



Changes of Channel Conditions of Zhangjiashou Waterway for the 2020 Hydrological Year and Maintenance Countermeasures

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Abstract. The 2020 hydrological year is featured with the high-water level and high flow period far exceeding the previous hydrological years. The sediment deposition in flood season shallowed and impeded the channel. Based on the hydrological analysis of 2020, the impact of the catastrophic flood year on the channel conditions in the upper shallow area of Nangang, and the reasons for the deterioration of the channel conditions in the shallow area are analyzed. Meanwhile, channel maintenance countermeasures, the necessity of emergency dredging, and the specific dredging scheme are proposed accordingly. The results show that: the upper shallow area of Nangang followed the law of silting in flood season and scouring in the dry season during a hydrological year. The channel conditions depend on the comparison between silting in the flood season and scouring after the flood season. In 2020, the flood lasted for a long time, so the water-falling period was relatively insufficient after flood season, and the upper shallow area was not sufficiently scoured, which resulted in navigation obstruction in the upper shallow area. Therefore, emergency dredging was necessary to be implemented on the channel, the dredging site was designed from #10 navigational mark to #9 navigational mark, the dredging bottom elevation was 4.2 m below the design water level, and the dredging width was 200 m. Considering the hysteresis of riverbed deformation, it is suggested to pay continuous attention to the water conditions and channel variation in the upper shallow area of Nangang in the future, and to formulate corresponding channel maintenance countermeasures.

Keywords: The 2020 hydrological year · Channel conditions · Countermeasures · Emergency dredging · Impact analysis

1 Introduction

In 2020, the Yangtze River Basin encountered continuous heavy rainfall, affected by which, this area experienced watershed flood which was second only to that in 1954 and 1998 since the founding of new China. The peak water level of Jianli to Datong

section in the middle and lower reaches ranked second to fifth in the measured records. Wherein, the peak water level of Jiujiang station and Hukou station ranked second in history, next to that in 1998. The tide level from Ma'anshan to the Zhenjiang section even exceeded the historical record (Feng 2020; Yao et al. 2020). The middle and lower reaches of the Yangtze River basin generally follow the law of “heavy water brought a heavy volume of sediment”. A high volume of sediment carried by the flood in 2020 was deposited in the channel, resulting in shallow channel conditions after the flood season, which influenced the channel maintenance and dredging, and navigation in waterways with good conditions previously was also impeded by shallowing of channels. Taking Zhangjiashou waterway as an example, this paper analyzed the impact of the flood in 2020 on the channel conditions of Zhangjiashou waterway and put forward countermeasures on channel maintenance and dredging.

2 Research Region and Data Source

Located at the junction of Hubei, Jiangxi, and Anhui provinces, Zhangjiashou waterway starts from Suojiang Building of Jiujiang City and ends at Bali River estuary, with a total length of about 30 km, belonging to a slightly curved double branch river. Zhangjiashou divides the river into Nangang and Beigang, which converge at Bali at the end of the Zhangjiashou, as shown in Fig. 1. Zhangjiashou waterway is one of the key navigation obstruction shoal waterways in the lower reaches of the Yangtze River. At present, the channel maintenance scale is 5.0 m × 200 m × 1050 m (water depth × navigation width × bending radius).

