wetland (UNDP report). The characteristics of these types are as follows:

(1) Epilittoral wetland**:** the zone with ground elevation 3-5 m, groundwater table -1 to -5 m, and degree of mineralization about 1 g/liter. The ground slope in the zone is between 1/8000 and 1/10000, with year-round or seasonal ponds and water detention of 0.2-1 m depth. The water supply is mainly from the precipitation and rivers. Vegetation is dominated by waterlogged and salty-alkali soil plants.

(2) Eulittoral wetland: the zone with ground elevation 0-3 m, groundwater table -1 to 0 m. The width of the zone can be as much as 10 km. The area is periodically inundated by sea water. Soil in the zone is seriously salinized and only salty-alkali soil plants can grow in the zone.

(3) Sublittoral wetland: the marine zone with bed elevation 0 to -6 m. Variation of tidal stage and complicated topography accommodate many species of fish, shrimp, shell fish and algae.

Secondly, according to the duration of water covered, wetlands can be classified into perennial watering, seasonal watering and eulittoral wetlands, s shown in Table 4.1

Table 4.1 The wetland types and areas in the Yellow River delta (Liu, 2000)

First level	Second level	Third level	Area(km^2)
Nature wetlands	Perennial inundated wetlands	Rivers	100.33
		Estuary lakes	49.07
		Intertidal water area	84.25
	Seasonal saturated wetlands	Uptidal high-saline area	228.93
		Reed marshes	243.82
		Other marshes	176.02
		Swamps	77.34
		Freshwater marshes	153.28
		Bogs	161.11
	Intertidal wetlands	Intertidal shoal	1019.14
Constructed wetlands	Perennial inundated wetlands	Ditches	267.9
		Reserviors	144.1
		Pools	188.46
		Shrimp or crab pools	212.28
		Brine pan	191.03
	Seasonal saturated wetlands	Paddy fields	37.21

Note: exclude sublittoral wetlands

Thirdly, according to the location and conformation features, wetlands can be classified into coastal wetlands, estuary wetlands, rivers, marshes, bogs and swamps,etc (as the natural wetlands) ,and reservoirs and paddy fields(as the constructed wetlands), as shown in Table 4.2.

Table 4.2 Wetland types and areas in the Yellow River delta (Cui, 2001)

Types		Sub-types	Area(km^2)	% to total area
Natural wetlands	Coastal wetlands	Undertidal wetlands	1500.00	24
		Intertidal littoral shore	1220.61	19.6
		Uptidal high-saline area	294.20	4.7
	Estuary wetlands	Intertidal estuary wetlands	147.05	2.4
		Undertidal estuary wetlands		
	Rivers	Watercourses	233.92	3.7
		Ancient rivers and eatuary lakes	332.78	5.4
	Fresh-water marshes	Reeds and typhas marshes	236.00	3.8
	Bogs	Reeds bogs	382.47	6.2
		Quitch bogs	146.74	2.3
	Swamps	Chinese tamarisk wetlands	81.26	1.3
		Willow wetlands	6.75	0.1
Constructed wetlands	Reserviors and hydro-projects	Reserviors	164.26	2.6
		Pools	63.82	1.1
		Channels	787.01	12.6
	Paddy fields	Stability paddy fields	97.00	1.6
		Unstability paddy fields	20.00	0.3
	Brine pan		169.36	2.7
	Shrimp pool		353.28	5.6

From Table.4.1 and Table 4.2, the main wetland types in the Yellow River delta are natural wetlands such as the coastal wetlands, rivers and marshes.

4.1.3 Wetland Distribution in the Yellow River Delta

In the littoral area in the east and north of the Yellow River Delta, especially between the Xiaodao River mouth in south and the Majia River mouth in north, there are large area continuity wetlands, in the forms of coastal shoal wetlands, the present and past channels of the Yellow River estuary wetlands, and riparian wetlands. While in the inland area in the middle and west area of the Yellow River Delta, owing to far away from the sea, high topography and human exploitation, etc. besides a few channels and depressions, there are scattered and separated constructed wetlands, such as reservoirs, pools and paddy fields, etc.（Xing, 2005). As shown in Fig 4.1 and Table 4.3.

Table 4.3 Wetlands area Statistic in 7 districts of the Yellow River delta (Cui, 2001) unit:km^2

County	Inundated	Ditches	Reed marshes	Brine pan	Shrimp pool	Shoal
Wuli	47.8	123.44		129.48	84	209.27
Zhanhua	112.28	132.73	1.42	8.95	88.5	100.34
Hekou	73.54	100.15	116.34		72.8	430.49
Lijin	33.46	71.58	17.77			129.74
Kenli	73.6	142.01	79.12		52.84	326.58
Dongying	106.88	156.5	18.96	8.33	55.29	110.55
Guangrao	14.46	60.6	2.94	22.6		21.78
Total	462.02	787.01	236	163.36	353.28	1328.75

I. Natural wetland
I_1. Sublittoral wetland
I_2. Intertidal wetland
II. River mouth wetland
III. River wetland
IV. Marshland
V. Wet meadow
VI. Constructed wetland
VII. Farmland

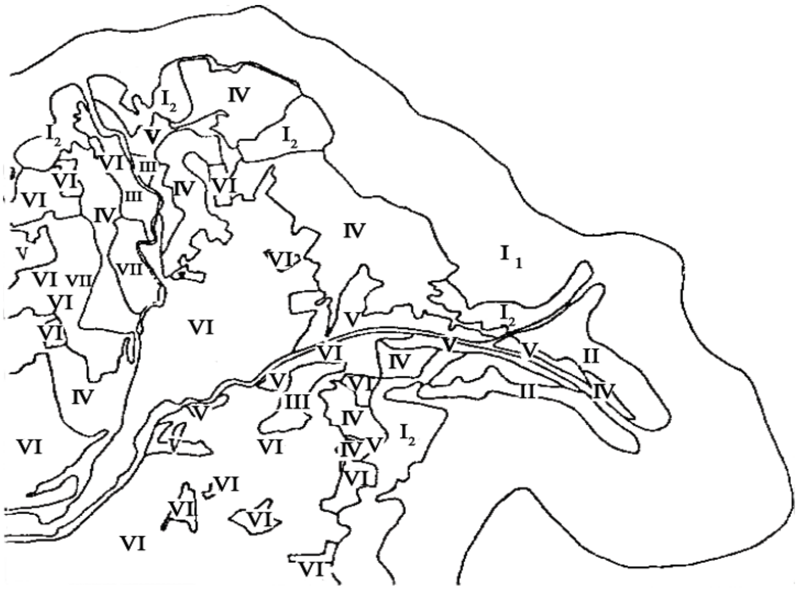

Fig. 4.1 Distribution of wetland in Yellow River Delta
(coastal line based on the navigation chart in 1996)

It is clear that the wetlands distribute densely in coastal areas, like the Hekou and Kenli districts, and more sparse with distance longer from sea, like Lijin and Guangrao districts.

