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ATROPHIC PHENOMENON OF ESTUARIES IN HAIHE RIVER BASIN

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Abstract: The basic conditions of the rivers in the Haihe River Basin are firstly introduced in this paper. According to the difference in the pondage ability of flood and sediment that caused by the different conditions of topography and geomorphy, the rivers within the basin are divided into two types. In addition, the conditions of each river that empties into the sea are analyzed, upon which some estuaries such as the Luanhe Estuary, Yongding New Estuary, Haihe Estuary, Duliujian Estuary, Ziya New Estuary and Zhangwei New Estuary, and their silting conditions including the hydrologic condition of the channel, the sediment character and the scour-and-fill character of the estuary, the effect of the tide and tidal barrage on the estuary and so on are discussed in detail. Finally, combined with the recent development tendency of the estuary, the reasons that may cause the atrophy of the estuaries are analyzed.

Key words: Haihe River Basin, Estuary, atrophy, Sediment

1. INTRODUCTION

Generally say, Haihe Drainage is the several larger drainages in Haihe Basin, including that of Haihe River, Luanhe River, Tuhai River, and Majia River. Luanhe Drainage is located in the northeast of Haihe Basin, and there are some single rivers of the coastal area in East Hebei Province pouring into the sea in its downstream. Haihe Drainage is located on the southeast of Luanhe Drainage, including Jiyun River, Chaobai River, Beiyun River, Yongding River, Daqing River, Ziya River, Zhangwei South canal and the mainstream of Haihe River; Tuhai-Majia Drainage is located in the Southernmost part of Haihe Basin, which belongs to the draining river on the flatland.

Considering the different topography and geomorphy, rivers in Haihe Basin can be divided into two types. One is the north rivers which originate from Mongolian Plateau and the southwest Rivers which originate from Loess Plateau. A lot of branches are collected in the mountain area, among which a main river becomes the flatland river and flows through this area. This type of rivers run a long way, which makes them have much stronger pondage ability and take much more sediment, including Luanhe River, Chaobai River, Yongding River, Tuohe River and Zhanghe River. Another is those originate in the windward area of Yan Mountain and Taihang Mountain. Compared with the first, this type of rivers has much rapider current, weaker pondage ability and less sediment, including Jiyun River, Beiyun River, Daqing River, Fuyang River and Wei River. The difference in the characters of these two types of the rivers in Haihe Basin determines the difference in their pondage ability of the flood and sediment, thus effecting the silting character of the estuary with different degrees. The catchment area and the river length in Haihe Basin are shown in Table 1.

It can be seen from table 1 that the rivers in Haihe basin which flows into the sea include: Luanhe River, Jiyun River, Chaobai-Chaobai New River, Yongding-Yongding New River; Daqing-Duliujian River; mainstream of Haihe River; Ziya New River; Zhangwei New River;

Tuhai River, Majia river. Because Jiyun River, Chaobai New River and Yongding New River converges into Yongding New River, Tuhai-Majia River is mainly a draining River and the atrophic condition of Luanhe Estuary is not heavy, so much more attention have been paid to the atrophic condition of the estuary in Yongding New River, Haihe River and Duliujian River.

Table 1 Catchment area, length and abouchement point of the rivers in Haihe River Basin

Drainage	name of the river	Catchment area (km^2)		Length of the river (km)	Abouchement point
		In mountain area	In plain		
Luanhe Drainage	Luanhe river and others	47120	7410	833	To coastal inlet
Haihe Drainage	Jiyun River	21708	14345	316	To coastal inlet
	Chaobai River			467	To Ningchegu Gate (Chaobai New Estuary
	Beiyun River			238	To Dahongqiao, Tianjin
	Yongding River	45179	1887	681 (747)	To Qujiadian Gate (Yong -ding New Estuary)
	Daqing River	18807	24258	483	To Gongnongbing Gate (Duliujian Estuary)
	Haihe Mainstream	0	2066	72	To coastal inlet
	Ziya River	30943	15385	751	To Xihe Gate
	Ziya New River			747	To coastal inlet
	Zhangwei South Canal	25738	11962	959	To Xihe Gate
	Zhangwei New River			655	To dike mouth (Dakou River)
Tuhai Drainage	Tuhai River	0	28773	417	To coastal inlet
Majia Drainage	Majia River			428	To coastal inlet

2. SILTING AND ATROPHY OF THE ESTUARIES WITHIN THE BASIN

Yongding New Estuary

The channel and the character of the estuary:

Yongding New River is the largest flood-draining tidal channel among the four drainages in Haihe Basin, which was built up in the end of 1970. From Qujiadian to Beitang it pours into the sea, the length of it is about 62 kilometers. Yongding New Estuary is the only estuary in Haihe Basin that does not set a tide gate.

