

Water and sediment graded management to alleviate the “secondary suspended river” in the lower reaches of the Yellow River

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Abstract: The “secondary suspended river” poses a huge threat to the safety of embankment in the lower reaches of the Yellow River. The formation of the “secondary suspended river” is mainly attributed to the “less water and more sediment, inconsistent water-sediment relationship” of the Yellow River. Through the analysis of the relationship between the evolution of the lower reaches of the Yellow River and the loss caused by disasters and flood and magnitude of sediment concentration, this paper thinks that the Yellow River must pay attention to the graded regulation of water and sediment. For small and medium-sized flood with small sediment concentration, according to the flood magnitude and the reservoir water volume in the upper and middle reaches, Impoundment and filling water to build the peak time at the right time is necessary and the flood processes which are less than 2600 m³/s should be avoided in the scheduling process. Based on the shape of river channel of high flow flood in floodplain and average flow flood in floodplain, and the difference between the sediment transport efficiency of flood and the difference between the loss to the lower floodplain area, the average flow flood in floodplain which is between 6000 m³/s should be avoided in the scheduling process as far as possible. In order to relieve the development trend of the “secondary suspended river”, the regulation of “brushing groove of silt beach” should be insisted on for large flood. But the high sediment concentration flood should be avoided because of its serious destructive effect on the lower reach. At the same time, it also calls for strengthening the research and popularization of reservoir sediment treatment and sediment resource utilization technology.

1 Introduction

The lower reaches of the Yellow River are in a state of intense sedimentation and lifting, and the river bed is higher than the two sides of the ground, forming the “suspended river”. In addition, small and medium floods and dry season sedimentation mainly occurs in the main river channel. Sedimentation degree near the newly formed floodplain is relatively large. However, because the exchange of water and sediment of the beach far from the main channel is not strong, the sedimentation degree is relatively small. Additionally, the serious “secondary suspended river” situation with “high channel, low beach, low-lying levee root” has been formed because of soil extraction from the levee root and compound levee. Less water and more sediment and inconsistent water-sediment relationship are the main reason for the rising of the lower reaches of the Yellow River. Among them, the “secondary suspended river” situation is the most serious in the reach from Dongbatou to Taochengpu, and it is also one of the most important flood control tasks in the lower reach of the Yellow River. Due to the long term sedimentation of the river, during the water and sediment regulation period in the year of 2002, the Shuangheling section is floodplain

whose discharge is 1800 m³/s. In recent years, the majority of bankfull discharge in the lower reaches of the Yellow River is more than 4000 m³/s. However, compared with flood carrying capacity of 6000 m³/s in the 1960s and 1970s, the current flood carrying capacity of the lower reaches of the Yellow River is still small. The situation of the “secondary suspended river” has not been improved effectively, and the flood control situation is still serious.

Because of the sedimentation and shrinkage of the river channel, the flood carrying capacity of the river is reduced and the average frequent floods can cause a large area of floodplain. At the same time, the situation of “secondary suspended river” with high beach lip and low-lying levee root is becoming more and more serious, which increases the burden of flood control and difficulty of river regulation in the lower reaches. Once flood overflow, the levees of the lower reaches will be against water on a large scale, and the water depth is very large, and even some reaches of the river still have the possibility of serious flood along the levee or even rolling river, which poses a huge threat to the flood control safety of the whole Huanghuaihai Plain. Therefore, how to alleviate the disadvantageous situation of the “secondary suspended river” effectively has always been one of the most important issues of the Yellow River management. The

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formation of the “secondary suspended river” is mainly attributed to the inconsistent relationship between water and sediment. Based on the evolution of the lower reaches of the Yellow River and the changes of the loss caused by disasters, the author discusses the concept of graded management of water and sediment in the lower reaches of the Yellow River, considers the influence of various factors and constructs a coordinated flood process to alleviate or contain the disadvantageous situation of the “secondary suspended river”.