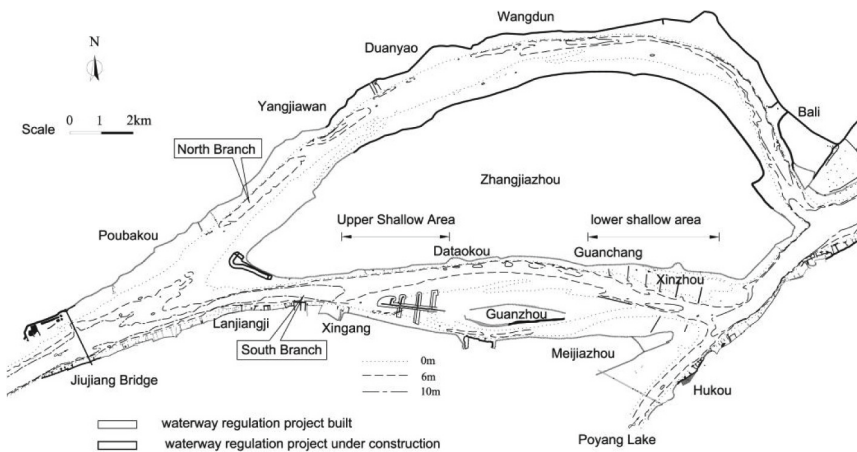


Fig. 1. River Regime of Zhangjiashou waterway (March 2018)

The channel of Nangang (also named South Branch) is smooth and straight. As the main channel of the Yangtze River, Nangang Channel has silting bodies such as Guanzhou and Xinzhou, with Poyang Lake flowing in from the right bank in the lower

section. There are two shallow areas in Nangang. Wherein, the upper shallow area is located in the widening section opposite to the new port. Due to the retreat of low shallow in front of Guanzhou, the thalweg swing increased, and the cross-section of the river in the shallow area was widened and shallowed (Xue et al. 2008), and the channel conditions deteriorated. In order to improve the channel conditions, Changjiang Waterway Bureau began to regulate the upper shallow area of Nangang of Zhangjiazhou in January 2009. The project passed the completion acceptance in February 2012. The regulation was successful, achieving the goal of $4.5 \text{ m} \times 200 \text{ m} \times 1050 \text{ m}$ (Liu 2015; Li et al. 2009); The lower shallow area was in the transition section between Guanchang and Poyang Lake estuary. The widening river surface and the diffusing water flow in this area resulted in serious navigation obstruction. So, this area was the key to the smooth flow of the Zhangjiazhou waterway. Changjiang Waterway Bureau began to regulate the lower shallow area of Nangang in January 2001 (Huang 2002). In March 2006, the project passed the completion acceptance. After the regulation, the waterway conditions were significantly improved, and the channel condition was good (Li et al. 2010). The channel scale exceeded the goal of $4.5 \text{ m} \times 200 \text{ m} \times 1050 \text{ m}$.

The channel of Beigang (also named North Branch) channel is long, narrow, and bending. Before 1989, it was used as the main channel in dry seasons. However, there were many shallow areas, and revetment riprap rocks extending into the river along the banks of Chengjiaying to Bali River, so the disordered flow pattern, the bending flow as well as the low maintenance scale make it difficult to maintain the waterway. After 1989, with the increase of the diversion ratio of Nangang, the channel maintenance department mainly maintained Nangang and stopped using Beigang as the main channel of the Yangtze River (Wang 1989).

In order to open the 6-m-deep channel in Wuhan to Anqing section, the 6 m deep channel regulation project is being carried out for Zhangjiazhou waterway (Chen et al. 2019; Deng 2019), mainly to build a new bottom protection belt at the entrance of Guanzhoujia, a new beach protection belt with hook head in the upper section of the left side of Guanzhou; and repairing the #1 comb dam. See Fig. 1 and Table 1.

Table 1. Regulation works completed and under-construction in Zhangjiazhou waterway

	Project name	Project contents	Construction period	Waterway construction scale
1	Regulation works of the upper shallow channel of Nangang	Constructing a comb dam at the front of Guanzhou and a bottom protection belt at Guanzhoujia inlet	2009 to 2013	$4.5 \text{ m} \times 200 \text{ m} \times 1050 \text{ m}$
2	Regulation works of the lower shallow channel of Nangang	Constructing 6 spur dikes on the left bank, and bank slope protection works between L3-L4# spur dikes; constructing 2 beach protection belts on Meijiashou of the right bank; constructing revetment on the point bar of the end of Guanzhou	2002 to 2007	$4.5 \text{ m} \times 200 \text{ m} \times 1050 \text{ m}$
3	6 m deep waterway regulation project in Wuhan to Anqing section	Constructing a bottom protection belt at Guanzhoujia inlet; a new beach protection belt with hook head in the upper section of the left side of Guanzhou Continent; and repairing #1 comb dam	2018 to now	$6.0 \text{ m} \times 200 \text{ m} \times 1050 \text{ m}$

The data on which this paper is based mainly include three aspects, namely, river topography, local topography of channel, and flow and sediment data of hydrological stations. The topography data source from the survey data of the Changjiang Waterway Survey Center and Changjiang Jiujiang Channel Section; the flow and sediment data of hydrological stations are based on the flow and water level published by the Hydrographic Office of Changjiang Water Resources Commission.