After the retention effect of lake on the fifty-year flood in Yongding River, The largest discharge appearing in Qujiadian is about $1800m^3/s$, in which, $400m^3/s$ is diverted by Beiyun River, and the remaining $1400m^3/s$ discharges into Yongding New River and flows into the sea in Beitang. Because the downstream of Yongding New River is converged by several rivers, so its bed surface becomes wider and wider and the discharge becomes larger and larger until sometimes the maximal discharge of the estuary can be up to $6000m^3/s$. Since Qujiadian hydrologic station has been built, the year-averaged water quantity is about $175,000,000m^3$, and the sediment quantity is about 49.2 thousand tons. According to the investigation on the tide from the 21st to the 22nd June in 1993, the characters of tide and sediment in Yongding New Estuary are shown in Table 2.

Table 2 Characters of tide and sediment in Yongding New Estuary

Section	Tidal level (m)		Tidal range (m)		Velocity (m/s)		Sediment concentration (kg/m^3)	
	High tide	Low tide	Rising tide	Falling tide	Rising tide	Falling tide	Rising tide	Falling tide
43+450	2.07	-0.86	2.79	2.93	0.554	0.297	9.875	3.985
59+108	1.68	-0.92	2.65	2.60	0.613	0.285	2.293	1.695
60+000	1.59	-0.911	2.58	2.49	0.625	0.426	1.956	1.08

The scour-and-fill and the evolution character of the channel and the estuary

According to the measurement on the six bridges from Yinhe Bridge to Huozhuang Bridge in May, 1974, the silting quantity of upstream was about 485m^3 during 3 years along its 22km-long silting section from Qujiadian.

According to the data calculated in May, 1976, the total silting quantity of the five years from 1971 to 1976 in the upstream was about 6,200,000m^3, in which that in the major trough was about 5,200,000m^3. And the erosion quantity of downstream section was about 800,000m^3, in which that in the major trough was about 600,000m^3. The silting area of each section was more than 200m^2 within the 20-kilometer domain from the down floodgate of Qujiadian to Huozhuangzi Bridge, in which the silting quantity on the section was more than 480m^2 from Dazhangzhuang to Lixinzhuang because of the sudden broadening on the original channel, and the silting quantity was decreasing from more than 25-kilometer down the floodgate. Different degrees of erosion appeared in the interval from 33-kilometer to 55-kilometer down the floodgate, and the maximum erosion area was up to 100m^2.

According to the data calculated in October, 1980, the total silting quantity of the 30 km range of the upstream was about 9,500,000 m^3. The silting area of each section within the range of 26 kilometers was more than 260 m^2, while the silting area of each section was up to 500 m^2 in the down floodgate of Dazhangzhuang, whose channel had a sudden broadening. And the silting quantity was decreasing from more than 30 kilometers down the floodgate and erosion have appeared in the channel 32kilometers down the gate.

From 1971, Yongding New River was excavated, to 1994, the silting variation in each sections is shown in Table 3. Among the silting estuaries of those tail channels in Haihe Basin, the atrophy of Yongding New River was the heaviest. Under the control of the flow and the tide, a large amount of sand was carried from the sea and silted in the channel, thus changing the sectional form of the channel. It can be seen that the silting began in the down floodgate of Qujiadian, and evolved towards downstream, making the discharge capability of the channel descends significantly.

Since 1992, a tidal weir had been built, the silting of the 34-kilometer long tidal channel down the weir exacerbated. According to the data estimated, the total silting quantity from March, 1989 to September, 1994 in the down weir was 16,983,400 m^3, and the average quantity in it was 3,088,888 m^3 per year, and its silting end has moved to 62+000. From May, 1971 to October, 1997, the total silting quantity in the channel was about 46,560,000 m^3, and the average quantity in it was about 1,760,000 m^3 per year. The silting condition of Yongding River during different time is shown in table 4.

Effected by the silting, the discharge capability of the channel down the weir descended significantly. The channel discharge capability on Section 28+192 descended from 1640 m^3/s and 1820 m^3/s to 260 m^3/s and 380m^3/s on the design and the check water level, respectively, and the flood protection standard also descended to be two-or-three –year.