As shown in Picture 1 ~ Picture 3, some typical wetland types in YRD are demonstrated.

Picture 1 Estuary wetland in YRD [website: www.sdhh.gov.cn]

Picture 2 Swamps in YRD [website: www.sdhh.gov.cn]

Picture 3 Riparian wetland in YRD [website: www.sdhh.gov.cn]

4.2 Nature Reserve

4.2.1 Nature Resources

The Yellow River Delta with richness of potential resources is in blooming development. This area is attractive in the world by its unique superiorities, such as abundant fresh water from Yellow River, endlessly increased lands and wetlands, plenty petroleum as the second oil field in China, moderate climate favorable for crops, wide shallow sea and shoals affluent in halobios and salt, rich biodiversity, and natural scenery, etc.

(1) Land resources

The Yellow River Delta is underpopulated, the average population density is 227.2p/km^2, 38.1% of the Shandong Province. According to the land investigation in 1996, the gross land area per capita was 0.44 ha, among that the cultivated land was 0.22 ha/capita. While in the littoral area, the gross land area per capita was 13.3 ha, the cultivated land was 0.45 ha/capita, mostly more than the average of the Shandong province (the gross land and cultivated land are 0.17 ha/capita and 0.1 ha/capita, respectively). The average excavation rate in the YRD was 31.4%, in that both the

Hekou and Kenli districts were only 21%. There were 22.3% of the total land underdeveloped except the land occupied by oil fields, inhabitants, transportation infrastructure, and inundated area. (Mao,1997 and Li, 1990)

(2) Water Resources

The local YRD yields little water resources. The direct surface runoff by precipitation is 0.4485 billion m^3; as for underground water, except brine, salt water or brackish water which are more than 90% of the total, the underground water useful for agriculture or domestic consumption is only 58.472 million m^3, mainly distributing in the south of the Xiaoqing River. Fortunately, the Yellow River flows through the Delta in the length of 188km, and supplies lot of foreign water. According to the field data, the annual water volume at Lijing gauging station was 33.1 billion m^3 in the years of 1952~2000. While due to the effects of precipitation decreasing in water original area and water diversion increasing along the River, the incoming water of Delta was in a reduced trend after 1970. The annual runoff at Lijin station was 31.108 billion m^3, 28.48 billion m^3 and 14.9 billion $^8m^3$ in the 1970's, 1980's and 1990's, respectively. Although water from the Yellow River is abundant in an annual average, it has the serous problem of seasonal shortage.

(3) Sediment resources

The Yellow River is well-known for its high sediment load, the average annual sediment concentration was 25kg/m^3, according to Lijin gauging station in the years of 1952~2000, correspondingly, the incoming sediment load of the YRD was 0.839 billion t annually. Both the runoff and sediment load are not uneven with season in YRD, the runoff in the flood season is 62% of the total year, not serious than the sediment load, which is 85% of total year (Xie, 1997). Among the sediment load transported by the Yellow River, nearly 20% of the incoming sediment load deposited in the river channel and the Delta, 50% in the estuary, and the rest 30% carried by tidal waves to the sea area deeper than 15m. Based on long time aggradation of the Yellow River sediment, the YRD land is extending to the sea year by year. The new land area was 420km^2 in the years of 1976~1995, equivalent to an annual increasing rate of 21km^2, while the annual increasing rate reduced to 12.8 km^2 in the years of 1992~1998, caused by less incoming runoff and sediment load. Owing to the sediment carried by the Yellow River is abundant in organic matter, nitrogen, phosphor and kalium, it can be used to meliorate saline land and improve the soil structure by warping.

(4) Petroleum, natural gas and salt resources

In the eyes of geologic structure, the YRD lies in the Jiyang downwarding belt, where is enriched in petroleum and natural gas. The Shengli oil field is a typical one in the YRD area. It was discovered in the 1960's; after more than 30 year survey, until the end of 1998, the aggregated geological reserves of petrolium is 3.82 billion t, of natural gas is 33.09 billion m^3, 85% of them distribute in Dongying city and other littoral area (Dongying Planning Coommittee, 2001).

The YRD is also abundant in reserves of salt and halogens. According to rough assessment, the total area of salt mineral is 600 km^2, located at 2900-4400 m underground, with an estimated geological reserve of around 598 billion ton. Above and around the salt mineral, there are reserve of halogens at around 2500-3000 m underground, with an in situ reserves of 3.5 billion m^3. Besides, the terrestrial heat resources area is 1150 km^2, with hot water of 0.127 billion m^3, heat energy reserves of 0.383×10^{15}kJ, equal to standard coal of 0.13 billion t (Dongying Planning Coommittee, 2001).

(4) Ocean resources

The YRD has nearly 350km coast line surrounding a shoal area of 1200 km^2. Besides, there are 4 800km^2 shallow sea area above the hydroisobaths of -10m, composed with silt and sand. Owing to the YRD coastline is in reciprocal of the cold and warm aquatic, in addition with a lot of alimenta elements carried by the river flow, there are abundant planktons, and consequently rich in many kinds of fish, prawns, crabs and seashells. The foundation for fishery and aquatics cultivation are stable. In the year of 1998, the marine aquatic product yield was 146.7 thousand t.