3 Water Regime Analysis for 2020

There were nearly 20 large-scale heavy rainfall processes in southern China since the flood season of 2020. From June 1 to July 9, the cumulative precipitations of 85 stations in Hubei, Anhui, Jiangsu, Guizhou, Zhejiang, Chongqing, Hunan, Jiangxi, Shanghai, Guangxi, Sichuan, etc. have exceeded half of the average annual precipitations. The average precipitation in the Yangtze River Basin reached 369.9 mm, 54.8 mm more than the same period in 1998, and hit the highest in the same period since 1961. The rainstorm increased the flood control pressure in the Yangtze River Basin. The water level of Hankou station on the Yangtze River reached 28.77 m (frozen by Wu Song), ranking 4th since 1865, second only to 1954, 1998, and 1999.

From the flow process of Jiujiang Hydrometric Station in the upper reaches of the studied river section in 2020, the flow from January to April was basically stable in recent years and dropped sharply in late April; the flow was smaller than that in previous years from April to the end of May, and began to rise in early June, reaching the peak of 67,400 m³/s on July 9; the flow remained above 60,000 m³/s by the end of July; as of December 31, there were 103 days with a flow above 40,000 m³/s, 53 days above 50,000 m³/s days, and 22 days above 60,000 m³/s. The high-flow period was much longer than that in previous years. See Fig. 2.

Therefore, the water regime in 2020 was featured with a high-water level and high flow period far exceeding that in previous years.

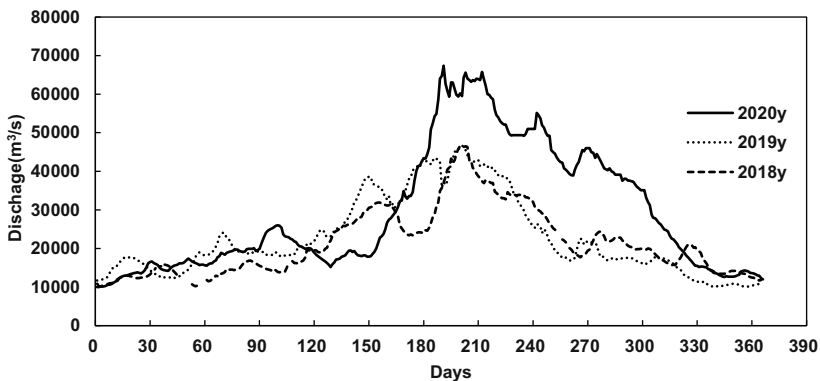


Fig. 2. Daily average flow process of Jiujiang hydrometric station in recent three years

4 Recent Riverbed Evolution

Zhangjiazhou waterway has been distributed into two branches for many years, and its river regime is relatively stable. Beigang is a slightly bending branch, which generally conforms to the general law of bend evolution, that is, silting on the convex bank and scouring on the concave bank. As bank protection works were imposed on the bank collapse section of the left bank of Beigang, the river coastline has been well controlled and was generally stable. The recent evolution is mainly manifested in the longitudinal scouring and silting deformation of the riverbed, the increasing and return of shoals due to siltation and scouring, and the reciprocating of the longitudinal change of thalweg. The plane shape of Nangang is relatively straight, but there is a secondary bifurcation in the middle and lower sections of the waterway, with Guangzhou in the upper section and Xinzhou in the lower section. Poyang Lake flows in from the right bank in the lower section. It generally conforms to the evolution law of a straight channel: the point bars on the sides of the river change alternately at the place where the waterway widens, and the mainstream swings indefinitely, which tends to form transition shoals.