Table 3 Scour-and-fill amplitude of the sand bar and the tidal creek in Yongding New Estuary

Distance away Beigang Harbor 59.4+	Silting thickness (m), 75-89	Silting thickness (m), 89-91	Silting thickness (m), 91-94	Average silting thickness (m)
1+500		0.48	0.72	0.24
2+500	1.2	0.2	0.60	0.11
3+500	1.5	0.1	0.1	0.04
4+500	1.5	0.3	0.0	0.09
5+500	1.1	0.0	0.1	0.06
6+500	0.8	0.2	0.3	0.07
7+500	0.4	0.0	0.0	0.02
8+500	-0.1	0.0	0.0	0.0
9+500	-0.3	-0.2	-0.2	-0.05
10+500	-0.4	-0.5	-0.2	-0.06
11+500		0.6	-0.1	-0.04

Table 4 Silting quantity of Yongding New River

		Total quantity (m^3)	Average silting quantity of each sections ($\times 10^4 m^3$)					
			0−26km	26−41km	41−54km	54−62km	0−62km	
Early stage	71.5−76.5	534	133	-25.8	-0.4		106.8	40
	76.5−80.1	-62	67.5	25.2	-26.8	-79.6	-13.7	
	80.1−84.12	71.1	81.9	6.6	0.4	-71.1	17.8	
Medium term	84.12−86.11	1014.9	120.4	166.4	40.2	180.5	507.5	331
	86.11−89.3	396			183.5	-11.3	172.2	
	89.3−90.11	416.5			250		250	
	90.11−92.7	370		155	84	-17	222	
	92.7−93.9	1037		200	382	305	887	
Late stage	93.9−94.9	240		46	68	126	240	216
	94.9−97.1	640					172	
1971.5−1997.10		4657.5					176	

It can be seen from above that there are some characters in the channel of the Yongding New River:

(a) At its early stage, the silting was little, at middle, it increased significantly and at last the speed slowed up, the silting quantity of these three stages was 400,000m^3, 3,310,000m^3 and 2,160,000m^3, respectively.

(b) At its early stage, heavy silting appeared in the upper region, ameliorated condition in the middle and erosion in the estuary. And at its middle stage, the silting developed towards the estuary region of the downstream little by little, until 1989, the end of the silting reached 51+600. Although the silt was cleaned out to build a weir in the channel in 1989, but heavy silting appeared in the channel (28+192) down the weir. The silting began in the down weir at first, at early stage, which became the heaviest, and moved towards the downstream until September, 1994, its end reached 58+000.

(c) The silting quantity in the major trough was much more than that in the marginal bank, and the sections were silted to be flat little by little.

(d) The silting difference was large among years, which mainly depended on the wind-wave condition, and the average silting quantity was about 1,760,000 m^3 per year. Section 63+000 was silted to be 1.14 meters higher than before because of the storm surf in September 1, 1992. The total silting quantity of the whole river from July, 1992 to September, 1993 was about 10,370,000 m^3, and the average silting quantity was about 8,870,000 m^3, which became the most silting quantity in all these years. The two storm surfs happened in August 2 and 21, respectively, made the total silting quantity from December, 1984 to November,1986 be 10,149,000 m^3 and the average silting quantity be 5,075,000 m^3 per year.

The general developing tendency on the estuary is: the longitudinal shape of the sandbar out the outfall that located 67-76 kilometers down Qujiadian (2.8-11.8 away Beitang Dock) presents as a saddle. The general tendency of variation on the sandbar is to erode the outside and silt the inside. Since 1975, the sandbar had moved in 1.5 kilometers, until 1991, when it became steady. The internal abyss presented cumulative silting, and had the tendency of moving left on plane (erosion in left and silting in right). With the silting end moving down in the channel, the more it was near the estuary, the more the silting quantity was, and the quantity in the navigate canal of the estuary increased with the time gone by.

2.2 HAIHE ESTUARY

2.2.1 The basic condition

2.2.1.1 Situations in brief

The main stream of Haihe River is a channel, which is the confluence of the five branches, Beiyun River, Yongding River, Daqing River, Ziya River and Nanyun River and flows into the sea directly. The catchment area of the river is about 2066 km^2. The main stream of Haihe River originates from Sancha River from its west, and flows through the urban district, the east suburb, the south suburb of Tianjin and pours into the sea in Dagukou of Tanggu District, which is about 74 kilometers long. To meet the need of the industrial water in the city and the living water of the people, a tide gate was built in December, 1958 in Haihe Estuary. From then on, Haihe Channel changes from the natural tidal gate into the one mainly stores the fresh water.

