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SEDIMENT ISSUES OF THE HAIHE AND LIAOHE RIVERS IN CHINA

INTERNATIONAL RESEARCH AND TRAINING CENTER ON EROSION AND SEDIMENTATION

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CONTENTS

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1. INTRODUCTION

There are many sediment-laden rivers in China. They have some special features different from those of clear rivers. Except the Yellow River, one of the most famous sediment-laden rivers in the world, the Haihe and Liaohe Rivers belong to sediment-laden rivers and are quite prominent in their characteristics of sediment and fluvial processes.

The Haihe River is in North China and has five large tributaries, among which the Yongding River is the most sediment-laden tributary. Beijing, capital of China, is just located at the riverside of the Yongding. Sedimentation in the Yongding River channel in the past made it a perched river, making the flood control situation in Beijing very dangerous. In 1954 Guanting Dam was built in the upper reaches of the Yongding River for flood control and water supply. Since then the flood control problem in Beijing has been improved significantly, but not thoroughly.

The Lioahe River is in Northeast China, which has two principal source regions. The eastern region is in a wet area with good vegetation cover, therefore, soil loss in this region is not so serious. The western region is situated in a dry area with poor vegetation cover, soil loss in this region is serious, resulted in several sediment-laden tributaries. As many sediment-laden rivers, flood control and channel aggradation in the rivers in the western region of the Liaohe River are more serious than in the eastern region.

Within the framework of UNESCO's Water Sciences activities, the International Research and Training Center on Erosion and Sedimentation compiles this bilingual publication entitled "Sediment issues of the Haihe and Liaohe Rivers in China" both in English and Chinese as a reference for those who are interested in the Chinese rivers.

2. THE HAIHE RIVER

2.1 Basic Features of the Watershed

The Haihe River is the most important river in North China and one of the seven largest rivers in China. The Taihang Mountain lies in the west of the watershed and the Mongolian Plateau is in the north. In the northeast is the Luanhe River watershed and in the east is the Bohai Sea. In the south is the Yellow River (Fig.2.1). The watershed area is 263.4 thousand km^2; among which mountainous regions and the plain account for 50% of the total, respectively. Beijing and Tianjin, two large cities directly under the Central Government, most of Hebei Province, a part of Henan, Shandong, Shanxi Provinces and Inner Mogolian Autonomoius Region belong to the Haihe River watershed.