After the 1990s, Nangang and the Beigang changed in an opposite way, with the diversion ratio of Nangang increasing gradually and that of Beigang reducing. With the increase of the diversion ratio of Nangang, the deep pool close to the right edge of Zhangjiazhou also began to develop scouring depth. At the same time, Guanzhou high beach gradually formed, and a relatively obvious branch was formed at Guangzhoujia. There is little change in the upper section of Nangang. In recent years, the thalweg in the upper shallow area has swung to the right, and the front of Guanzhou has retreated due to scouring; the bank lines of the lower section of Nangang is stable, and the evolution over the years is mainly manifested in the swing of thalweg and the growth and decline of upper- and lower-point bars.

From 2010 to 2016, the inlet channels of Nangang and Beigang of Zhangjiazhou were scoured and the low beach at the front of Zhangjiazhou was silted up. The river bed in Beigang was subject to both scouring and silting, mainly silting; Nangang showed both scouring and silting trends, with the low beach on the left edge and the tail of Guanzhou showing a scouring trend, and the inner part of Guanzhou showing slightly scouring and silting; From 2010 to 2016, back siltation with high volume was observed in the scouring area at the right edge of the front of Zhangjiazhou. The siltation area at the front of the regulation project of the lower shallow area moved downward. The low beach at the left edge of Guanzhou and the end showed a scouring trend. The deep pool gradually closed to the lower section of the left edge of Guanzhou, and there was no obvious scouring in Guanzhoujia.

From 2016 to 2019, the river channel generally showed a scouring trend. There was relatively obvious scouring in the inlet section of Beigang and the low beach area at the front of Zhangjiazhou, and the low beach at the front of Guanzhou and its left and right edges were dominated by scouring.

From July 2019 to August 2020, affected by the flood in 2020, the inlet section of Nangang was mainly formed by siltation, with a thickness of 1 to 3 m; the siltation thickness in the middle section was about 1 to 2 m; the region near L2 # and L3 # spur dikes in the lower section was subject to scouring of some extent, with an amplitude of

about 2m. The scouring amplitude at the front of R1 # and R2 # beach protection belts was about 1m. The riverbed downstream of the confluence section of the lake mouth was generally silted up, with a maximum siltation thickness of about 5 m (Fig. 3).