2 Materials and Methods

In order to discuss the application of Xiaolangdi reservoir, the flood characteristics in the lower reaches are discussed first. The floods in the lower reaches of the Yellow River are mostly concentrated in 7 and 8 months. The flood rises and falls sharply, and the peak value is high and the flow is small^[1]. For example, in July 1958, the measured flood peak flow of Huayuankou was 22300 m³/s, and the 7-day flood volume was 5.02 billion m³, which was about one-tenth of the average 7-day flood volume of Yichang Station on the Yangtze River for many years. The flood problem of the Yellow River is so serious, not only because the flood of the Yellow River rises and falls sharply, but also because the sediment concentration is too high. For example, the flood with sediment concentration as high as 933 kg/m³ occurred in the main stream at Sanmenxia station, and the flood with high sediment concentration of 1000-1500 kg/m³ in the tributary. The measured value of average annual water volume is 47 billion m³, and the sediment volume is 1.6 billion tons, with an average sediment concentration of 35 kg/m³. Regardless of annual sediment discharge or average sediment concentration, the Yellow River ranks first in the world's rivers^[2]. It is precisely because the flood of the Yellow River rises and falls sharply, and the peak value is high and the flow is small and the damage of the high sediment concentration flood sedimentation to the river channel is serious that the flood has caused great harm to the flood control safety of the lower reaches.

The lower reaches of the Yellow River are composed of compound sections of main channels and flood plain areas, and flood plain areas account for about 84% of the river area. The vast flood plain areas are populated by about 1.8 million people and has 3.75 million arable land. From the point of view of flood control in the flood plain areas, the greater of the flood carrying capacity of the main channel, the smaller the probability of flooding, and the smaller the loss of flood plain area. However, the flood plain area of the Yellow River is also a major component of the river channel. Since 1949, the average peak-clipping rate of reach from Huayuankou to Sunkou is about 24% among the nine floods with flow greater than 8000 m³/s at Huayuankou in the lower reaches of the Yellow River, and annual mean sedimentation amount in the flood plain area accounts for about 69% of the total sedimentation amount. Therefore, the flood detention and sediment deposition in the flood plain area are necessary to relieve the pressure of flood control in the narrow reaches of the lower reaches and to ease the development

of the “secondary suspended river” in the wide reaches.

Therefore, in the case of incomplete control of sediment into the Yellow River, the sedimentation in the lower reaches of the Yellow River will inevitably exist. To alleviate this disadvantageous situation, it is necessary to require a certain probability of flooding, but flooding will inevitably cause economic losses in the flood plain area. It is of great significance to find an optimized flood control scheme between positive and negative benefits.

3 Experimental soil sample and physical properties

3.1 Evolution characteristics of flood in the lower reaches of the Yellow River

The flood evolution form in the lower reaches of the Yellow River can be divided into non-overbank flood, general overbank flood and large overbank flood according to the characteristics of transverse flow of flood (i.e., only flooding in the main channel, flooding in the newly formed flood plain area and flooding in the large flood plain area). At present, the boundary flow of the three floods can be considered as 4000 m³/s and 8000 m³/s (the flow is slightly different in different reaches, different historical periods and different boundary conditions). The sediment in the lower reaches of the Yellow River mainly comes from flood period, but the main channel of the lower reaches is the main channel for flood discharge and sediment reduction. After flooding, the flood discharge capacity of main channel accounts for about 80% of the total section. During the flood period, the change of scour and silting follows the universal law of rising and falling. For example, in the flood of 1958, the scour depth of the main channel of Huayuankou Station was 1.82 m when flooding, and the depth was 1.25 m when falling, and the scour depth of the whole flood peak was still 0.57 m.

The lower reaches of the Yellow River are wide at the top and narrow at the bottom. After flooding, the vast flood plain areas play the role of detaining flood and reducing flood peak, which reduces the flood control pressure of the lower reaches of the river. For example, for four typical floods in 1954, 1958, 1982 and 1996, the peak reduction value of reaches from Huayuankou to Aishan are 7100, 9700, 7870, and 2800 m³/s respectively, accounting for 47%, 43%, 51% and 36% of the peak flow of Huayuankou, among which the peak shaving effect of reaches from Jiahetan to Aishan is more significant. The flood storage effect of overbank flood is very significant. The flood detention and storage volume of reaches from Huayuankou to Sunkou was 2.589 billion m³ and 2.454 billion m³ respectively in July 1958 and July 1982. Among them, the flood detention effect of reaches from Gaocun to Sunkou is the greatest, accounting for 52%-71% of the reaches from Huayuankou to Sunkou. Its flood detention capacity is equivalent to the total reservoir capacity of Guxian Reservoir and Lahun Reservoir, which greatly reduces the flood control pressure of the narrow channel in the lower reaches^[3].

The river evolution and disaster losses in the lower reaches of the Yellow River are obviously related to the

flood magnitude and sediment concentration carried by flood.