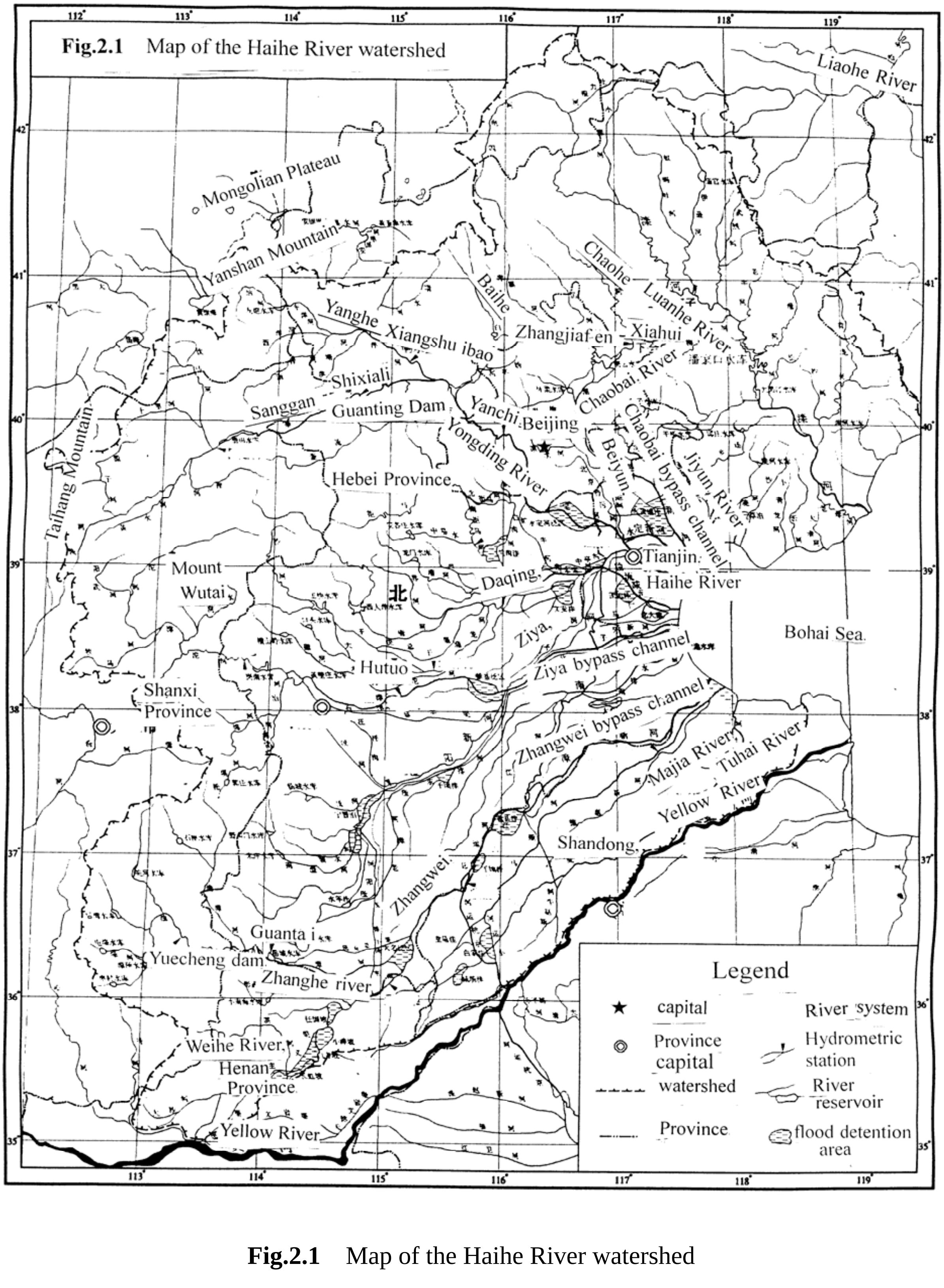

Fig.2.1 Map of the Haihe River watershed

The Haihe River watershed is situated at 35°-41° 30' north latitude and 112°-118° 30' east longitude. The northern and western parts of the watershed belong to mountainous region or plateau and the eastern and southeastern parts belong to North China Plain. The Taihang and Yanshan Mountains stretch from southwest to northeast, encircling the plain. The mountainous regions have elevations in the range of 500 m to 2000 m. The highest mountain is the Mount Wutai with an elevation of 3058 m. There are loess hilly areas with poor vegetation cover in the western part of the watershed, accounting for 30% of the mountainous regions. Those areas are the principal sediment sources of the watershed. The plain is an alluvial plain formed jointly by the Yellow River and the Haihe River in the historical epoch. The elevation of the plain is below 50 m. Since it was formed in a long period of time and affected by many times avulsions of the two rivers in different times, the plain surface is undulant with many ridges, ponds and low-lying lands. The transitional area between the mountainous regions and the plain is quite small.

The Haihe River system consists of the Zhangwei, Ziya, Daqing, Yongding, Chaobai, Beiyun, Jiyun, Tuhai and Majia Rivers.The first six rivers join the main stem of Haihe at Tianjin, which empties into the Bohai Sea at Dagu. The total length of the river, originated from the source of the Weihe River, is 1090 km and the length of the mainstem of the Haihe is only 73 km.

The climate of the Haihe River watershed belongs to continental monsoon climate. The annual precipitation of the total watershed is 560 mm with an uneven distribution of precipitation in the watershed; 700-800mm in the region near the Taihang and Yanshan Mountains, less than 400mm in the Yanbei region in Shanxi Province and 500-600mm in the eastern plain area.

The total amount of water resources in the watershed is 35.3 billion m^3, of which 22.8 billion m^3 are river runoff. The total annual sediment load of the watershed is 0.15 billion ton. The Yongding, Hutuo and Zhanghe rivers are the most sediment-laden rivers. The hydropower potential of the total watershed is 1.62 million kw, among which 0.45 million kw have been exploited. Navigation in the main stem of the Haihe River prevails all year round; it was so in some tributaries before the 1970’s and it was stopped because of lack of enough water.

The total population in the watershed is about 100 million. It is one of the densely populated area in China. In the watershed there are two largest cities, Beijing and Tianjin, several important coal mine bases, such as Datong, Yangquan, Jingxing, Fengfeng and Hebi and two oil fields, Huabei and Dagang oilfields.

The Haihe River watershed is one of the most severe flood-stricken areas in China. In 540 years (1368-1911, Ming and Qing Dynasties) there were 360 times of floods. Since the 17th century there were 19 times of large floods, i.e. once in 20 years. Every large flood caused huge damage, inundated over 100 counties and more than 1 to 2 million hm^2, among which 5 large floods inundated Beijing and 8 large floods inundated Tianjin. After the founding of the People’s Republic of China (1949) large floods occurred in 1956 and 1963 resulted in huge inundated areas of 4.02 and 4.4 million hm^2. In August 1963 a record high 7 day storm precipitation of 2050 mm occurred in the Haihe River watershed, which was the largest on the mainland.

Large-scale river harnessing works have been carried out since 1949. There are 1375 reservoirs with a total storage capacity of 22.5 billion m^3; of which 25 are large-scale reservoirs with a total storage capacity of 18.1 billion m^3, controlling 85% of mountainous regions; Guanting, Miyun, Gangnan, Huangbizhuang and Yuecheng reservoirs are the largest. For rapid release of floods from the main tributaries to reduce the burden of the main stem of the Haihe, several bypass channels have been excavated, such as Chaobai bypass channel, Yongding bypass channel, Ziya bypass channel, Zhangwei bypass channel and Duliu bypass channel. 26 depressions have been prepared as flood detention areas. Thus, a preliminary comprehensive flood control system has been established.

2.2 Basic Features of the Rivers

2.2.1 Runoffs and Sediment Loads

The Haihe River was the first river to carry out hydometric measurement in China. In 1892 Xiaosunzhuang station carried out sediment concentration measurement.