2.2.1.2The hydrographic sediment character

According to the statistical data from 1917 to 1981, the hydraulic condition has changed much after a floodgate had been built. The detail is shown in Table 5.

It can be seen from table 5: the average runoff volume after a floodgate had been built was only 25.8% of that before, and the average sediment runoff was only 0.8%. The reason why it decreased was that after a floodgate had been built, the floodgate was always closed to store the fresh water and the water conservancy facilities were built along its upstream, in addition, dry years came consecutively. The runoff volume from the first year after building the floodgate i.e. 1959 decreased from 8,600,000,000 m^3 to 92,000,000 m^3 in 1981. Besides, the dispersion coefficient of the average runoff volume and the average sediment runoff increased significantly after building the floodgate. The reason why the differences in the average runoff volume among the years after building the floodgate were great is that only when it was during the period of flood, some water was released.

Table 5 Flow and sediment characteristic values in Haihe Mainstream before and after building the gate

Time	Year	$\overline{W}$ ($\times 10^8$ m^3)	C_v	$\overline{G}_S$ ($\times 10^4$ m^3)	C_v	Reference
Before building gate	1917−1957	95.61	0.36	812.73	0.70	$\overline{W}$:average run-off volume $\overline{G}$:average sediment runoff C_v :dispersion coefficient
After building gate	1959−1981	24.62	0.99	6.52	1.33	

The distribution of the runoff volume in a year was not so even in the mainstream of Haihe River. According to the 23-year data after building the floodgate, the average runoff volume during the flood season (June to September) was about 50% of the total in a year, and the data before building the floodgate also shows that 50%-70% of water quantity of a year concentrated in the flood season, which means that more than half of the water quantity of a year concentrated in the flood period in the main stream of Haihe River.

2.2.1.3 The character of the sediment

The analysis result of the sand sample taken in Dagusha Shallow Shoal shows: The deposit on the shallow shoal is mainly silt and sometimes a little clay, whose diameter range is from 0.005 to 0.02 millimeters and the average volume weight is about 1.43 tons per cubic meter.

The character of the tide

Before building the floodgate, the main stream of Haihe River was a natural tidal channel, whose tidal limit was more than one hundred meters. After this, the up-bound of the tide were stopped by the tidal barrage, making the characteristic values of the tide change much. For example, because of the silting on the down floodgate, the average high tide level and the average low tide level were elevated.In addition, the rising and falling tide duration also changed. It can be seen from the data of the tidal level process line of the tide observation before and after building the floodgate: after building the floodgate, because of the blocking on the current, the tidal wave changed its form, making the duration of the rising tide decrease and that of the falling tide increase.

2.2.2 The silting condition

2.2.2.1The silting in the channel up Haihe gate

During the 20 years from 1958 building the gate to 1978, the 106-kilometer long channel had been silted 25,500,000 m^3 from Xihe Gate to Qujiadian Gate to Haihe Gate. Only 4,960,000 m^3 was removed, 20,810,000 m^3 left in the channel. Most part of the quantity distributed in the lower section of the channel, for example, the silting quantity of the 40-kilometer long downstream channel near the gate was 70% of that of the whole channel.

Along the 40-kilometer long silting section near the gate, the silting within the range of 1 kilometer up the gate was the heaviest. Take the section 200 meters up the gate as a example: from its first stage of building the gate on, the altitude of the river bed rose from –6.4 meters to –0.2 meters, that is the silting thickness reaches 6.2 meters during the 18 years (up to august, 1977). With the development on the silting, the wetted cross-sectional area decreased significantly. Below 0.0 meters altitude, the cross-sectional area was 1418 m^3 in 1959, which decreased to 901 m^3 in 1970 and to 60.7 m^3 in august, 1977, only 4.3% of the original area. After 1977, although several times of lifting the gate to release the water made the cross-sectional area up the gate return to 507 m^3, and the altitude of the river bottom decrease, but after closing the gate, the altitude increased little by little with the time gone by.

According to the 11-year statistic data from 1958 to 1969: 9,770,000 m^3 soil had been silted in the 11.1-kilometer long thalweg channel down the gate. And its distribution is shown in Table 6.