3.2 Impact of different floods on scouring channels in the lower reaches of the Yellow River

For Non- overbank flood with general sediment concentration or rinsing, especially for flood close to bankfull discharge, the flow mainly evolves in the main channel, which is very beneficial to scouring the main channel, improving the shape of river cross section and improving the flood discharge capacity of the main channel. Especially for flood close to bankfull discharge, which has a strong effect on shaping the main channel and the effect is better. For example, since 2002, the practice of water and sediment regulation in the Yellow River has effectively improved the shape of the lower reaches of the Yellow River, reduced the river facies coefficients in different reaches, reduced flood level, enlarged the channel area and increased the bankfull discharge.

The large overbank flood with low sediment concentration and large water volume is generally characterized by obvious scour in the main channel and sedimentation in the flood plain area, which is very beneficial to shaping the river channel. For example, for flood in 1975, the peak discharge of Huayuankou is 7580 m³/s, and the water volume is 3.38 billion m³, and the sediment volume is 0.148 billion t. The floodplain occurred in the lower reaches, and the main channel of Huayuankou – Lijin scoured 0.268 billion t, and the flood plain area deposited 0.339 billion t. For flood in 1976, the peak discharge of Huayuankou is 9210 m³/s, and the water volume is 7.55 billion m³, and the sediment volume is 0.286 billion t. The floodplain also occurred in the lower reaches, and the main channel of Huayuankou – Lijin scoured 0.106 billion t, and the flood plain area deposited 0.339 billion t. However, such floods may encounter rather than pray, especially with the joint debugging of a single reservoir or reservoir groups, making the probability of the occurrence of such floods smaller.

High sediment concentration floods are generally divided into non-flooding or general flooding high sediment concentration floods and large flooding high sediment concentration floods. Han Qiwei analyzed the water and sediment and erosion and deposition data of 36 years from September 1960 to June 1996 under the Sanmenxia, during which 20 high sediment concentration floods occurred and 3.632 billion tons of sediment deposited in the whole lower reaches in 36years. If the 3.722 billion tons sediment deposition caused by the 20 high sediment concentration floods was removed, the riverbed would instead scour 0.09 billion tons deposition. It can be seen that high sediment concentration floods is the main factor to cause river channel sedimentation.

Non-overbank or general overbank flood with high sediment concentration often results in serious sedimentation of riverbed in the main channel and newly formed flood plain area, making the section narrow and deep and making the water level rise and fall sharply. If the river channel is silted up seriously in the earlier stage, high water level will often occur, and flood peak will

deform in the process of flood propagation, which poses a serious threat to the safety of flood control in the lower reaches. For example, in the period of high sediment concentration flood in 1992, the lower reaches deposited 0.358 billion tons sediment, accounting for 62% of the annual sediment volume. Sedimentation mainly concentrated in the main channel and newly formed flood plain areas above the reaches of Gaocun. In the period of high sediment concentration flood in 1996, the whole lower reaches deposited 0.355 billion tons sediment, accounting for 71% of 0.498 billion tons of sediments, of which 0.303 billion tons of sediments were deposited above Gaocun, accounting for 85% of the sediment volume in the whole lower reaches. Because of the sedimentation of non-overbank or general overbank flood on the main channels and the newly formed flood plain areas, the beach lip becomes higher and the levee root becomes lower, which aggravates the unfavorable development of the “secondary suspended river”. In the regulation and control, it is necessary to avoid such flood directly entering the lower reaches.

For large overbank flood with high sediment concentration, in the process of flood evolution, the main channel is brushed deep, and sedimentation occurs in the flood plain area, and the river channel often forms high beach and deep channel. However, in the propagation process from top to bottom of high sediment concentration floods or when the change of water and sediment combination in the upper reaches is incompatible with the existing riverbed boundary conditions, it is difficult to sustain high beach and deep channel for a long time even if it has been formed. On the other hand, because of the drastic adjustment of the boundary shape of the riverbed, the roughness of the riverbed increases while the river channel is cut down, which in turn affects the structure of the flow with high sediment concentration. Once the steady state of water movement is destroyed, the shape of the cross section will be affected. After flood, the main channel and the flood plain area are often raised synchronously. For example, in 1977, 591 million tons of sediment was deposited in the lower reaches from Huayuankou to Aishan caused by two high sediment concentration floods, and 333 million tons of sediment was deposited in the main channel, accounting for 56% of the whole section. The whole section was silted up.