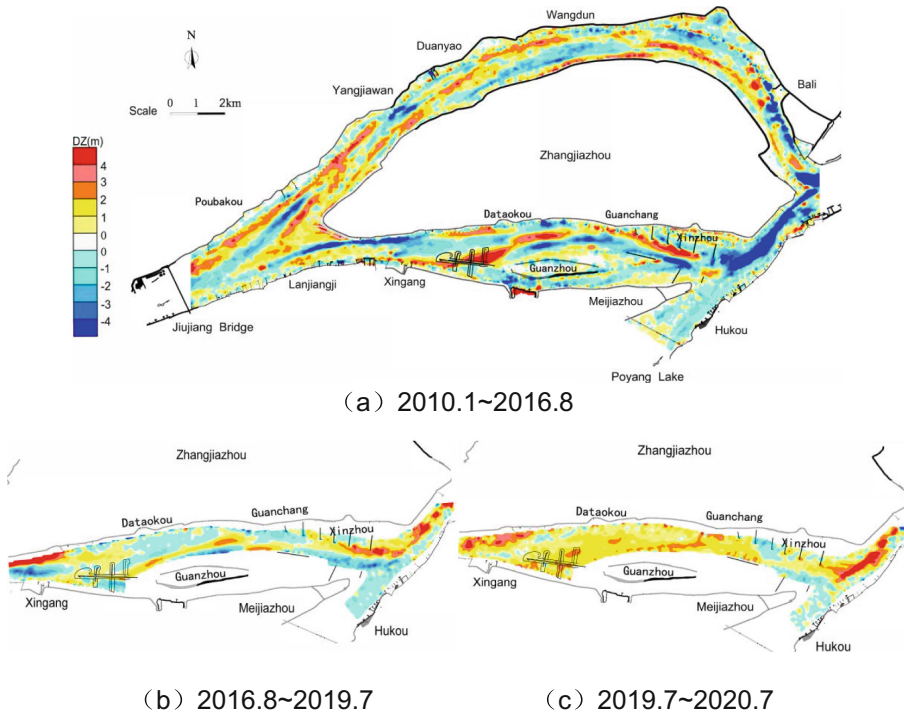


Fig. 3. Recent channel scouring and silting of Zhangjiazhou waterway

5 Impact of Catastrophic Flood Year on Channel Conditions

5.1 Conditions of Shallow Channel

Comparing the channel conditions in the upper shallow area over the years, it was found that: in March 2013, the 5 m isobath at the narrowest part of the upper area of Zhangjiazhou South waterway was 310 m wide; in May 2018, the 5 m channel of Zhangjiazhou South waterway was penetrated with a width of more than 400 m; in April 2020, the 5 m isobath was penetrated with a minimum width of 400 m. By July 2020, due to a large volume of sediment deposition during the flood period, the 5 m isobath in the upper shallow area was disconnected, with a disconnection length of 370 m.

The large flow in the flood season in 2020 caused the flood plain of the main flow, the flow contraction capacity at the front of Guanzhou was weakened, the waterway in the upper shallow area of Zhangjiazhou was widened, and the sediment was deposited. In addition, the main flow transited from the right bank to the left bank in this section.

The flood in 2020 led to the staggering of the upper and lower deep grooves, and a shallow obstruction was formed in the middle.

In Comparison with the local mapping at the end of the water return period in 2019 and 2020 (Fig. 4), the 4 m isobath in November 2020 silted up about 330 m into the channel, compared with November 2019. The 4 m isobath in the channel was penetrated with a minimum width of only 25 m, while the 3 m isobath was penetrated with a minimum width of 215 m. The thalweg swung from the original north side to the middle position. The channel presented an “S” shape, which was difficult for the layout of navigation marks and navigation of vessels in the upper and lower area.

Since November 2020, according to the decline of water level and the change of scouring and silting of the channel, Jiujiang Channel Section has added conical side shore beacons for the upper shallow area of Nangang of Zhangjiazhou, Zhangnan 9-1 red float, and adjusted 25 navigation beacons. However, with the further decline of the water level, the channel cannot be effectively scoured, and dredging shall be implemented to meet the minimum maintenance scale of the channel.

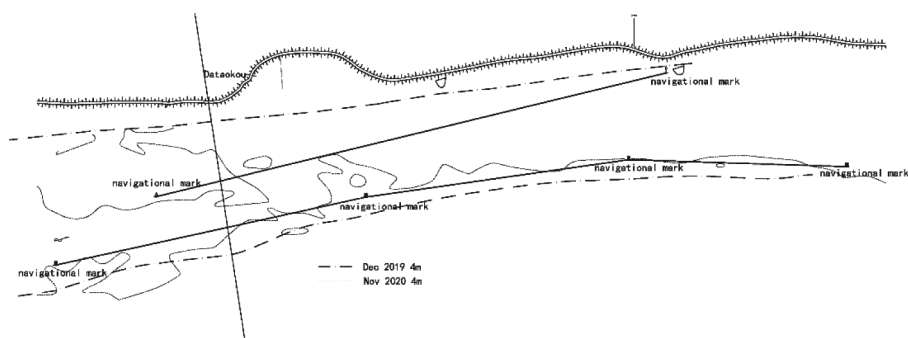


Fig. 4. Comparison of Isobaths between November 2019 and November 2020 in the upper shallow area of Nangang of Zhangjiazhou

5.2 Causes to Change of Channel in Shallow Area

Combined with the riverbed changes of Zhangjiazhou waterway over the years, the upper shallow area of Nangang followed the evolution law of “siltation in flood season and scouring in the dry season” in the year. During the flood season, the point bar was silted up and the navigation channel was narrowed. With the recession of water after the flood season, the flow returned to the channel and scoured the channel, and the channel conditions were improved. Influenced by the flood in 2020, as in previous years, Nangang was still characterized by “siltation in flood season and scouring in the dry season” (Fig. 5). In the dry season after the flood period in 2019 to April 2020, the inlet section and middle section of Nangang were mainly subject to scouring; in the flood season of 2020, due to the large flow and long flood period, the siltation range and amplitude in Nangang far exceeded those in previous years, wherein, the siltation amplitude in the inlet section exceeded 3 m locally.