4.2.2 Biodiversity and Its Features

Depending on the integrated investigation of biodiversity in the YRD in 1996~1998, the biodiversity of YRD was classified into 4 groups, as shown in Table 4.4. First one is halobios, the 116 phytoplanktons have been appraised, belong to 4 phylums, 11 orders and 16 families; 79 zooplanktons belong to 4 phylums, 17 orders and 46 families; 222 benthic faunas belong to 7 phylums, 41orders and 115 families; 192 intertidal animals belong to 13 phylums, 40 orders and 95 families; and 112 fishes belong to 16 orders and 53 families of elasmobranch and teleostean. Second one is fresh-water fauna and flora, the 291 limnoplankton have been appraised, belong to 8 phylums, 41 orders and 97 families; 144 zooplanktons belong to 4 phylums, 47orders and 85 families; 69 fresh-water benthic faunas fresh-water fishes belong to 17 orders and 65 families of teleostean. Third one is advanced plant, the 4 muskegs have been appraised, belong to 4 orders and 4 families; 17 ferns belong to 8 orders and 10 families; 18 gymnbsperm belong to 5 orders and 9 families; 569 angiosperm belong to 94 orders and 357 families. Fourth one is terrestrial inhabited animal, 922 hexapods have been appraised, belong to 5 phylums, 25 orders and 189 families; 6 amphibians belong to 1 order and 3 families; 12 reptiles belong to 3 orders and 5 families; 284 birds belong to 17 orders and 47 families; and 23 beasts belong to 5 orders and 12 families.

Table 4.4 Statistics of biological species in the Yellow River Delta (Jia, 2002)

Groups	Types	Phylums	Orders	Families	Species
Halobios	Phytoplankton	4	11	16	116
	Zooplanktons	4	17	46	79
	Benthic faunas	7	41	115	222
	Intertidal animals	13	40	95	192
	Fishes		16	53	112
Fresh-water fauna and flora	Limnplankton	8	41	97	291
	Zooplanktons	4	47	85	144
	Benthic faunas	3	38	62	69
	Fishes				17
Advanced plant	Muskeg		4	4	4
	Fern		8	10	17
	Gymnbsperm		5	9	18
	Angiosperm		94	357	569
Terrestrial inhabited animal	Hexapod	6	25	189	922
	Amphibian		1	3	6
	Reptile		3	5	12
	Bird		17	47	284
	Beast		5	12	23

In the Yellow River Delta, the biodiversity of the shallow sea, littoral wetlands is various, so does the inland wetlands, such as the plants, insects, fishes, amphibians and birds. While the diversity of advanced inland plants and insects are few, especially the crawlers and beasts are scarce, same as in Shandong Province. In YRD, the widely distributed wetlands deduce various biodiversity, mainly embodying at the inland vegetation types multiplicity, birds diversity enrichment, urgently endangered birds, various in species but large in amount.

4.2.3 Nature Preservation Zone in the Yellow River Delta

The nature preserve of the YRD is located at the new continent-building belt near the both sides of the Yellow River mouth, with the total area of 153,000 ha. It is one of the thirteen priority preserved wetlands zone appraised by the United Nations Environment Programme [UNEP], it also was approved as the State Nature Preserve by the State Council of China in 1997 for protecting the wetland ecosystem of newly-formed land, rare and imminent-endangered birds. There are 393 vegetable planting and 1542 wildlife inhabiting in the China newest, widest and youngest wetland ecosystem zone. [website: www.sdhh.gov.cn]

(1) Abundant vegetation resources

The vegetation area in the Nature Reserve is 65,319 ha, 53.7% of the total coverage. Among that 50915 ha is natural vegetation, accounting for 77.9% of the total vegetation area. The vegetation in the reserve is divided into 5 vegetation groups, 9 vegetation types and 26 plant formations and plant association. Among that, the artificial vegetation in the reserve is *Robinia pseudoacacia* plantation with the area of 5603 ha, which connects with the *Robinia pseudoacucia* plantation around the reserve with the total area of 11300ha.

The nature reserve is a newly formed wetland ecosystem which has three features. Firstly, due to it is young land, various plant resources are still in the initial stage of succession and development. Secondly, because the increase in the land toward the sea, the plant resources are continuously extending toward the sea, and the formation and succession of plant communities are frequent. Thirdly, for the scarce human disturbance, the formation, development and succession of various plant resources are carried on the natural states.

(2) The animal resources

According to the geographic division of China terrestrial animals, the terrestrial animals in the reserve belong to Neoarctic pattern, northeast sub-pattern, North China region, Yellow-Huaihe River Plain sub-region. The animals in the reserve have the characteristics of Neoarctic pattern. It is a transitional zone from Oriental pattern to Neoarctic pattern. In the geographic division of China marine animals, the marine animals in the reserve are the components of Huanghai-Bohai sea fauna. It is the intersect belt of cold-warm aquatic animals with the dominance of both the cold-warm and warm water species since the influx of fresh water bring a large quantity of nourishment and there are abundance of molluse and crustacean resources, making the marine environment exceptionally suitable for fish, this area is a main spawning spot of fish.

With its large areas of shallow sea and bogs, abundance of wetland vegetation and aquatic biological resources, this reserve provides the birds with exceptional habitat for breeding, migrating, and wintering, making the reserve become an important "transfer station" in the inland of northeast Asia and around western Pacific ocean for bird migration.

(3) Rare Birds and Important Species Protected

In the list of state priority wildlife, there are 11 species of birds listed as the first class priority, such as *Red-crowned crane, White-head crane, White marabou, Golden* *vulture, bustard, Chinese goosander*, etc.; 47 species listed as the second class priority [website: www.sdhh.gov.cn]; 7 species of birds of convention on international trade in endangered species of wild fauna and flora (CITES). This reserve is a significant base for bird protection and research, biodiversity conservation, and environmental pollution monitoring in China, even in the world.

All of the 5 species of mammals in the reserve listed as key protection by the state are marine animals, such as *Phoca vilutima, Neophocaena phocaenides, Balaenopte a aculorostrata.* Among reptiles, only *Dermochelys coriacea* was listed as the second class protected animals.

Among fish, only *Trachidermus fasciatus* was listed by state as key protected species. In addition, among other aquatic animals, *Branchiostoma belcheri* was one of the key protected animals.