The above analyses show that the bankfull discharge floods with general sediment concentration or close to rinsing and large overbank flood with low sediment concentration are the most favorable for the erosion of the river channel. The channel of large overbank flood with high sediment concentration occur sedimentation, and the main channel and the flood plain area rise synchronously. Although it is extremely unfavorable to river sedimentation, there are still some advantages in shaping the channel shape. However, as for non-flooding or general flooding floods with high sediment concentration, serious sedimentation often occurs in the main channel and newly formed flood plain area, which is the most disadvantageous to flood control. At the same time, if the flood is temporarily stored in the reservoir, on the one hand, the reservoir capacity will be greatly damaged. On the other hand, when the small water after the flood

discharges sediment, these sediments will still be deposited in the main channel, which is the most destructive to the channel shape (see the next section). Floods in different periods and of different types, the

scouring and silting of the lower reaches of the Yellow River is shown in Table 1.

Table 1 Table of the volume of scour and fill of historical flood channels in the lower reaches of the Yellow River

Period of time (year. month. day)	Huayuankou			Huayuankou-Aishan (one hundred million t)			Aishan-Lijin (one hundred million t)			Remarks
	Peak discharge (m ³ /s)	Water volume (one hundred million m ³)	Sediment volume (one hundred million t)	Main channel	Flood plain area	Whole section	Main channel	Flood plain area	Whole section	
2002.7.4~7.15	3170	27.5	0.36	-0.57	0.56	-0.01	-0.20	0	-0.2	Low water Low sediment
1992.8.10~19	6430	-	-			2.83			0.11	
1996.8.3~8.15	7860	44.6	3.39	-1.50	4.40	2.90	-0.11	0.05	-0.06	Middle water Much sediment
1977.7.6~13 1977.8.7~10	6360 10800	-	-	3.33	2.58	5.91	-	-	0.39	Large water Large sediment
1957.7.12~8.4	13000	90.2	4.66	-3.23	4.66	1.43	-1.1	0.61	-0.49	
1958.7.13~7.23	22300	73.3	5.60	-7.1	9.20	2.10	-1.5	1.49	-0.01	
1975.9.29~10.5	7580	37.7	1.48	-1.42	2.14	0.72	-1.26	1.25	-0.01	Ample water Low sediment
1976.8.25~9.6	9210	80.8	2.86	-0.11	1.57	1.46	-0.95	1.24	0.29	
1982.7.30~8.9	15300	61.1	1.99	-1.54	2.17	0.63	-0.73	0.39	-0.34	
1988.8.11~8.26	7000	65.1	5.00	-1.05	1.53	0.48	-0.25	0	-0.25	

3.3. Different shaping effects on river channel morphology of different floods

Hu Chunhong et al.^[5] analyzed the measured data of the hydrological stations in the lower reaches of the Yellow River from 1950 to 2003. The results showed that the flat beach area of the typical section in the lower reaches of the Yellow River increased not only with the increase of the annual water volume, but also with the increase of the maximum peak discharge of the year. However, the flat beach area of each section increased with the maximum peak discharge of the year differently. The flat beach area of Huayuankou and Gaocun sections not only increased with the increase of the maximum peak discharge of the year, but also was affected by the continuous 5-year sliding mean of the water volume of the flood season. When the continuous 5-year sliding mean of the water volume of the flood season was less than 25 billion m³, the flat beach area was smaller, and increased slowly with the maximum peak discharge of the year. When the continuous 5-year sliding mean of the water volume of the flood season was more than 25 billion m³, the flat area was larger, and increased faster with the maximum peak discharge of the year. The flat area of the two sections of Aishan and Lijin increased only with the increase of the maximum peak discharge.

Through the experiment of the sections shaping by the peak discharge in the lower reaches of the Yellow River, Dai Qing et al.^[6] considered that after peak discharge of

large flooding flood, the flood plain area was deposited, and the river channel was eroded, and the main channel was obviously widened, and the area increased and the ratio of width to depth increased. After peak discharge of general flooding flood, the main channel was widened. When the sediment concentration was high, the river channel was deposited, and the area of the main channel decreased and the ratio of width to depth increased. When the sediment concentration was low, the river channel was eroded, and the area of the main channel increased and the ratio of width to depth decreased. After peak discharge of non-flooding flood, the elevation of thalweg rose. When the sediment concentration was high, the area decreased. When the sediment concentration was low, and area increased slightly.