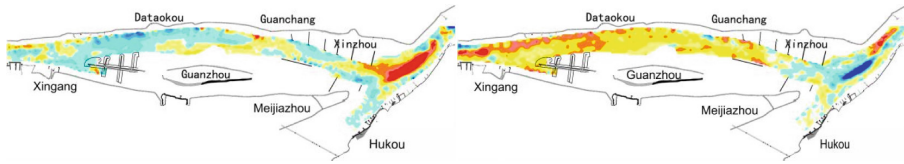


Fig. 5. Scouring and silting of Zhangjiashou South Waterway in the year

According to the measured data from Jiujiang Channel Section, the water depth of shoal (below the navigational datum) in the upper shallow area of Zhangjiashou Nangang changed with the inflow process of the year. When the water level was low, the shoal was scoured and the water depth increased, and when the water level was high, the shoal was silted up and the water depth decreased. Therefore, by comparing the days of high-water level period (above the flood land line water level) and days of backwater scouring in the years from 2017 to 2020 (Table 2), the relationship between channel conditions and inflow process in that year can be reflected. Research (Tang et al. 2012) showed that when the water level of Zhangjiashou waterway retreated to about 6 m of the navigational datum, the shallow would be scoured. Therefore, the water level 6 m above the navigational datum was taken as the critical water level, the days that the shallow was lower than the critical water level shall be taken as the days of backwater scouring. When the ratio of the days of backwater scouring and the days of high water level was large, the scouring time would be relatively long, and the channel conditions were generally good in that year. For example, from 2017 to 2019, the ratio was between 0.39 and 0.87, so dredging maintenance was not required; when the ratio of the days of backwater scouring and the days of the high-water level was small, the scouring time will be relatively short. For example, in 2020, the days of backwater scouring after the flood season was only 0.26 of the days of high water level, the sediment deposited in the shoal couldn't be scoured sufficiently, resulting in insufficient channel width, and channel conditions shall be maintained through dredging (Fig. 6).

Table 2. Statistics of days of high-water level and days of backwater scouring from 2017 to 2020

Year	Days of high water level	Days of recession	Ratio	Channel conditions
2017	109	42	0.39	Good, no dredging
2018	84	42	0.50	Good, no dredging
2019	101	88	0.87	Good, no dredging
2020	150	39	0.26	Insufficient navigation width

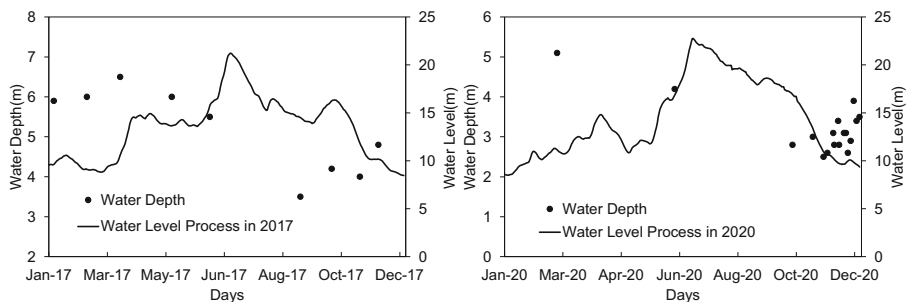


Fig. 6. Water depth and water level process of Shoal Ridge in the upper shallow area of Zhangjiazhou south waterway