Among the major tributaries of the Haihe River the Yongding River carries the largest amount of sediment load. Nantuling Hydrometric Station on the Huliu River, a tributary of the Yongding, measured a record high sediment concentration of 1010 kg/m^3 on July 6, 1967.

In Table 2.1 the annual runoff and annual sediment load of several key hydrometric stations in the Haihe watershed are listed. Since the 1970s the annual runoff and annual sediment load reduced significantly. One of the reasons was the reduction of annual precipitation, but the effect of hydraulic projects was also prominent.

Table 2.1 Annual Runoff and Annual Sediment Load of Key Hydrometric Stations

River		Sanggan	Yanghe	Yongding	Chaohe	Baihe	Haihe
Station		Shixiali	Xiangshuibao	Yanchi	Xiahui	Zhangjiafen	Haihezha
Watershed area (thousand km^2)		23.9	14.5	43.7	5.3	8.5	
Annual runoff (billion m^3)	Mean	0.527 (1952-2000)	0.400 (1952-2000)	0.724 (1963-2000)	0.293 (1966-2000)	0.470 (1961-2000)	0.971 (1960-2000)
	Maximum	1.735	0.987	1.623	0.887	1.338	8.283
	Minimum	0.074	0.106	0.246	0.059	0.91	0.00
Annual sediment load (million ton)	Mean	10.90 (1952-2000)	7.48 (1952-2000)	0.153 (1963-2000)	1.00 (1961-2000)	1.21 (1961-2000)	0.095 (1960-2000)
	Maximum	107	30.6	3.81	4.97	8.01	2.03
	Minimum	0.069	0.033	0	0.013	0.004	0
Annual sediment concentration (kg/m^3)	Mean	20.7 (1952-2000)	18.7 (1952-2000)	0.211 (1963-2000)	3.41 (1961-2000)	2.57 (1961-2000)	0.098 (1960-2000)
	Maximum	64.1	47.7	2.35	10.6	6.28	0.245
	Minimum	0.606	0.307	0.00	0.190	0.045	0.00
Mean annual d_{50} (suspended load) (mm)		0.030	0.037				

Note: The Sanggan and Yanghe Rivers are the principal tributaries of the Yongding. The Chaohe and Baihe Rivers are the principal tributaries of the Chaobai River.

2.2.2 Floods

The floods of the Haihe River mainly originate from storms in July and August. The recorded maximum floods of the major tributaries are listed in Table 2.2. According to historical records and flood reconnaissance, there were 387 times of flood disasters in the Haihe River Watershed from 1368 to 1948 (580 years), among which Beijing suffered 12 times (5 times inundated the city proper) and Tianjin 13 times. Since the 16th century flood disasters in 1569 and in 1801 were the most serious. In 1569 the floods mainly occurred in the Daqing and Ziya Rivers while in 1801 the floods mainly occurred in the Yongding and Daqing Rivers

Table 2.2 Floods of Major Tributaries of the Haihe River

River		Watershed area (km^2)	River length (km)	Mean annual flood (m^3/s)	Hydrometric station	Watershed area controlled (km^2)	Maximum flood (m^3/s)	Date	Remark
Jiyun		10288	310	250	Jiuwangzhuang	5120	572	1950. 08.04	

Chaobai		19354	458	1560	Suzhuang	17627	5470	1949.07.31	Pre-Miyun dam
		Ditto	Ditto	356	ditto	ditto	940	1969.08.17	Post-Miyun dam
Beiyun		6166	186	378	Tongxian	2478	2200	1939.07.27	
Yongding		47016	650	1572	Lugouqiao	44400	5560	1939.07.25	Pre-Guanting dam
Daqing	Daqing	43014	448	1160	Xingaifang	10000	3540	1963.08.09	
	Zhulong			771	Beiguocun	8550	5380	1963.08.08	
Ziya	Hutuo	46868	706	2241	Huangbizhuang	23000	13100	1956.08.04	Pre-Huangbizhuang dam
	Minghe			760	Linmingguan	2300	12300	1963.08.06	
Nanyun	Zhanghe	37894	1090	1350	Guantai	17800	9200	1956.08.04	
	Weihe			427	Chuwang	14286	1580	1963.08.08	

2.2.3 Characteristics of Rivers

All the major tributaries of the Haihe River can be divided into three reaches: the mountainous reach, the transitional reach and the plain reach. The transitional reach between the mountainous reach and the plain reach is quite short. The plain reach is either a meandering reach or a wandering one. The plain reaches of the Yongding and Zhanghe Rivers belong to the wandering reach. For controlling floods dams were built at the lowest section of the mountainous reach mainly in the 1950s.

(1) The Yongding River: The catchment area of the Yongding River is 47016 km^2, among which 95% of the catchment area is above the Guanting Gorge, 3% is in the Guanting Gorge and the remaining 1% is the plain area. In the area above Guanting, about 70% are mountainous regions, the rests are hilly areas of red soil, loess and alluvial soil, which provide a large amount of sediment to the Yongding River. The annual precipitation in this area is less than 400 mm. As the soil is quite loose and seepage is serious, therefore the annual runoff is quite small. But the storms and corresponding floods are fierce and concentrated in a short period of time. The Guanting Gorge with an area of 1520 km^2 is a mountainous area with steep slope. Heavy rainfall may induce big floods in this area.