According to Jiang Enhui's study on the law of forming riverbed by overbank flood with high sediment concentration, for non-overbank flood and general overbank flood, the near-wall flow area was greatly affected by the resistance of the bank wall and velocity of the flow was small, so the carrying capacity of the flow was small and the sediment of high concentration can not be carried down with the flow. A great deal of sediment was deposited in the side wall (slope) of the two banks, and the width of the river surface of the channel was gradually reduced, and the slope was steeper, and the channel became relatively narrow and deep, and the water level rose. Then when the narrow and deep channel formed gradually, the flow of velocity increased and the unit discharge concentrated, so the sediment carrying

capacity of the flow increased, and the channel was eroded, and the water level decreased accordingly. After the riverbed was eroded and cut down, the channel became narrower and deeper, and the bed became coarser, and the flow became incompatible with the channel, and the sediment carrying capacity of the muddy water flow decreased. So the bed erosion stopped, and the sedimentation increased, and the water level rose. That is to say, riverbed and water flow are always in a dialectical development process of mutual adjustment and adaptation.

For large overbank flood with high sediment concentration, after flooding, the cross-section of river increases suddenly, and the average flow velocity of section decreases, and the sediment carrying capacity of water flow decreases, and the sediment deposits in a large amount, forming a new lip along the beach, increasing the transverse slope of the beach. After the formation of the new beach lip, the flood floodplain area is obviously reduced, and even the flood flow is only carried out in the channel, becoming relatively non-overbank flood, and then forming a relatively narrow and deep channel. The flooding floods with high sediment concentration form riverbeds strongly, and the riverbeds adjust automatically and rapidly. The rule of forming riverbed is: forming a new beach lip, affecting the floodplain pattern of the follow-up flood, thus shaping a relatively narrow and deep riverbed with obvious uplift. Although floods with high sediment concentration can create relatively narrow and deep channels, this result is at the cost of serious deposition of the previous riverbed, and the narrow and deep channels can not be maintained for a long time. After the flood, with the change of water and sediment conditions, it soon returns to the cross-section shape before the flood. Fig. 1 is a result of prototype measured cross-section, which fully demonstrates the above viewpoints. A flood with high sediment concentration can make the main channel deposited and narrow obviously, the new beach suddenly appear and the transverse slope increase within one or two days.

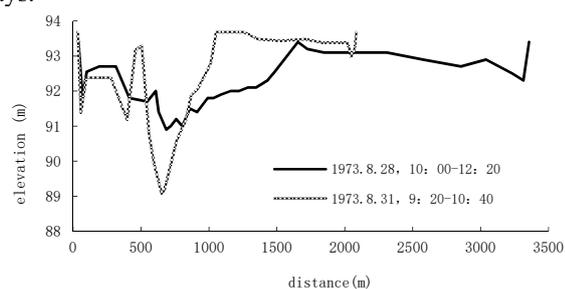


Fig.1 Plotting of cross section before and after floods with high sediment concentration in prototype Huayuankou section

The above research shows that overbank flood has a certain effect on increasing the cross-sectional area of the channel and improving the flood and sediment discharge capacity of the channel. However, the narrow and deep channel formed by floods with high sediment concentration is at the cost of serious deposition of the main channel in the early stage, and this narrow and deep channel can not be maintained for a long time. Considering the need of maintaining the middle river

channel and meeting the economic and social development of the river basin, according to the study results of most experts, it is more appropriate to control the peak discharge of Huayuankou at 4000m³/s.

3.4. Differences between sediment transportation efficiency of different magnitudes of floods

The lower reaches of the Yellow River are divided into wandering, flexural and transitional types according to their nature. The sediment transport capacity of different reaches in the lower reaches is also different due to different river types, and the situation is very complicated. At present, many scholars have carried out a certain amount of research work, and obtained some understanding, briefly described as follows.

For non-overbank flood, Shi Chunxian et al^[9] analyzed the scouring and silting characteristics of the lower reaches of the Yellow River under the condition of discharge less than 4000 m³/s. It is considered that the main channel can keep non-silting or even scouring after controlling a certain sediment concentration when the discharge is more than 2300 m³/s. In the range of 800-2300 m³/s, when the sediment concentration is less than 20 kg/m³, the upper reaches scour and the lower reaches deposit. When the sediment concentration is more than 20 kg/m³, the whole lower reaches deposit, and the sediment discharge ratio is only 51%-84%. When the discharge is less than 800 m³/s, the flow intensity is relatively weak, and the sediment transport capacity is very low, and the deposition ratio of the channel in the lower reaches is very small.