Table 6 Silting distribution down Haihe Gate, 1958−1969

From the gate (km)	Section	Length (km)	Silting quantity ($\times 10^4 m^3$)	Total silting quantity ($\times 10^4 m^3$)	Silting quantity per kilometer ($\times 10^4 m^3$/km)
0−2.1	Near the gate	2.1	237	237	112.8
2.1−5.7	Internal abyss	3.6	300	537	93.3
5.7−8.1	External abyss	2.4	221	758	92.1
8.1−11.1	Dagusha outfall	3.0	219	977	73.0

It can be seen from Table 6: from 1958 to 1969, the silting quantity per kilometer near the gate was the most, that in the external abyss was the second, that in the internal abyss was the third and that in the outfall section of Dagusha was the least. So the silting in the channel near the gate is the heaviest.

The sectional area of the major trough decreased significantly after the channel was silted. It can be seen from the variation curve of the area below 0.0 m altitude in the sections 400 meters, 1000 meters and 2000 meters away the floodgate: with the time gone by, the area of each section decreased little by little. Take the 225# section that 1000 meters down the floodgate as a example, the area below 0.0 m altitude was 1050 m^2 in October, 1959, the early period of building the floodgate, and decreased to 398 m^2 in November,1967, and further decreased to 360 m^2 in September, 1970, which was only 24.5% of that before building the gate, and finally decreased to zero in the end of August,1975. Meanwhile, it can also be seen: the discharge section after Ludeng down the gate was silted to be flat in the end of August, 1975.

The silting and dredging quantity in the section near the gate (from Haihe Gate to Ludeng)is shown in Table 7.

Table 7 Measured silting and dredging quantity in the section near the gate, 1959−1982

Year	Dedging quantity ($\times 10^4 m^3$)	Total dredging quantity ($\times 10^4 m^3$)	Remaining silting quantity	
			Month	($\times 10^4 m^3$)
1959			10	0
1969			11	200
1977	35.5	35.5		
1978	30.8	66.3		
1979	45.0	111.3	9	176
1980	50.0	161.3	4	235
1981	55.8	217.1	4	240
1982	61.3	278.4	4	253

According to the measurement result in April, 1982, before desilting: 2,520,000 m^3 soil was silted in the 2.1-kilometer long canal, whose average altitude was 0.0 m, 6 meters higher than that of the sluice board and as high as the highest point of the sandbar 5 kilometers away the floodgate out the estuary.

Comparing the measured terrain of the estuary in August,1995 with that in 1958, the maximal silting thickness in the lock site was 6 meters. The internal abyss within the range of 4 kilometers down the floodgate was silted to be flat. The top altitude of the sandbar rose from −5.0 meter to −1.7 meter, and the climax position of the sandbar moved from 10 kilometers to 5 kilometer away the floodgate. And about 22,590,000 m^3 soil was silted in the main channel within 11 kilometers down the floodgate.

Silting in the estuary was one of the main reasons that cause the attenuation on the discharge capability of the main stream of Haihe River. According to the several experimental researches on the mathematical and physical model in Haihe Estuary, on the condition of the original design water level in the up gate (2.6 meters), the discharge capability of Haihe Gate was 3,170,000 m^3/s in 1986, 1,100,000 m^3/s in 1989, only 500,000 m^3/s in 1995, before flooding.

To pass the flood safely, the desilting in the estuary was begun in 1973 in Tianjin. The desilting engineering of the estuary was administrated by Downstream Bureau of Haihe River Conservancy Commission, Ministry of Water Resources in 1981. From 1981 to 1994, the desilting quantity was 400,000−600,000 m^3, and combined with the treatment on the mainstream of Haihe River, the desilting scale was extended in 1995. Although the silt had been cleaned as the standard of the design section whose discharge capability was 800 m^3/s

before the flood in 1999 and 2000, but under the control of the tidal current, the marine sediment returned to the desilting channel, again.

2.3 DULIUJIAN ESTUARY

2.3.1 The Basic Condition

Duliujian River is a channel excavated in 1953, which flows into the sea directly. The original design discharge quantity of Duliujian River was 1020 m3/s until the sixties. From the winter of 1968 to the spring of 1969, Duliujian River was extended to meet the need of the actual flood draining, whose design discharge quantity became 3200 m3/s. And an intake floodgate and Gongnongbing Gate in the estuary were also extended and built.