Before 1180 AD there was no levee systems in the Yongding River. The levees from Lugouqiao to Guojiawu were first built in1698 (Kangxi Emperor 37th year, Qing Dynasty). Since then, the river has been confined in between two levees and a perched river has been gradually formed. At present the old floodplains between the levees are 5-7 m higher than the ground surface outside the levees.

In 1954 Guanting dam, controlling 91% of the total watershed of the Yongding, was built in the Guanting gorge to safeguard Beijing and Tianjin. Since then 4 times of reconstruction (including dam heightening and consolidation) have been carried out. In 1989 the total storage capacity of the reservoir was 4.16 billion m^3. In the first 10 years of reservoir operation a large amount of sediment deposited in the reservoir. In 1960 Cetian dam was built on the Sanggan River and in 1963 Youyi Dam was built on the Dongyang River, two major tributaries above Guanting dam. Meantime a large amount of small and medium-sized dams have been built above Guanting dam. Consequently, sediment was mainly trapped in those reservoirs and sedimentation in Guanting reservoir has been reduced significantly since the 1970s

The Yongding bypass channel was dug in the 1980s, which directly diverted the flood into the sea. Thus, the burden of the main stem of Haihe has been reduced.

(2) The Zhanghe River: The situation of the Zhanghe River is similar to the Yongding River. Yuecheng dam, controlling 95% of the total watershed, was built in 1958 to control mountainous floods and the Zhangwei bypass channel was dug to directly divert the flood into the sea. As the sediment load of the Zhanghe River is not so large, reservoir sedimentation in the Yuecheng reservoir has been not as serious as in Guanting Reservoir..

2.3 Issues of Flood Control

2.3.1 Characteristics of flood control

(1) Complex conditions of physical geography: There are so many river systems with a fan-shaped distribution. The transitional reaches between the mountainous regions and the plain region are so short that the storm floods pour down from the mountainous regions to the plain in a short period of time. From the start of a storm in the mountainous region to the occurrence of a storm flood only needs 1-2 days, even several hours.

(2) Importance of geographicl location: Most of the flood disasters take place in the plain region, where Beijing, Tianjing, and several other cities, major railways and highways, large oilfields and fertile farmland are located. Therefore, safety of this region during floods is related not only to this region itself but also to the whole country.

(3) Incomplete flood control system and low standard of flood control works: The standard of flood control of many reservoirs, including large-size reservoirs, dose not comply with the national standard of flood control. The quality of the levees, totaling 20 thousand km long, is poor. The flood carrying capacity of the rivers and bypass channels has been reduced significantly due to sedimentation and vegetation. The total design flood carrying capacity was 24680 m^3/s, but now the flood carrying capacity is only15040 m^3/s. Table 2.3 lists the flood carrying capacity of some rivers.

(4) Difficulty in operation of flood detention areas: There are 26 planned flood detention areas with a total storage volume of 17 billion m^3. 4.61 million people live in those areas, but 80% of them are without guarantee of safety. The warning system of flood control is still not complete. It is quite difficult to use those flood detention areas when it is necessary.

Table 2.3 Flood Carrying Capacity of Some Rivers

River	Design discharge(m^3/s)	Present (m^3/s)	Reduction of capacity (%)
Yongding bypass channel	1400	260	81.4
Haihe main stem	800	400	50
Duliu bypass channel	3600	2000	44.4
Ziya bypass channel	9000	6000	33.3
Zhangwei bypass channel	3500	2250	35.7
Tuhai	1779	890	50
Majia	1384	750	45.8
Total	21463	12550	41.5

(5) High frequency of floods and serious flood disasters: From the first century to present there were 1410 times of serious flood disasters in China, of which 517 times took place in Henan, Hebei, Shandong and Shanxi Provinces, which are closely related to the Haihe River. In August 1963 a huge flood occurred in the Haihe River, which inundated 107 counties

belonging to 7 prefectures. Beijing-Guanzhou Railway, Beijing-Dezhou Railway and Shijiazhuang-Taiyuan Railway were destroyed. 6 medium-sized and 330 small dams were collapsed. 62% of irrigation works and 90% drainage works were destroyed. The direct economic loss was 6 billion RMB yuan (the same year).

2.3.2 Measures of flood control

The guideline of flood control in the Haihe watershed is to build a comprehensive system of flood control in which structural measures are combined with non-structural measures. As for structural measures the principle is “to build dams to impound flood water in the reservoirs in the mountainous regions, to harness river channels in the middle reaches, and to discharge floods rapidly in the lower reaches”. In the mountainous regions soil conservation measures should be emphasized to reduce soil erosion and to promote local economic development. In the middle reaches bypass channels are inevitable for a long period of time and flood detention areas will be put into use when there is an extraordinary flood. In the estuaries comprehensive regulation should be adopted to improve their situation in terms of flood release, environment and ecology.

As water resources are in serious shortage there is no enough water to flow in the river channels and estuaries. Therefore, sedimentation in river channels in the middle reaches and in estuaries is inevitable, which results in the decrease in flood carrying capacity of the rivers. Although interbasin water transfer may be one solution to increase water resources in the Haihe River basin, it will be too expensive to use diverted water for the purpose to maintain the normal condition of the river channels. A feasible way is to regulate the river channels properly to restore and maintain their flood carrying capacity. In the estuaries dredging is a useful and feasible measure to counter sedimentation in order to maintain flood carrying capacity.