Based on the change of river patterns along the lower reaches of the Yellow River, Han Qiwei^[10] use the established relationship between river facies coefficient and discharge to reveal the change and put forward the concept of balanced sediment transport, which is considered that the critical discharge of river scour in Shandong Province is about 2500 m³/s. When the discharge is less than 2500 m³/s, the situation of “scouring in Henan and silting in Shandong” is easy to occur. Therefore, the situation of less than 2500 m³/s should be avoided in the flow magnitude control of flood regulation.

Li Xiaoping et al^[11] analyzed the scouring efficiency of the floods with low sediment concentration in the lower reaches of the Yellow River during the sediment interception period of the Sanmenxia Reservoir and Xiaolangdi Reservoir. The average discharge of the floods is less than 6000m³/s, as shown in Figure 2. It can be seen from the figure that the total sediment scouring efficiency of the floods in the lower reaches of the Yellow River during the sediment retention period of reservoirs increases with the increase of the average discharge of floods when the average discharge is less than 4000 m³/s. When the discharge reaches 4000 m³/s, the scouring efficiency no longer increases significantly with the increase of the discharge, and basically remains at 20 kg/m³.

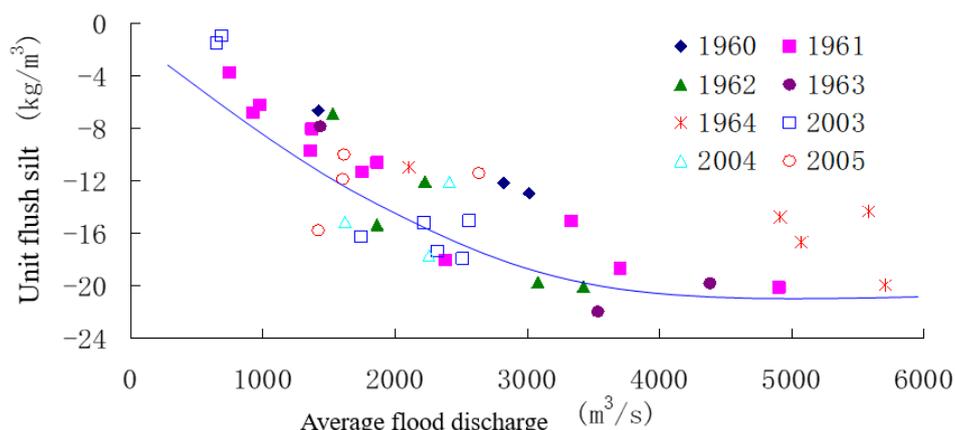


Fig.2 Relationship between scour efficiency and average discharge in the lower reaches of the Yellow River in the period of clear water discharge

For overbank flood, silted floodplain and scoured channel is often produced, which is very beneficial to shaping and maintaining the middle channel, but flooding flood will cause economic losses to the flood plain areas. It is very useful to define the lowest overbank flood magnitude for guaranteeing the obvious silting and scouring effect of overbank flood and reducing flooding frequency. Zhang Yuanfeng [12] counted more than 20 overbank floods in the lower reaches of the Yellow River. It was found that there was a certain relationship between the volume of deposition on the flood plain area and the ratio of the difference between flood discharge and bankfull discharge (the ratio of the difference between peak discharge and bankfull discharge to bankfull discharge). When overbank flood occurs in the lower reaches of the Yellow River, the minimum overbank discharge should be controlled around 0.5 according to the value of β . If the discharge capacity of the main channel is about $4000\text{m}^3/\text{s}$, the minimum overbank discharge should be controlled not less than $6000\text{m}^3/\text{s}$, so that obvious silted floodplain and scoured channel will occur in the channel in the lower reaches of the Yellow River to maximize the discharge capacity of the main channel. When small overbank floods occur in the lower reaches of the Yellow River, the Xiaolangdi Reservoir can store and control the discharge according to the discharge of $4000\text{m}^3/\text{s}$ at the Huayuankou, and the corresponding sediment concentration can be controlled to about $50\text{kg}/\text{m}^3$, so that the lower reaches of the river can be non-silting basically. During the process of control and operation of Xiaolangdi Reservoir, the flood process of $4000\sim 6000\text{m}^3/\text{s}$ should be avoided as far as possible.