Duliujian River is from Duliu Intake Floodgate of the sixth port in Tianjin to Gongnongbing Gate, whose length is about 70 kilometers. And it can be divided into four sections, Jianhe Section, Dagang Section, the section from Haida Road to the tidal gate and the channel down the gate.

From point 19+000 of Jianhe Section to Gongnongbing Gate, there are two major troughs compared with other channels only one major trough. The flood is mainly in the quirk except for in Dagang Section. The gate is 1.5 kilometers away the coastline and 9 kilometers away the open sea. The diversion canal is about 3.5 kilometers long, whose design cross-section of the major trough can be divided into three sections and is wide in the top and narrow in the bottom, representing as a form of stair-step. The bottom of the upper section is 260 meters wide, whose altitude is –2.80 meters, and that of the end section is 50 meters wide, and they connect each other with a longitudinal slope of one the ten thousandth.

Gongnongbing Gate, the tail of Duliujian River, was built in 1967 to prevent the tide and store the fresh water. The altitude of the sluice board is –2.80 meters (of Yellow Sea), and the design discharge is 3,200 m^3/s. An observation station of the discharge was built in it in 1971. According to the 11-year statistic data from 1971 to 1981, the average runoff volume was 400,000,000 m^3, and the maximal runoff volume was 2,320,000,000 m^3.

2.3.2 The silting condition of the diversion canal

According to the analysis on the survey data of the terrain under the water from 2.0 kilometers to 2.8 kilometers and from 0.0 kilometers to 2.0 kilometers down the floodgate taken by Tianjin Channel Engineering Department and Tianjin Hydraulic Research Institute, the silting in the diversion canal increased year by year after building the gate, especially in 1976, when the total silting quantity was 2,376,000 m^3 within the range of 3 kilometers away the gate. After 1976, because some dredging measurements such as the excavating and the dragging had been taken, so the silting alleviated. The total silting quantity decreased to 2,152,000 m^3 in March, 1979, and further decreased to 1,410,000 m^3 in March, 1982. Correspondingly, the average silting thickness in the diversion canal also decreased. It was 3.44 meters in 1976, and 1.31 meters in March,1982. And the maximal silting thickness in the most serious section also decreased from 4.21 meters in 1976 to 2.10 meters in 1982. The silting thickness in the typical year is shown in Table 8.

Table 8 Silting thickness in the diversion canal down the gate

	Silting thickness (m)	Heaviest section (m)			Reference
		Position (from the gate)	Average thickness	Maximal thickness	
1976.6	3.44	0−1000	3.84	4.21	Compared with design bottom
1979.3	3.38	0−1000	3.66	3.90	
1982.3	1.31	0−700	1.80	2.10	

2.3.3 The scour-and-fill variance in the diversion canal

Since 1967 building the gate, the silting in the channel can be divided into two stages: the first was from 1967 to 1976. During these ten years, no measurement had been taken in the diversion canal, and the channel was in the natural scour-and-fill state. The second stage was from 1976. Because some measurement such as dragging the silt with the boat, cleaning the silt with the dredge in the diversion canal has been taken, so the channel was in the unnatural scour-and-fill state. The silting characters of two stages are described as follows.

After a gate was built in 1967, effected by the gate-building and the decreasing of the discharge, the diversion canal was mainly controlled by the tidal power, thus causing heavy silting in the down gate. Up to 1976, the altitude of the deepest point in the diversion canal was 3.4 meters higher than that of the design bottom. The silting in the down gate was the heaviest, 4.2 meters, and decreased little by little downward.

According to the data of 1976, the 3.0 kilometers long design excavated cross-section down the gate was silted to be flat, and the total silting quantity was 2,370,000 m^3. The silting within 1000 meters down the gate was the heaviest, whose quantity was 43.6% of that in 3 kilometers long diversion canal. And that in other sections was only 22.4% and 33.85 of total, respectively.

Since 1967, a tidal gate built in Duliujian Estuary, because the tidal gate was in closing state all year long, so large quantity of marine sediment was silted in the down gate, which made the discharge much more difficult. From 1967 to March, 1998, the total silting quantity in the major trough within 2.0 kilometers down the gate was 1,392,000 m^3, and the altitude was approximately 0.0 meters, and the average thickness was 2-3 meters. The silting was the heaviest at the first stage of building the gate near the gate, whose thickness was about 4 meters. The silting condition down the gate in the estuary is shown in Table 9.