2.4 Discussions

In the Haihe River basin lack of enough water resources and abundant sediment source are two leading reasons of sedimentation in river channels and estuaries, which seriously affect flood control situation. It seems that it is impossible to have enough water resources to maintain the river channels and estuaries under a normal condition in a predictable period of time. How to reduce sedimentation becomes more important in the Haihe River basin. First, it is important to carry out soil conservation in the mountainous regions. Second, comprehensive planning, design, construction and maintenance of river harnessing works (including those in estuaries) are useful in keeping the flood control situation in shape.

3. THE LIAOHE RIVER

3.1 Basic Features of the Watershed

The Liaohe River is one of the 7 largest rivers in China. It is an important river in Northeast China. It is 1345 km long, flowing through Hebei, Jilin, Liaoning Provinces and Inner Mongolia Autonomous Region with a watershed area of 220 thousand km^2. The Liaohe River is composed by two major river systems. The source of the western river system is the Laoha River, originated from Hebei Province and flowing northeastward, passing Inner Mongolia Autonomous Region, there it takes the title of the Xiliao River, then flowing into Liaoning

Province. The source of the eastern river system is the Dongliao River originated in Jilin Province and joining the Xiliao River in Liaoning Province. Below the confluence it is called the Liaohe River. It empties into the Liaodong Bay of the Bohai Sea (Fig. 3.1). In 1968 a tidal barrier, 65.8 km above the river mouth, was built in the estuary.

The Liaohe River watershed is located between 40^o 30’-45^o 10’ north latitude and 117^o –125^o 30’ east longitude. In the watershed mountainous regions account for 35.7% of the total area, hilly regions 23.5%, plain regions 34.5% and sand dune regions 6.3%. Daxing’an, Qilaotu and Nuluerhu Mountains lie in the west of the watershed with elevations between 500-1500 m; Jilinhada, Longgang and Qianshan Mountains lie in the east with elevations between 500-2000 m. In the middle and lower reaches is the Liaohe Plain with elevations below 200 m.

The average temperature of the whole basin is 4-9 degree Celsius. The average annual precipitation is 350-1000 mm, decreasing gradually from southeast to northwest. Flood disasters and drought disasters are frequent. In the past century there were more than 50 times of flood disasters. Serious drought disasters occurred once in 6-7 years, mainly in the western part.

At present there are 688 dams of various sizes with a total reservoir storage capacity of 13.8 billion m^3; among which 17 are large reservoirs with a total reservoir storage capacity of 13.2 billion m^3.

The eastern region of the watershed is good in vegetative cover and small in soil erosion except the tributary of the Dongliao River, which carries more sediment load than that of the others in this region. The western region is an area with dry climate, poor vegetative cover, and loose land surface of sand and loess; soil erosion in this region is serious. The Liuhe River is the most sediment-laden river in this basin. The Laoha River is another sediment-laden river. The Hongshan Reservoir with a collecting area of 24 thousand km^2 in the upper reach of the Laoha River was impounded in 1962 and until 1985 the dead storage capacity was fulfilled with sediment.