The results of the above research show that for non-overbank floods, considering the influence of balanced sediment transport between the upper reaches and the lower reaches, the discharge should be controlled below $800\text{m}^3/\text{s}$ and above $2500\text{m}^3/\text{s}$. In terms of sediment transportation efficiency, the flood of $4000\text{m}^3/\text{s}$ has the highest scouring efficiency on the lower reaches of the Yellow River. For overbank flood, the flood between $4000\text{m}^3/\text{s}$ and $6000\text{m}^3/\text{s}$ should be avoided, because the effect of silting floodplain and scouring channel of such kind of floods is limited, but they will cause some losses to the flood plain areas.

3.5. Inundation losses of flood plain areas caused by different magnitudes of floods

Zuo Ping [13] analyzed the inundation loss caused by floods of different magnitudes on the basis of the discharge capacity of the main channel of the lower reaches of the Yellow River before the flood period in 2004, and estimated the compensation amount for inundation of each magnitude, as shown in Table 2.

Table 2 Loss estimation for different magnitudes of flood inundates of different schemes

Units: ten thousand yuan

Magnitudes	Inundate farmland (ten thousand km^2)	Loss ratio (%)	Estimation by soybean	Estimation by corn	Estimation by all crops
4000	8.78	99.03	62186	75361	74966
5000	12.12	99.03	85814	103995	103450
6000	17.48	99.03	123758	149978	149192
8000	18.68	99.03	132226	160240	159400
10000	21.04	99.03	148940	180495	179548
12000	21.94	99.03	155316	188222	187235
15000	22.19	99.03	157138	190430	189431

In the development of the “Study on flood risk mapping establishment (pilot) of flood plain areas in lower reaches of the Yellow River”, the Yellow River Institute of Hydraulic Research has calculated the inundation loss caused by floods of different magnitudes, among which the inundated areas of each reach of different magnitudes is as shown in Table 3. The populations affected by floods of different magnitudes is shown in Table 4.

Table 3 Statistical table of inundated areas of different magnitudes of floods in all reaches of river in flood plain areas
Units: km^2

Magnitudes (m^3/s)	Huayuankou-Dongbatou	Dongbatou-Taochengpu	Taochengpu-Lijin
6000	434.09	1206.79	578.27
8000	684.23	1276.11	645.28
10000	854.48	1280.75	696.28
12500	858.78	1282.70	705.72
16500	894.32	1282.78	718.07
22000	898.98	1283.29	731.28

Table 4 Statistical table of affected people in different magnitudes of floods in flood plain areas in reaches from Huayuankou-Lijin

Discharge	6000	8000	10000	12500	16500	22000
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(m ³ /s)						
Affected people (ten thousand people)	77.61	113	128.55	129.64	133	134.57

As can be seen from the above tables, the increase of inundation losses in the flood plain area with discharge from 4000 m³/s to 6000 m³/s is much greater than that from 6000 m³/s to 8000 m³/s. The losses of general overbank flood is not much different from that of large overbank flood, but the effect of large overbank flood on the silting floodplain and scouring channel is much greater. Of course, the inundation losses of the flood plain area is closely related to the flood discharging capacity of the main channel. In different periods, the flood discharging capacity of the main channel is different (bankfull discharge is different), and the inundation loss of the flood plain area and flooding discharge are different. That is, the boundary of 6000 or 8000m³/s also changes dynamically with the bankfull discharge.

4 Conclusions

“Less water and more sediment, inconsistent water-sediment relationship” are the crux of the Yellow River, which is also one of the main reasons for the formation of the "secondary suspended river". Floods of a certain magnitude play an important role in recovery of the flood carrying capacity of the lower reaches of the Yellow River, which has been proved by the practice of water and sediment regulation in the lower reaches of the Yellow River in recent years. However, the flood of the Yellow River rise and fall sharply, and flood as a long-term resource does not meet the conditions. How to effectively use the flood needs our careful consideration. Based on the current situation of the development of the "secondary suspended river" in the lower reaches of the Yellow River, we believe that the flood of the Yellow River must put graded management into practice. The analyses show that the graded management of flood regulation should follow the following principles: ① The middle and small flood with low sediment concentration should be properly intercepted, and the regulation of "water and sediment regulation" should be flexibly carried out, and the flood process less than 2600m³/s should be avoided in the regulation process. ② Considering the loss to the lower reaches caused by large overbank flood and general overbank flood and the shaping of river channel and the efficiency of sediment transport, the general overbank flood of 6000m³/s should be avoided as far as possible in the regulation process. ③ Must adhere to the regulation of “silted floodplain and scoured channel” for large floods. ④ For floods with high sediment concentration, due to their great damage to the lower reaches of the river, it should be through the joint regulation of reservoirs to prevent it from entering the lower reaches of the Yellow River directly. At the same time, a large number of sediment deposited in the reservoir, which is disadvantageous to the maintaining of the long-term effective storage capacity. So call on the vast number of colleagues to scale up the scientific research and

technology promotion of sediment treatment and resource utilization.