As shown in Picture 4~ Picture 6, beautiful scenery of the nature YRD.

Picture 4 The Yellow River flowing into the sea [Yellow River Conservancy Commission]

Picture 5 Birds frolicking in YRD [Yellow River Conservancy Commission]


Picture 6 Harvest reeds in YRD in autumn [website: www.sdhh.gov.cn]

4.3 Wetland Reserves in the Yellow River Delta

The wetlands in the Yellow River delta are formed and developed by the co-action of neo-tectonic movement, sediment siltation, local precipitation, runoff and tidal currents. In recent years, although with more hydro-projects built, more constructed wetlands are appearing, some natural wetlands degraded or even disappeared by human activities, such as urban sprawl, landfill, diking, dredging, pollution, flood control, residential development, etc.

4.3.1 Wetlands Exploitation and Wetland Conservation

The Yellow River Delta bordering on the Bohai Bay and Laizhou Bay in north and east, respectively, lies in the center of the Shandong and Liaodong peninsulas. The YRD has superiority condition in local situation, the region including Beijing, Tianjin and Tangshan cities in north, Qingdao, Yantai and Weifang cities in south. It not only stands at the front of the north-east economic sub-circle, the joint area of Bohai economic circle and Yellow River economic belt, but also is an important passage from Northeast to North and Southeast China. (Mao. 2003)

The biodiversity of YRD wetlands is very vulnerable. Firstly, due to low elevation, two-thirds of the total YRD area locating lower than 4 m above sea level, in addition with lots of depressions at the back of levees along the Yellow River, are liable to be inundated by sea flow back-wash. Secondly, owing to the short history of YRD (less than 150 years), the siltation layers have not been thickened aggregately, and neither in swampiness fully. Further more with strong evaporation, the soil salinity in deep layers easily moves to upward and makes soil salinization. Thirdly, based on the shallow underground water (generally 1~3 m under ground), and with high degree of mineralization (most area are more than 10 g/l), under the condition of strong evaporation in dry seasons especially in spring, the soil would suffer secondary salinization by upward movement of mineral. Fourthly, the local plants mostly are salt tolerance herbage, they not only adapt to the local natural condition, but also favor to increase soil organic matter and restrain soil water evaporation. But as soon as the original plants destroyed by soil reclamation, the soil structure would be deteriorated. At present, the area of saline-alkaline soil is 3/4 of the whole YRD area. Among that, high and moderate grades of saline-alkaline soil are nearly 440×10^3 hm^2, accounting for 56.2% of the total.

From the beginning of YRD reclamation in 1910, the YRD has experienced 4 stages since 1949, when P.R China was founded. The first one was increasing the efficiency of reclamation and areas of farmland in the 1950's and most of 1960's; the second one was taking advantage of land potential resources and enlarging the re-cultivation area at the end of 1960's and the beginning of 1970's; the third one was advocating the chemistry agriculture in 1970's; and the last one was diversified farming in 1980's. Generally speaking, at various reclamation stages, the YRD soil suffered only exploitation and extensive cultivation, but no protection; in recent decades, it has been gradually in rational development by the ways of reclamation congruously with construction, comprehensive planning, integrated exploitation, coordinate management (of water, farmland, forest and road), and exploitation one by one district.（Cui,2001)

As shown in Table 4.5, since 1980s, the total areas of wetlands and coastal shoal in the Yellow River delta have been still in increase, while the areas of reed marshes decreased in some degrees. The areas of constructed wetlands, reservoirs and pools also have been in a stable increase, while the paddy field changed from increase to decrease. Human activities, the Yellow River drying-up, and water resources shortage are the reasons for the area of wetlands alternation. (Chen, 2003)

Table 4.5 Changes in wetland areas of Yellow River Delta in different years (unit:km^2)

Types / Years	Paddy field	Reed marshes	Shoal	Brine pan	Reservoirs	Pools	Total
1981	4763.6	69223.9	80000.4	335.2	1954.1	3000	159277.2
1990	25409	32721	86068	2627.5	12831.6	14410	174067.1
1998	19103	24382	101914	3721	14410	18846	182376.0

Due to the low altitude of the YRD and instability of the Yellow River tail channel, the eco-environment of this region is vulnerable by natural disasters. Floods, tidal storms, ice jam floods and waterlogs, etc. would make loss of enormous property, and even human life. As an important ecosystem, wetlands can alleviate these disasters, thanks to the ability of large water storage. Furthermore excessive wetlands resources exploitation will change local weather, decrease the valuable wildlife, perish original habitat, and finally leave ecological tragedy to our offspring.

Wetlands exploitation is aimed to meet the demands of socio-economic development of contemporary human at present, while the wetlands conservation is to preserve favorable eco-environment assets to offspring in future. Excessive exploitation of the resources is contradictive with the ecosystem conservation, only the sustainable development is coordinated with ecosystem protection; consequently the more improvement, the better socio-economic development.

4.3.2 Crisis of Wetlands in the Yellow River Delta

(1) The neo-tectonic motion and sea-level rising

The Bohai Bay is dominated by long-term settlement in neo-tectonic motion; the average depth of the bay is 18 m. At Bohai seashore, most of areas covered by silt settling from the Yellow River are in an altitude lower than 3~5m [UNDP report, 1997]. Relative rising of sea level will inundate the coastal wetlands directly, then contribute to more storm surges and floods, and hence deteriorate the coastal wetlands eco-environment.

The coast of the Yellow River Delta belongs to silty sand, mostly composing with silty soil, and it is very instable in depression structure and physiognomy dynamics. Whether the coast aggradated or eroded, it fully depends on the incoming sediment load of the river. Once the volume of incoming sediment is insufficient, the wetlands in silt coast are easy to be eroded. Calculating the amounts and areas of eroded coast by satellite photography, it illustrated that besides the Yellow River mouth area, which was continually in aggradation, the other coast shores were eroded in past 20 years. Especially, the estuary of Diaokouhe River, the Yellow River old channel, and at the north edge of the delta, were eroded fastest and located in the focus of the tidal erosion. The farther from the estuary of Diaokouhe River, the less the erosion occurs. In the past, owing to lots of incoming sediment from the Yellow River, the total alluviation area is larger than the erosion area; while with the less incoming sediment of the Yellow River, extremely drying-up, in addition to the rising sea level, the coast would be eroded quickly, even the net erosion would take place.