6 Channel Maintenance Countermeasures

6.1 Maintenance Countermeasures for 2020

(1) Necessity of dredging

Influenced by the flood in 2020, the channel in the upper shallow area of Nangang was greatly silted up, with the shallowest point of only 2.7 m below the navigational datum. On December 2, the water level of Jiujiang station was only 3.37 m above the navigational datum, and the water depth in the channel was only 6.07 m. Considering that the rainfall would decrease significantly in December, it was very likely that the water level would fall further and rapidly. If the water level fell further, the water depth would not meet the channel maintenance scale (5 m \times 200 m, water depth \times width) in the dry season. In addition, the shallow area of Zhangjiazhou was large, so maintenance volume and pressure were great. Therefore, according to the Measures for the Management of Maintenance and Dredging of the Yangtze River Trunk Line (Trial Implementation) and the Provisions on the Management of Channel Maintenance, when the channel scale was sharply reduced to near or even lower than the planned channel scale due to external conditions, emergency dredging and maintenance should be carried out immediately to ensure smooth navigation in the dry season.

(2) Emergency dredging scheme

Dredging depth: According to the statistics of water level in the dry season of Jiujiang Station in recent years, the lowest water level was 0.96 m above the navigational datum. To ensure the 5 m \times 200 m maintenance scale of this waterway, the dredging bottom elevation was 4.24 m below the navigation foundation surface (considering the depth reserved for sedimentation of 0.2 m), and the design slope was 1:5.

Dredging width: According to the actual needs of channel maintenance, the dredging width shall not exceed 200 m.

Dredging site: The dredging site is located between Zhangnan #10 red float and Zhangnan #9 red float in the upper shallow area of Zhangjiazhou. The specific direction

of the dredging site can be adjusted dynamically according to the dynamic changes of the shallow area during the dredging process, which shall be jointly determined by the maintenance unit, design unit, and the construction company according to the dynamic mapping during the construction.

Dredging volume: According to the mapping analysis on November 24, 2020, the dredging volume in the channel was expected to reach 290,000 m³ in 2020.

Through the implementation of the above emergency dredging project, the minimum maintenance scale (5 m × 200 m, water depth × width) of Zhangjiazhou waterway in 2020 was guaranteed.

6.2 Future Concerns on Waterway Maintenance

Due to the impact of the catastrophic flood year in 2020, the siltation amplitude and range of the upper shallow area of the Nangang of Zhangjiazhou waterway were comparatively larger, which has an adverse impact on the channel pattern. At the end of the flood season, emergency dredging was carried out on some navigation channels to meet the minimum maintenance scale of the channel. Since the flow conditions change rapidly, a long time is required for the riverbed scouring and silting to adapt to the flow conditions, and the riverbed deformation has a certain lag in time, dredging may still be necessary to maintain channel conditions in the coming years. In dredging, attention should be paid to the action time of the flood in flood season and the effective scouring time in the recession period to reasonably determine the dredging scheme (intervention time, site, and dredging intensity) to meet the requirements of a smooth channel.

7 Conclusions

- (1) The upper shallow area of Nangang of Zhangjiazhou follows the law of depositing in flood season and scouring in the dry season of the year. The channel conditions depend on the comparison between deposition in the flood season and backwater scouring after the flood season. Normally, the channels conditions were good if the backwater scouring period was long. In 2020, impacted by the special hydrologic year, the flood lasted for a long time, so the return time was relatively insufficient after flood season, and the upper shallow area was not sufficiently scoured, resulting in insufficient water depth and channel width in the shallow area, and hence larger navigation obstruction range.
- (2) According to the channel mapping in November 2020 and the changing trend of the water level of Jiujiang station in the dry season, the necessity of emergency dredging was explained, and the dredging design parameters were put forward. Wherein, the dredging site was from Zhangnan #10 red float to Zhangnan #9 red float, the dredging elevation was 4.2 m below the navigational datum, and the dredging width was 200 m.
- (3) In light of the lag in time of riverbed deformation, it is suggested to pay continuous attention to the channel changes in the upper shallow area of Nangang of Zhangjiazhou waterway and the water regime in the year to formulate corresponding channel maintenance countermeasures.

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