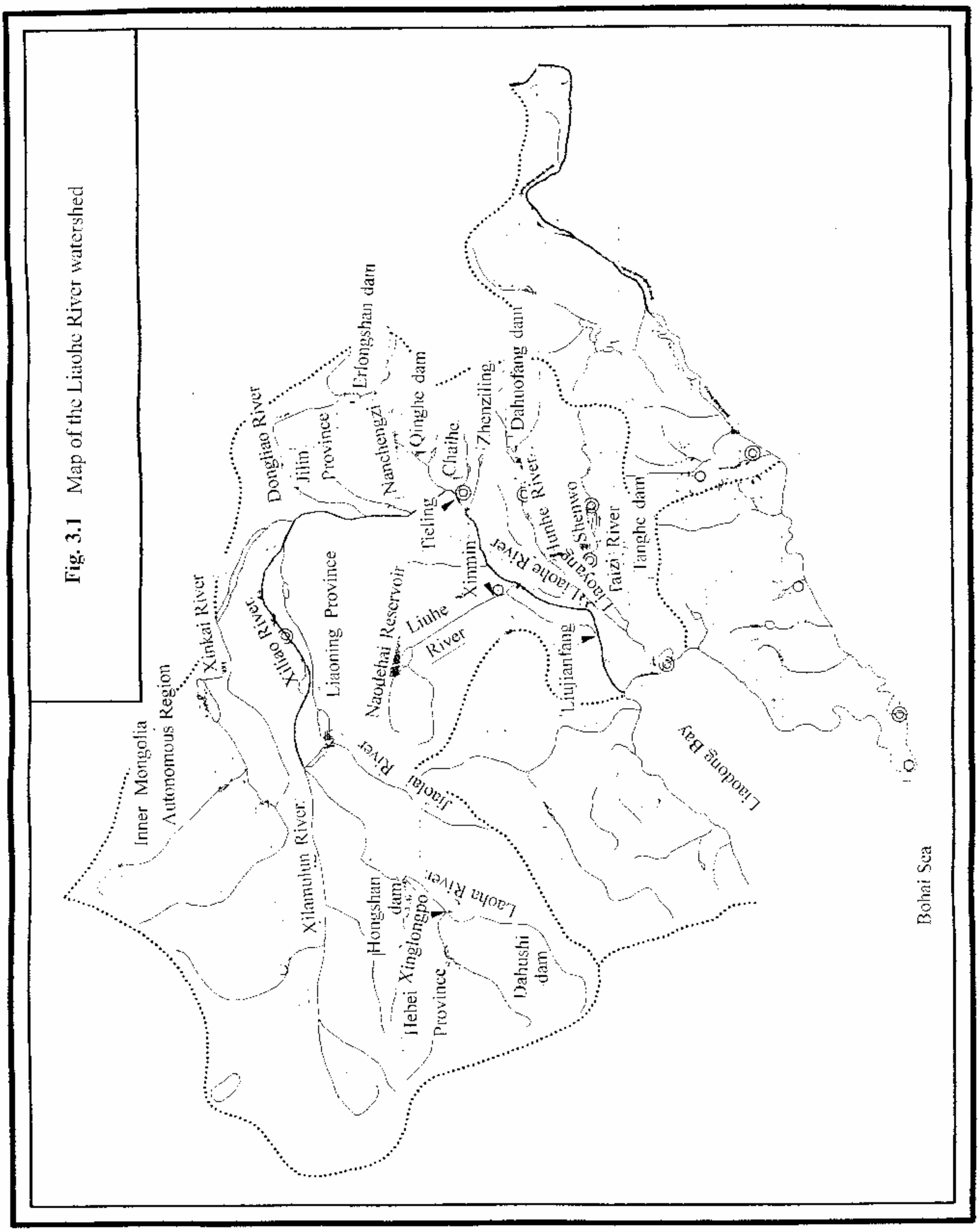

Fig. 3.1 Map of the Liaohe River watershed

3.2 Basic Features of the Rivers

3.2.1 Runoffs and Sediment Loads

In Table 3.1 the annual runoffs and the annual sediment loads are listed. The mean annual sediment load and annual sediment concentration of the main stem of the Lioahe River decreased longitudinally because of the effect of construction of hydraulic engineering works.

Table 3.1 Annual Runoff and Annual Sediment load of the Liaohe River

River		Laoha	Liuhe	Liaohe	Liaohe
Hydrometric station		Xinglongpo	Xinmin	Tieling	Liujianfang
Collecting area (thousand km^2)		19.1	6.8	120.8	136.5
Annual runoff (billion m^3)	Mean	0.597 (1963-2000)	0.265 (1965-2000)	3.237 (1954-2000)	3.674 (1987-2000)
	Maximum	1.640	0.474	9.34	7.561
	Minimum	0.0393	0.108	0.497	0.585
Annual sediment load (million ton)	Mean	17.3 (1963-2000)	4.88 (1965-2000)	13.8 (1954-2000)	6.24 (1987-2000)
	Maximum	51.6	18.9	85.5	12.7
	Minimum	0.737	0.767	0.124	0.235
Annual sediment concentration (kg/m^3)	Mean	27.5 (1963-2000)	16.0 (1965-2000)	3.09 (1954-2000)	1.55 (1987-2000)
	Maximum	59.9	53.8	14.5	3.65
	Minimum	4.31	5.77	0.180	0.400
Annual D_{50} of suspended load (mm)	Mean	0.027 (1982-2000)		0.034 (1962-2000)	
	Maximum	0.036		0.054	
	Minimum	0.018		0.019	

3.2.2 Floods

In the Liaohe River basin the floods are mainly induced by monsoon storms in July and August. (70-80)% of annual precipitation concentrate in June through September and 50% concentrate in July and August. The recorded maximum daily precipitation was 401.8 mm (August, 1960). The characteristics of the floods of the Liaohe River are listed in Table 3.2.

Table 3.2 Characteristics of Floods in the Liaohe River

River	Watershed area (km^2)	River length (km)	Hydrometric station	Collecting area (km^2)	Mean annual runoff (billion m^3)	Maximum flood (m^3/s)			
						Surveyed		Measured	
						Value	(year. month)	Value	(year. month)
Laoha	28270	455	Xiaoheyan	18599	1.16	7830	1883	12200	1962.7
Liaohe	219000	1345	Tieling	172107	4.14	8740	1886.8	14200	1951.8
Xilamulun	31866	380	Xilaximiao	26567	1.06			1760	1966.8
Jiaolai	12776	559	Xiawa	2083	0.141			4170	1962.7
Dongliao	11306	383	Erlongshan	3799	0.053	4090	1917.8	5850	1953.8
Qinghe	4846	171	Kaiyuan	4668	1.08	12300	1951.8	9500	1953.8
Hunhe	11481	415	Fushun	6688	2.00	11300	1888.8	8200	1960.8
Taizi	13883	425	Liaoyang	8082	2.67	13900	1888.8	18100	1960.8
Raoyang	9946	290	Dongbaichengzi	2138	0.107			2110	1962.7

3.2.3 Basic Features of Rivers

The Liaohe River has two major tributaries: the Xiliao River and the Dongliao River. There are two major tributaries of the Xiliao River, the Laoha River and the Xilamulun River. The basic characteristics of the rivers are listed in Table 3.3.