(2) Natural disasters（Ding, 2001）

The natural disasters effecting on the YRD wetlands mainly are storm surges and floods. Either in Bohai Bay or in Laizhou Bay, the surge phenomenon would occur when strong northeast wind blows in spring and typhoon in summer. Unfortunately, if a surge meets with a high tide accidentally in the Yellow River estuary, the storm surge of 2-3 m high brings disasters to the delta. According to local records [UNDP report, 1997] there occurred 96 storm surges of 2-3 m high in the Laizhou Bay from BC 48 to AD 1949, and 21 of them were specially great. Storm surges with wave height larger than 3 m may cause serious disasters due to the low and flat delta landform. Tidal surges hazard the wetlands biology, directly damage the vegetation, and consequently threaten the animals and birds inhabitant environment.

Floods are the most serious disasters in YRD. In history recorded, the biggest flood disaster occurred in 1846 with peak discharge of 36000 m^3/s at Sanmenxia station and a runoff of 12 billion m^3 in 12 days. The second largest flood occurred in 1933 with a peak discharge 22000 m^3/s. Owing to the capacity of the Yellow River channel downstream of Aishan is limited, it could not afford the flood discharge larger than 10000 m^3/s, serious disaster and great loss were brought by large floods. According to local historical records, the dikes of the Yellow River in the delta area were broken at more than 70 places in 23 years within the period of 1883-1938, among which 50 dike breaks were caused by overtopping and 22 were caused by bank scouring. The flood not only made the wetlands suffering lots of economic damages, but also made the animals have to be immigrated. The depression would not be resumed in a long time after floods.

(3) Human activities (Chen, 2003)

Firstly, the agricultural development surely in some degrees destroyed the wetlands ecosystem, and decreased the biodiversity of wetlands, such as wetlands reclamation, irrational structure of crops, creating field by filling shoals, abused arrest and hunting of wildlife, excessive pasturage, etc. Secondly, as petroleum is concerned, in pursuit of high-yield and exploitation easy, the oil field was transferring to coastal wetlands with the new land formed by warping in recent years. Oil field construction not only occupied lots of wetlands, but also destroyed the potential ecosystem of stored wetlands for the rare birds. Thirdly, with the agriculture and oil field exploitation, the infrastructure of traffic and road are in fast development, which inevitably crash the unitary of wetlands ecosystem, and make wetlands gridding. Lastly, with the economic blooming of YRD, the wetlands were badly polluted by the petroleum leakiness, industrial waste (including sewage, exhaust gas and scrap), and agricultural non-point source discharge and consumer waste, among that the petroleum pollution is always the most serious one. More attention should be paid to the water quality of YRD, due to the increasing effluent of industrial and domestic sewage, water quality has and is being constantly deteriorated. For example, the integrated index of pollution in the Xiaoqing River and Guangli River was inferior to national grade V.

4.3.3 Wetlands Conservation in the Yellow River Delta

Depending on the above-mentioned crisis of the wetlands suffered, conservation measures should be emphasized on the following aspects:

(1) Rationally utilizing the water and sediment resources of the Yellow River

The Yellow River water is of dominance for forming and keeping YRD original wetland ecosystem, and of main water resources. The Yellow River drying-up inevitably makes YRD water shortage. Rational and scientific allocation of water resource along the Yellow River is very important to shorten or prevent the Yellow River from drying-up. Firstly, by legislation, the reservation measures of water source region should be strengthened; the schemes of water allocation and diversion in each district of the Yellow River basin should be scientifically planned. Secondly, the water-saving society should be gradually constructed and implemented both in ordinary life of citizens and agriculture irrigation, especially abolishment of the surface flooding irrigation. Thirdly, the structure of property should be modified. Such as some planned constructive items with large water consumption should be prudently considered, avoiding the conflict of the industry and agriculture with the wetlands. These actions would guarantee the sufficient water amount for sound sustainable development of wetlands.

The costal area of YRD is in alternations of extending by siltation of river sediment and retrograding by erosion of tidal current. According to expert calculation, the rate of siltation to retrogradation of the coastal line approximately is 4 to 1 (Mao, 2003). As the YRD coast is concerned, the equilibrium condition should be 0.3 billion t of incoming river sediment load, that is when the incoming sediment load is larger than 0.3 billion t, the coast will be extended, otherwise it will be retrograded.

Sediment as resources mainly uses to continent-building. It is assessed that the sediment deposited and build new land in the YRD at a rate of $23km^2/a$. Besides, it is an economic way to take advantage of sedimentation to fill offshore oil field and change the offshore operation to land extraction.

(2) Efficiently controlling natural disasters

The frequent avulsions resulted from abundant sediment load of the Yellow River make the fluvial processes of the river tail channel so complicatedly, as well as the wetlands consequently. Stabilizing the tail channel of the Yellow River in a limited regime as long as possible is the essential strategy. The Qingshuigou River is the recent outlet of the Yellow River, and it has in operation for nearly 30 years in generally stable. For the flooding and tidal surge control of the YRD, the dikes and dams are the efficient tools. In the past few years, the increasing fresh wetlands extended 30 km to ocean by training dikes (Ding, 2001). In addition with new pools and swamps constructed by water diversion for warping near the levees back, the artificial wetlands increase rapidly. Regulated construction of wetlands can rationally mediate the distribution of inhabitant in the Delta and accordingly beneficial to local economic and eco-environmental development, and it also has been recognized as a feature of the Yellow River Delta wetlands evolution.

(3) Harmonizing the wetlands exploitation and conservation and reducing the influence of human activities

The wetlands exploitation should be consistent with wetlands sustainable development. Wetlands allocation adjusting, wetlands function alternation and wetlands reproduction planning should be guaranteed in time to maintain or enhance the total amount or summarized area of wetlands. It is proved by long time practice that Nature Reserve is one of the best measures to protect the wetlands. Along with the industry and agriculture exploitation in the delta, the construction of Nature Reserve should be added in amount and enlarged in area. As the main invasion factor to the wetlands, oil field construction should be reduced to the lowest, and the annually occupied area should not larger than the wetlands accrual, especially if the oil extraction occurred in Nature Reserve, it would be forbad.