5 Discussion

The yellow river is a river with more sediment. Flood discharge and sediment transport are its most important functions. Flood processes of a certain frequency and magnitude play an important role in sediment transport. At the same time, the Yellow River not only shoulders the development of water along the Yellow River for industry and agriculture, but also shoulders the task of diverting water from other parts of the river basin. Water resources are very precious, which requires us to make more effective use of the water and sediment resources of the Yellow River, to provide more favorable conditions for river sediment transport, in order to improve the adverse situation of "secondary suspended river". The above analyses show that:

When the regulation discharge of non-overbank flood is between 2600 m³/s and bankfull discharge, it has a very positive effect on improving the form of "secondary suspended river" and maintaining the sediment transport in the river channel. This type of floods should be adopted more frequently in regulation.

When the flood discharge of general overbank flood is about 6000m³/s, not only the inundation loss of the flood plain area is caused, but also the sediment transport efficiency of the river is not improved greatly. Therefore, it is necessary to prevent such floods from entering the lower reaches as far as possible in regulation and control. The discharge can be reduced to less than the bankfull discharge through reservoir regulation. Or the peak can be filled appropriately by reservoir to adjust the flood to large overbank flood with low sediment concentration and large water volume, so as to play the role of silting floodplain and scouring channel and to play a beneficial role of improving the “secondary suspended river”. But such floods will surely cause certain economic losses to the flood plain area, and the government is urged to promulgate a compensation policy for flood plain areas of the lower reaches of the Yellow River as soon as possible.

For non-flooding or general flooding floods with high sediment concentration, deposition often occurs in the newly formed flood plain areas and the main channels, which will accelerate the development of the "secondary suspended river" situation rapidly. Such floods should be firmly prevented from entering the lower reaches of the river in regulation.

For large flooding floods with high sediment concentration, although a large amount of deposition will occur in the flood plain areas, which is beneficial to the improvement of channel shape, a large amount of deposition will also occur in the main channel at the same time, which will bring great harm to the overall flood control situation in the lower reaches of the Yellow River. Therefore, such floods in the regulation should also be avoided as far as possible. Of course, to prevent floods with high sediment concentration directly entering the lower reaches of the river, the floods will be intercepted in the reservoir, which is extremely unfavorable to the

reservoir deposition and long-term effective reservoir capacity maintenance. Therefore, it is very necessary to scale up the scientific research of reservoir sediment treatment and sediment resource utilization.

The natural conditions of the Yellow River determine the continuity of its sedimentation process, and determine that it must be an overground river. The crux of the "secondary suspended river" lies in the extremely inconsistent water and sediment conditions entering the lower reaches of the river. In terms of climatic conditions, the Yellow River basin spans semi-humid and semi-arid areas, most of which are semi-humid areas, and the interannual and seasonal variations of precipitation are obvious. In terms of geological conditions, most of the Yellow River basin belongs to the Loess Plateau. The basic geological process is to move mountains and fill the sea, to scour the Loess Plateau, and to shape the North China Plain. The function of the Yellow River is to transport the water and sediment resources in the basin to the North China Plain and the sea. For thousands of years, people have accumulated rich experience in harnessing the Yellow River. From "learning sands with converging flow" to "upper intercept and lower discharge", which has condensed the painstaking efforts of the people of generations in harnessing the Yellow River. Through various harnessing measures, they try to delay the continuous deposition of the river. From the past experience, only by improving the water and sediment conditions in the lower reaches of the river can we better improve the disadvantageous situation of the "secondary suspended river". Therefore, it is necessary to create a coordinated water and sediment conditions through water and sediment resource recovery and use natural forces to improve the adverse situation of "secondary suspended river".

Acknowledgments

This research was supported by National Key R&D Program of China (2018YFC0407400), and Supported by National Natural Science Foundation of China (51539004,51709123, 51479080).

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