Table 3.3 Basic Characteristics of the Rivers

River	River section	Channel width (m)	Sinuosity ratio	Longitudinal slope
Xiliao	Sujiapu-Fudedian	100	1.69	1/1500--1/2500
Liaohe	Fudedian-Liuhekou	60-525	1.66-1.69	1/4350—1/5560
	Liuhekou-river mouth	90-1369	1.40-1.68	1/4760—1/14295
Hunhe and Taizi	Plain area	95-425		1/2500—1/10000

After the commission of many reservoirs the fluvial processes of the Liaohe River have been changed. The first dam was built in 1942 and the newest was in the 1980s. Taking 1968 as the initial year of the effect of the reservoirs, a comparison of water and sediment conditions before and after the commission of dams is listed in Table 3.4. After the commission of the dams the runoff and flood peaks have been reduced to one half of the original while the reduction of sediment load was much larger, about 16% of the original. But the percentage of runoff and sediment load in the flood seasons only changed a little.

Table 3.4 Water and Sediment Characteristics at Juliuhe Hydrometric Station of the Liaohe River

	Annual runoff (10^9 m^3)	Annual flood peak discharge (m^3/s)	Percentage of runoff in a flood season to a total year (%)	Annual sediment load (10^6 t)	Annual sediment concentration (kg/m^3)	Percentage of sediment load in a flood season to a total year (%)
Pre-dam period (1954-1968)	5.29	1750	71	29	5.48	87
Post-dam period	2.60	846	58	4.66	1.79	75
Post-dam/Pre-dam (%)	49.1	48.3	81.7	16.1	32.7	86.2

The Liuhe River, joining the main stream below Juliuhe station, is one of the major sediment sources of the Liaohe River. Before 1971 the Naodehai Reservoir had been operated under the mode of flood detention while after 1971 it was operated under the mode of impounding the clear in the dry season and discharging the muddy in the flood season. Table 3.5 lists the characteristics of water and sediment at Xinmin Station and a station just below the confluence of the Liuhe and the Liaohe. It can be seen that before Naodehai dam was commissioned the percentage of sediment load of the Liuhe River was 26% of the Liaohe River. While after the commission of the Naodehai dam the percentage increased to 59.2% as the reduction of sediment load in the main stream was much larger than that in the Liuhe River.

Table 3.5 Water and Sediment Characteristics of the Liuhe and the Liaohe

	Station below the confluence on the Liaohe		Xinmin Station on the Liuhe	
	Annual runoff (10^9m^3)	Annual sediment load (10^6 t)	Annual runoff (10^9m^3)	Annual sediment load (10^6 t)
Pre-dam	5.67	39.18	0.283	10.17
Post-dam	2.89	11.43	0.289	6.77
Post-dam/Pre-dam (%)	51.0	29.2	75.5	66.6

Along with the variation of water and sediment characteristics the behavior of the river channel has been changed correspondingly. Table 3.6 lists the changes in river channels.

As for the main channel it has become wider and shallower than pre-dam. Table 3-7 lists the main features of the main channel, showing the changes after dam construction. The variation was obvious, especially in the reach between Liuhekou and Kalima.

Table 3.6 Changes in Deposition or Erosion in River Channels

	Time period	Annual amount of deposition or erosion (10^6 t)		Thickness of deposition in the main channel (cm/a)			
River section		Liuhekou-Kalima	Kalima-Liujianfang	Liuhekou-Kalima	Kalima-Zhujiafang	Zhujiafang-Liujianfang	Liujianfang-Panshan
Pre-dam	1963-1964	+10.4	+3.91	6.9	1.3	8	12
	1964-1965	+0.736	+14.12				
	1965-1966	+8.43	-3.58				
Post-dam	1968-1969	+9.46 (Liuhekou-Zhujiafang)					
	1973-1974	-3.85 (Liuhekou-Zhujiafang)		16	10.8	19	4

Note: + for deposition, -for erosion

Table 3.7 Features of the Main Channels of the Liaohe River

River section	Length (km)	Slope (%)	Main channel width (m)	Elevation Difference* (m)	D_{50} of bed material (mm)	Bankful discharge (m^3/s)		$B^{1/2}/h$	
						1962	1979	1962	1979
Juliuhe-Liuhekou	29.4	0.14	210-350	2.24	-	-	-	-	-
Liuhekou-Kalima	58.4	0.2	150-460	1.12	0.050	614	206	4.8-16.6	7.5-37.4
Kalima-Zhujiafang	29.4	0.18	190-250	1.73	0.047	475	282	4.4-8.0	4.7-9.9
Zhujiafang-Liujianfang	20.8	0.075	170-210	2.04	0.049	736	310	2.5-5.9	4.5-10.1
Liujianfang-Panshan	55.0	0.11	100-260	2.61	0.050	720	419	1.9-7.0	1.8-7.7

* The elevation difference is between the surface of floodplains and the average bottom of the main channel.