As shown in Picture 7~Picture 10, great efforts are being made to conserve wetlands.

Picture 7 Protection zone of nature Chinese willows in YRD [Photo by Chen Liu, 2001]


Picture 8 Wetlands-building [website: www.sdhh.gov.cn]

Picture 9 Farmland in YRD [website: www.sdhh.gov.cn]

Picture 10 Harmonious between nature and human activities [website: www.sdhh.gov.cn]

5. Socio-Economic Impact of Sedimentation and Wetland Conservation

Thanks to abundant incoming sediment load deposited in the Yellow River estuary, the YRD is one of the quickest continent-building deltas. The continually increasing new land supplies a wide space for wetlands development.

5.1 Value of Wetland

The wetland is one of the highest productive environmental systems. It provides numerous beneficial services for people and for fish and wildlifes. It is not only the cradle of the biodiversity, but also the inherit genes data base of vegetation. Wetlands supply water and basic nutrients and organic material surviving numerous plants and animals. Resent research illuminates that the global ecosystem provides beneficial services annually at least 33 trillion US dollars, among that 4.9 trillion US dollars coming from wetlands ecosystem [websit: www.wetlands.cn]. According to a US researcher, the value created by wetlands per hectare is 4000~14000 US dollars, which is 2~7 times to tropic rain forest and 45~60 times to farmland, respectively [websit: www.wetlands.cn].

5.2 Advantageous Impacts of Sedimentation and Wetland Conservation

5.2.1 Advantageous Impacts of Sedimentation

(1) Increase in new land

The Yellow River is well-know as a high sediment load river in the world, it carries lots of sediment to the estuarine area annually, and builds new continent continuously. At littoral belts, the total areas of continent-building estuary and submerged delta have been accumulated to 2500 km^2 after the year of 1855. As shown in Table.5, in the period of 1855~1954, according to 64 years of active runoff flowing, the continent-building area was 1510 km^2 cumulatively, at the rate of 23.6km^2 annually; in the periods of 1954~1976, 1976~1992 and 1992~2001, the cumulative continent-building areas were 548.3 km^2 at the annual rate of 24.9km^2; 364.4 km^2 at the rate of 22.8km^2 and 77.3 km^2 at the rate of 8.6km^2, respectively.

Table 5.1 Continent-building after 1855 in YRD (Liu, 2003)

Peroid	Incoming runoff (bil m^3)	Incoming sediment load（bil t）	Net silting area(km^2)	Net silting rate(km^2/a)	Remark
1855~1954			1510.0	23.6	Natural flow way
1954~1976	44.51	1.148	548.3	24.9	Shenxiangou and
1976~1992	27.12	0.657	364.4	22.8	Diaohekou outlets
1992~2001	10.90	0.306	77.3	8.6	Qingshuigou outlet

(2) Prevent coastal line erosion

As shown in Fig.5.1, the general trend of the Yellow River coast was extension during 1855~2000. After the outlet divagated to Qingshuigou outlet in 1976, the average annual extension rate was 2.3km in the years of 1976~1994. Especially the offshore of Qingshuigou outlet extended 11km in 1976, 5km in 1977, although the extended rate reduced sharply in the followed years. Some offshore areas were retrograded evidently.

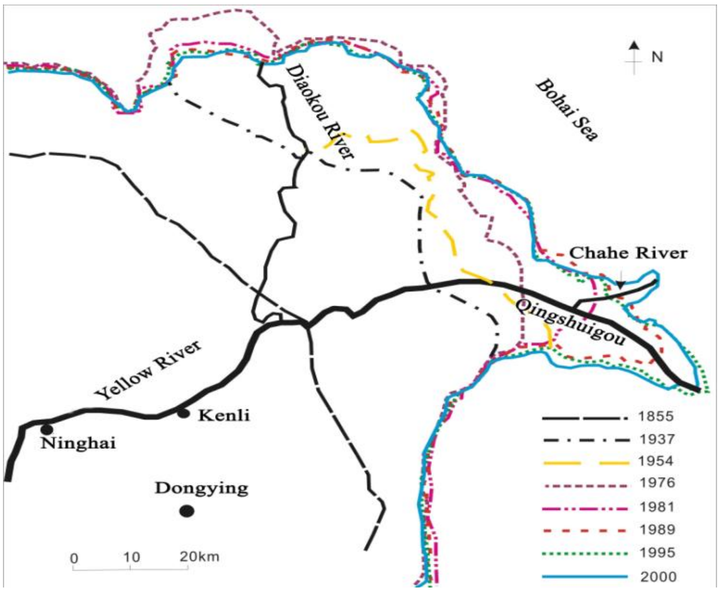

Fig. 5.1 Yellow River coastline shifts after 1855

(3) Creating wetlands

As mentioned above, sedimentation builds new continent and inevitably derives new wetland. The forming and vanishing of coastal wetlands are related closely in sedimentation. At estuary, the sediment carried by the river runoff will be suspended by tidal wave and re-deposit along coastwise by diffusion effect, and finally forms new wetlands periodically submerged by tidal waves.

(4) Facility to petroleum and nature gas exploitation

There are lots of petroleum and nature gas resources distributing in shoal belt and shallow sea (depth of 5~10 m) of the YRD coastal area. In order to facilitate exploitation, the submerged oil extraction site has better to be transformed to emerge. Thanks to lots of incoming sediment carried by the Yellow River, the tidal flat and continent-building in planned sites are feasible. By this remarkable economic way, 6 high yield (more than 1 million t annually) oil fields have been constructed, such as Gugdong and Didao oil fields.

5.2.2 Advantage Impacts of Wetland Conservation

Wetlands are recognized as one of the most valuable environments, they also are appraised as one of the most important eco-systems with rich biodiversity and high productivity. Wetlands not only provide with lots of resources, but also bear the function of environment adjusting and ecology benefits, such as protecting and improving water quality, adjusting local climate, self-restraining fresh water, flatting flood peaks, promoting new land, filtering and assimilating pollutants, protecting bio-diversity and providing resources for production and consumption, etc.