Table 9 Silting condition down Gongnongbing Gate in Duliujian Estuary

time	1967.11	1976.3	1979.3	1980.3	1995.3	1996.3	1997.3	1998.3
Calculation scope (km)		0~3.33	0~3.33	0~3.33	0~1.5	0~1.5	0~1.5	0~2.0
Silting quantity ($\times 10^4 m^3$)	0	237.6	215.2	115.5	171.1	139.7	89.9	139.2

3. ANALYSIS

Whether it is a channel, in which a gate was built or not, as far as the reasons of the silting are concerned, there are three aspects:

- The decrease on the runoff volume and the storage quantity

Because the estuary is the region, in which the runoff that flows from the land coacts with the tidal current that up-bound from the sea, so the storage quantity of the estuary and the runoff volume of the channel are the main factors that control the scour-and-fill variance of the channel. In certain boundary condition, the runoff combined with the current maintains the scour-and-fill balance of the estuary pro ratio, and if there is a change on one of the both, the scour-and-fill balance will be damaged. From the cross-section formula of the tidal estuary in the plain $A = KQ^{8/9}$, the significant decrease on the runoff or the current quantity will cause that on the cross-sectional area, that is silting will appear in the estuary. For example, the storage quantity of the estuary was 25,000,000 m^3 before building the gate in the mainstream of Haihe River, when silting seldom happened in the estuary. After 1958, a gate was built, because the storage quantity decreased to 3,000,000 m^3 and the average runoff volume decreased to 925,000,000 m^3, so the original cross-section of the channel could not maintain itself, and it developed to be smaller to adapt to the new condition though silting, thus causing heavy silting in the estuary.

● The deforming of the tidal wave

When the tidal wave enters the estuary, it is deformed and reflected by the various resistances. If a tide gate is built in the region of the estuary, the duration of rising tide is shortened, and that of falling tide is increased, thus, the average velocity of rising tide is greater than that of falling tide, the force of rising tide that carrying the sediment is greater than that of falling tide, and the sediment runoff of rising tide is greater than that of falling tide, finally causing the silting in the channel. Comparing the graph of the tide level before and after building the gate, the average duration of the rising tide was 5 hours and 48 minutes and that of the falling tide was 6 hour and 24 minutes before building the gate, and the duration of the rising tide became only 4 hours and 30 minutes and that of the falling tide became 7 hours and 30 minutes after building the gate. It shows that the tidal wave is deformed heavily.

● The uneven sediment discharge character of rising and falling tide

It is shown in the analysis result of the measured data: even when the velocities of the rising tide and the falling tide are same, the measured sediment concentration of the rising tide is greater than that of the falling tide, causing the input sediment quantity of the rising tide can not be carried out of the estuary, and causing the silting in the channel. According to the velocity-sediment concentration relation curve in Section 1+600 of Qingjinghuang Conduit, when the velocities are same, the sediment concentration of the rising tide is much greater than that of the falling tide. For example, when the velocities are both equal to 0.2 m/s, the sediment concentration of the rising tide is 6 times as much as that of the falling tide. It is because besides the force of the current that carries the sediment, the sediment concentration of the rising and the falling tide also has the relationship with the provision condition of the sediment. Because the sediment provision in the estuary of the silty plain in Haihe Basin is sufficient, so the force that carries the sediment of the falling tide can be made good use, and the sediment concentrate that carried by the rising tide is supersaturated. Because when the velocity of rising tide decreases below the stopping velocity, the sediment deposits; when the tide is falling, and only when the velocity is above the starting velocity, the force that carries the sediment of the falling tide can be made good use, so its time lags behind the rising tide time. Just because of this kind of “late effect”, the phenomenon that the sediment runoff of the rising tide is larger than that of the falling tide appears, and results in the silting in the channel.

4. CONCLUSION

An estuary is located in the region that the river and the sea converges. The variance of scour-and-fill in estuary mainly depends on the water and sediment conditions and the boundary conditions. The shape of an estuary is the result that the tide and the current coact with each other. Because the shortage of water resources in the Haihe River Basin is serious, the water quantity of the river that flows into the sea is small, and the estuary is mainly controlled by the tide power. As there are abundant sediment on the shallow shoals of the estuary, so it is inevitable that the silty estuary with no runoff is silted. If no measures are taken to prevent and alleviate silting, the silting in the estuary will develop, and the sediment bar moves toward the coast, finally the estuary is silted up. It is the inexorable law of the silty estuary.

REFERENCES

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