3.3 Issues of Flood Control

3.2.1 Characteristics of Flood Control

Floods and flood disasters occur frequently in the Liaohe River basin. In the past hundred years or so there were more than 50 times of flood disasters, i.e. once in two years in average; among which serious flood disasters were 17 times. Since the founding of the People's Republic of China, flood disasters took place in 1949, 1951, 1953, 1954, 1960, 1962, 1985, 1986, and 1995; among which serious flood disasters took place in 1951, 1953, and 1960. For example, 33 cities and counties suffered serious flood disaster in 1951, the affected people by the flood were 880 thousand and 138 thousand rooms were collapsed, 434 thousand hm^2 farmland were inundated. In 1953 the affected people were about one million, 129 thousand rooms were collapsed and the inundated farmland was 602 thousand hm^2.

3.2.2 Measures of Flood Control

A preliminary flood control system has been established, which has played an important role in defending local people and properties. At present there are 17 large reservoirs and 64 medium-sized reservoirs in the whole watershed. The large reservoirs with a total storage capacity of 13.2 billion m^3 control 57.3 thousand km^2 of watershed, accounting for 26% of the total watershed area. Dams have been built on most of the tributaries, such as Guanyinge, Shenwo, and Tanghe dams on the Tazi River, Dahuofang dam on the Hunhe River, Hongshan, Dahushi, and Tuerjishan dams on the Xiliao River, Erlongshan dam on the Dongliao River, Naodehai dam on the Liuhe River , Chaihe, Zhenziling, Nanchengzi, and Qinghe dams on the main stem of the Liaohe River. These dams played significant role in flood control. For example, a big flood took place in the upper reaches of the Laoha River in 1962. The incoming flood peak of the Honshan Reservoir was as high as 12700 m^3/s. Because of impounding of the flood water, the maximum released discharge from the reservoir was only 995 m^3/s. Thus, the damage of the flood reduced significantly.

The levees in the plain area are 2862 km long, protecting 195 cities and county seats. The situation of the levees in different river sections is listed in Table 3.8.

Table 3.8 Situation of Levees in the Liaohe River basin

River	Section	Length (km)	Width (m)	Standard of flood control (recurrence of years)	Remark
Xiliao	Sujiapu-Fudedian	643	660-3970	10-20	
Dongliao	Erlongshan dam-Fudedian	518	294-2000	10-20	
Main stem of Liaohe	Fudedian-Estuary	779	847-5668	20-30 20	Above Shifosi Below Shifosi
Hunhe	Shenyang-Sanchahe	302	650-3000	20-30	To be increased to 50 years in the near future
Taizi	Liaoyang-river mouth	360	720-4000	50	
Raoyang	Dongbaichengzi-river mouth	260	400-6800	10-20 20-30	Above railway bridge Below railway bridge

3.4 Discussions

(1) Sediment problem is one of the key issues in water resources development and flood control in the Liaohe River Basin. A comprehensive sediment management measure is important in the planning, design and regulation of the whole basin, from the river source region to the estuary. An overall planning for the basin and detailed planning for every reaches should be worked out to guide the practice of river regulation.

(2) In the upper reaches due attention should be paid to soil conservation works, particularly in the western region of the basin to reduce soil erosion and to promote the development of local economy and to raise the living standard of the local people. Meantime, the method of mitigation of reservoir sedimentation should be applied to reservoirs with abundant incoming sediment load to extend the life span of the reservoirs.

(3) In the middle reaches river harnessing, including heightening the existing levees should be strengthened to protect the large plain area. As upstream reservoirs have changed the outgoing water and sediment load to the lower reaches, the changed river channel characteristics should be fully considered when the planning of river harnessing is made.

As water shortage is prevailing in the Liaohe River Basin it is important to utilize flood water when possible. In 1954-1958 warping was carried out along the riparian areas (18 thousand hm^2) of the Jiaolai and Xinkai Rivers. After warping the crop yield in the same areas increased from 50-100 kg/mu to 100-200 kg/mu (1 ha=15 mu). This method not only decreases the flood peak and sediment deposition in the river channel but also increases the crop yield in the warping areas.

(4) In the estuary sedimentation in the river channel is the key problem to be dealt with. A

rational alignment is the first priority for harnessing of the estuary. The measures to reduce sedimentation in the estuary should be studied.

4. CONCLUDING REMARKS

(1) For sediment-laden rivers, such as the Haihe and Liaohe Rivers, due attention should be paid to sediment problems in the development of water resources and flood control.

(2) Reservoir sedimentation in reservoirs built on sediment-laden rivers is serious. It should be seriously considered in the planning and design of such resevoirs.

(3) Reservoirs change the water and sediment regimes of the river reaches below the dams. Therefore, there will be corresponding changes in the river channel characteristics. When river harnessing works are constructed, the changes in the river channel characteristics should be fully considered in the planning, design and implementation of the engineering works.

(4) Soil conservation is vital not only for reducing soil erosion but also for increasing the development of local economy and for raising the living standard of the local people. As soil conservation is a hard work and needs a long period of time, it must be persisted to achieve its goal.

(5) Warping in the low-lying lands along the Xiliao River is an efficient measure to reduce flood peak and sediment deposition in river channels and to increase agricultural production. It should be executed in regions where it is appropriate.