(1) Ecology benefits of Wetlands

Maintaining biodiversity. In view of wild fauna and flora protection, the YRD was endowed with the national rare and imminent-endangered wild soybean; the national protected birds, 7 species like white crane, Chinese goosander, etc. and 2 fishes; the national grade protected birds 33 species and leatherback (Xing and Zhang, 2005) .

Storing flood and preventing natural disasters. Wetlands play important roles in water storing, runoff adjusting, underground water supplying and water distribution balancing. It is regarded as natural “sponge” with double functions of storing and flood control. The YRD lies in warm temperate zone, and the precipitation is uneven in seasons in a year. By adjusting of natural and constructed wetlands, excessive precipitation and runoff are stored, and floods are avoided, and stable volume of water supply to industry and agriculture is guaranteed. Besides, with the function of resistance to tidal waves and sea currents, coastal wetlands control offshore erosion efficiently.

Filtering and assimilating pollutants. With economy development and human activity effects, more and more pesticide, industry pollutants and toxicant materials are produced with agricultural chemistry and industrial productions. Additionally, these toxicant matters are scattered with circle process of sewage outfalls, agricultural runoffs, rainfalls and runoffs. Thanks for its powerful decomposition ability by bio-chemistry processes, wetlands can be used to filter and assimilate pollutants, improve water quality and benefit to local and downstream regions.

(2) Economic benefits of Wetlands

Supply abundant raw materials. Wetlands flourish with hydrophytes like lotus, lotus roots, water chestnut, Gordon Euryale; also are abundant in aquatic animals like fishes, shrimps, and shellfish; and are rich in algae. These are nutritive foodstuffs. Besides, some wetlands flora and fauna are medicine, some are light industry raw materials like the reed for paper making, and by utilizing these resources, some processing plants are developed.

Supply water resources. Water is one of the indispensable ecological elements for any biology. Due to the shortage of local water resources, water stored in wetlands is the main origin for local industry production, agriculture activity and domestic water consumption.

Supply mineral resources. Wetlands are endowed with many types of mineral sands and salt and halogen. Saltern is an important industry for local economy development. Furthermore, the YRD reserves China second oil field-Shengli oil field. It is significant to national economy if enormous petroleum and natural gas underground are exploited and utilized.

(3) Social benefits of Wetlands

Sightseeing and touring. Wetlands nourish with esthetics value by beautiful natural scene. The YRD has been an important touring beauty spot. Wetlands tour not only increases economic benefits directly, but also makes local culture benefits prevalent. For example, in coastal city of Dongying, the wetlands supply important benefits in beautifying environment, adjusting climate, providing entertainment space, etc.

Education and research. The unique features of wetlands in ecosystem, biodiversity, and endangered species lie in important situation in research and education. Some wetlands remain important information of evolvement process in biology and geography both at foretime and current time. This information is valuable for research on environmental evolvement and paleogeography.

5.3 Disadvantageous Impacts of Sedimentation and Wetland Conservation

5.3.1 Disadvantageous Impacts of Sedimentation

(1) Lessening wetlands area and changing bio-structure

Firstly, inland deposition raises river channel, lakes and reservoirs beds, shrank water surface area, and accordingly lessens the wetlands and declines many functions. Finally siltation derives the total basin unstable in dynamics, and destroys its ecosystem. Secondly, irrational siltation heightens the littoral belt and some lagoon mouth, blocks off saltwater intrusion, which would lead to some of halobios species vanished and change the wetlands species structure.

(2) Venturing on river natural avulsion and divagation and aggravating natural disasters

Owing to the high sediment load of the Yellow River, siltation leads to frequent avulsion of outlets. In the past 140 years, the Yellow River occurred large avulsion 11 times, divagation more than 50 times. The outlet swinging range was 160 km. Especially in the year of 1976, the outlet alternated 15 times. When an avulsion or a divagation takes place, the in-site natural vegetation is completely collapsed, and biodiversity is destroyed seriously.

5.3.2 Disadvantageous Impacts of Wetland Conservation

(1) Contradicted with high requirement for natural resources of increasing population and socio-economic development

The YRD population was 23.7 million in 1949, while it was 52 million in 2000. The gross output value of industry and agriculture was only 0.27 billion RMB Yuan in 1949, while it was 40 billion RMB Yuan in 2000, which was 147 times of the former. In order to offset the pressure of population and economic development, the more the natural resources grabbed, the more the biology survive environment destroyed, even crashed, inevitably the wetland preservation was ignored. Measures depredating nature such as irregulated land cultivation, irrational meadow reclamation, excessive depasture, abused hunting, overladen fishing in the shallow sea, exhausted pool to fishery, etc. make the ecosystem wrecked and biodiversity reduced.

(2) Limiting to urbanization, industrialization and infrastructure construction

Wetlands conservation needs the ecosystem to keep in virgin situation. But presently, 11% of land is occupied by towns and industry factories. For example, in the process of plain reservoir (now there are 18 reservoirs volume large than 10 million m^3) construction, the virgin vegetation and species have been destroyed entirely and the ecosystem influenced badly. Although the Shengli oil field has been established nearly 40 years, the destructed eco-environment still could not be resumed. Meanwhile urbanization contaminated the environment and river system and the pollutant accidents damaged the hydrophily species fatally.

(3) Vulnerability of ecosystem of YRD

The soil of YRD is easy to be salinized because of short history, highly saline concentration and rapid surface evaporation. The YRD ecosystem self-adjusting ability is too weak to maintain stable, due to the seldom higher plant diversity, single vegetation types, simple community structure, and fast dynamic diversity change. It is the congenital deficiency that the wetlands diversity is vulnerable, and make against with the wetlands exploitation for economic development.

6. Institutional Arrangements in Sediment Control and Wetland Conservation

6.1 Main State Laws and Regulations Related to Water and Wetlands

The main state laws related to management of water resources and environment conservation in China are listed in Table 6.1. They were adopted by the National People's Congress of the People' Republic of China, aiming at preserving environment and rationally developing water, land and other natural resources(which includes wetlands) in the basins. These laws constitute the legal base for administration of all the rivers in the country.

Table 6.1 Main state laws related to water and wetland

No.	Year	Laws
1	1989	Law of The People's Republic of China on the Environment Conservation
2	1991	Law of The People's Republic of China on the Conservation of Soil and Water
3	1996	Law of the People's Republic of China on the Prevention and Control of Water Pollution
4	2000	Law of The People's Republic of China on the Conservation of Ocean Environment
5	2002	Water Law of The People's Republic of China
6	2004	Law of The People's Republic of China on the Conservation of Wild Animal
7	2003	Law of The People's Republic of China on the Evaluation of Environment Influence

Based on the above-mentioned laws, some relevant regulations and rules were issued by central and local governments for special subjects and/or in accordance with the local conditions so as to form a relatively complete system of water and environment laws and regulations in China. The main regulations and rules implemented in the Yellow River basin are listed in Table 6.2.

Table 6.2. Main regulations and rules of river and water resources

No.	**Regulations and rules**
1	Regulations of river channel management
2	Regulations of soil and water conservation works
3	Regulations of waterways management
4	Regulations of flood control
5	Rules of Yellow River mouth management
6	Rules of supervision of sewage water discharged to rivers
7	Rules of water regulation management of Yellow River
8	Management rules of irrigation in the Lower Yellow River
9	Notice on strengthening wetland conservation management
10	Some local rules of wetland conservation

6.2 Organizations Responsible for Estuary Management

6.2.1 Yellow River Conservancy Commission(YRCC)

The Yellow River Conservancy Commission(YRCC) as an agency of the Ministry of Water Resources takes, on behalf of the Ministry of Water Resources, the responsibilities of water administration in the Yellow River basin and the inland river basins in several provinces of Qinghai, Gansu and Xinjiang Uyghur Autonomous Region, Inner Mongolia Autonomous Region.

There are several professional departments under the YRCC, such as Department of Water and Soil Conservation, Hydrological Bureau, Yellow River Shandong Bureau, and Yellow River Henan Bureau, of which Yellow River Shandong Bureau takes charge of all works in the Yellow River estuary.

6.2.2 Department of Yellow River Estuary

On behalf of the Yellow River Conservancy Commission, the Department of Yellow River Estuary takes the responsibilities of water and wetland administration in the Yellow River Estuary as an agency of the Yellow River Shandong Bureau. Its main duties are as follows:

(1) Taking charge of the implementation, supervision and inspection of Water Law, Flood Control Law, Regulations of River Channel Management and other regulations concerned; studying regulations and policies concerning the control and development of the Yellow River estuary;

(2) According to a general layout of the development and regulation in the Yellow River, mapping a comprehensive professional plan for the Yellow River estuary; answering for the supervision and implementation of the plan; undertaking the preparatory works of key projects; compiling annual investment plan of water conservancy construction in the Yellow River estuary.

(3) Carrying out an integrated management of water resources (including surface water and ground water) in the precinct; answering for organization, implementation and supervision in the water allocation scheme of the Yellow River in Dongying city; organizing or directing the evaluation of water resource construction in the Yellow River.

(4) Answering for setting down and implementing flood control scheme of the Yellow River in Dongying city; directing and supervising engineering construction and operation compensation in the precinct.

(5) Answering for management and protection of channel, water area, shoal, bank line and dike, bank control engineering works and sluice, etc.; presiding over construction and management of water conservancy projects in the precinct.

(6) According to the regulation or authorization, taking charge of the supervision and operation in the state-owned assets of water conservancy in the Yellow River; charging for utilization of water resources based on some regulations; answering for use, inspection and supervision of water conservancy fund in the precinct.

(7) Taking charge of exploitation, research and management on modern construction in the Yellow River estuary regulation; organizing and undertaking extension and application in technical fruits, and cooperation and exchange with other countries.

(8) Constituting the layout of economic development in the Yellow River estuary; organizing and developing integrated management and water conservancy economy.

6.3 Some Ideas and Plans in Sediment Control and Wetland Conservation

The layout of Yellow River estuary regulation was finished by Yellow River Engineering Consulting Institute in 2000 and went through the examination presided by Hydropower & Water Resources Planning and Design General Institute. It is useful to improves the social, economic and environmental development in the Yellow River Estuary. Overall arrangement of the estuary regulation engineering, channel path, flood control, water resource utilization, environment protection planning and so on was given in the layout of Yellow River estuary regulation, which is a technical support for the engineering construction of flood and tide control and development of water, soil and wetland resources.

The national conference on the Yellow river estuary problem and its regulation measures was held in 2003 at Dongying City, Shandong Province. All experts attending this conference made suggestions on strengthening research on Yellow River estuary and quickening estuary regulation. These suggestions are as follows:

(1) Establishing comprehensive regulation layout of Yellow River estuary as soon as possible. It concerns many sections and fields such as water conservancy, oil, agriculture, forest, fishery, zoology and environment in the Yellow River estuary regulation. There is not a good holistic layout at present, which is not favorable to comprehensive regulation and the social and economic development in the Yellow River Estuary. Therefore, it is essential to establish a comprehensive regulation layout of Yellow River estuary as soon as possible by the Yellow River Conservancy Commission (YRCC).

(2) Strengthening scientific research on the Yellow River estuary regulation. The Yellow River estuary regulation is such a complicated systems engineering which concerns river, ocean, zoology, environment, social economy and so on that many natural laws need to be researched. Scientific research on the Yellow River estuary drops behind its development, which influences on estuary regulation. Therefore, it is very important to strengthen scientific research on the Yellow River estuary regulation, such as establishing scientific research fund of the estuary, strengthening prototype observation with advanced technology, researching on the estuary problems with mathematical model and physical model, especially establishing model experiment base of the estuary.

(3) Carrying on unitive management of the Yellow River estuary regulation. The estuary regulation includes not only in the present tail channel, but also in the preparing outlet, coastal line, and allocation of water resources, entironment protection and their engineering construction, which concerns a lots of units and sections. Only carrying on unitive management, the estuary regulation can be guaranteed to implement in order.

(4) Increasing investment of estuary research and regulation. It is important to put investment of the channel engineering construction and management in the estuary into national budget.

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