Research and exploration on flood control and management schemes in the Songli area of Dongting Lake

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Abstract. The Songli area of Dongting Lake is an important link between the Yangtze River and Dongting Lake, located in the two provinces of Hubei province and Hunan province in China. The water system conditions in the Songli area are extremely complex. The Songzi River, which passes through the area, connects with the tail end of the Li River, supporting each other, resulting in severe floods in the region throughout history. Since the completion of the Three Gorges Dam, there have been significant changes in the erosion and sedimentation of the riverbed in the Songli area. It is necessary to use newer terrain data to reproduce historical floods and study the flood control situation in the Songli area under the changed terrain conditions. Therefore, this article uses a hydrodynamic model to study the current flood control situation in the Songli area after the completion of the Three Gorges project, and proposes three possible flood control and control schemes. The analysis results show that compared with the construction of Yichongqiao Reservoir and the use of flood detention areas, the Songzi Gate has a better effect on flood control in the Songli area. The research results of this article can serve as a reference for subsequent comprehensive governance projects in the Songli area.

Keywords: Songli area, Dongting lake, Flood control and management.

1 Introduction

Dongting Lake is located in the middle reaches of the Yangtze River, which is the second largest freshwater lake in China. The Songli area of Dongting lake is the link between Dongting Lake and the Yangtze River. There are a total of 41 embankments of various sizes in the area, with a total population of about 2.56 million. The total area of Songli area is 1864 km^2, including 2.35 million mu of arable land, which is an important grain production base in China.

The Songzi River is the river with the largest diversion volume among the main rivers connecting the Yangtze River and Dongting Lake. It flows south through the plain river network and connects with the tail end of the Li River, and then flows into

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the west Dongting Lake. Li River is the famous rainstorm area of the Yangtze River. The area of west Dongting Lake, where the Songzi River system and the tail end of the Li River are located, has been plagued by severe flood disasters due to the complex sources of floods, severe siltation of river (flood) channels, and the interconnection between the Songzi River and the tail end of the Li River.

Serious flood disasters occurred in years such as 1935, 1954, 1980, 1983, 1991, 1998, and 2003. In the 1954 flood, 356 embankments collapsed in the Dongting Lake area, Hubei Province has 21.27 million mu of flooded farmland, with 9.26 million disaster victims, and Hunan Province has 5.89 million mu of flooded farmland, with 2.57 million disaster victims. The Songli area between Hubei and Hunan Province has also been severely affected by flood disasters.

In the past 20 years, the hydrological, sediment, and geomorphological processes of global lakes have undergone profound changes due to global climate change and human activities [1][2][3].

Before and after the completion of the Three Gorges Project (TGP), there were significant changes in the erosion and sedimentation of the riverbed in the Songli area and Dongting Lake areas [4][5][6]. The evolution of the Yangtze River's main stream was influenced by the TGP, which further led to the drying up of Dongting Lake and a decrease in the amount of water entering the lake [7]. It is necessary to use newer terrain data to reproduce historical floods and study the flood situation in the Songli area under the changed terrain conditions.

2 Current flood control situation in Songli area

2.1 Boundary conditions

Using data to construct a one-dimensional (2019-2020 terrain) and two-dimensional (2011-2012 terrain) coupled hydrodynamic mathematical model for Yichang Hankou (including Dongting Lake area, Four Waters Tail, etc.), analyze the flood level and excess flood volume of the TGP and upstream reservoir groups under different typical annual flood conditions, and evaluate the flood situation in the Songli area under the existing flood control engineering system conditions. The hydrodynamic model used in this article has been widely used in multiple flood control consultations and basin planning in the Yangtze River-Dongting Lake basin, and has the conditions and capabilities to study the flood control capacity analysis of the Songli areas in the middle reaches of the Yangtze River.

According to the Comprehensive Plan for the Li River Basin, a total of 200 million cubic meters of Jiangpinghe Reservoir, 740 million cubic meters of Jiangya Reservoir, and 780 million cubic meters of Zaoshi Reservoir have been built on the tributary of Li River. The main stream Yichongqiao Reservoir (not yet completed) is 160 million cubic meters. The evaluation of the current flood situation adopts the operation calculation of three completed reservoirs.

The TGP is built at the end of the upper reaches of the Yangtze River, with a controlled basin area of 1 million km^2. The flood control storage capacity of TGP is 22.15 billion cubic meters. According to the 2023 Joint Operation Plan for Water Engineering

in the Changjiang River Basin approved by the Ministry of Water Resources, in the event of floods in the Yangtze River section that occur once in a hundred years or less, under the current river and lake relationship conditions, the flow rate in Zhicheng can be controlled to not exceed 56700m^3/s, ensuring that the water level in Shashi under 44.50m; When encountering floods that occur once every 1000 years or the same magnitude in 1870, the flow rate in Zhicheng can be restricted to not exceed 80000m^3/s. In conjunction with the use of flood storage and detention areas in the Jingjiang area, the water level in Shashi can be limited to not exceed 45.0m. Consider scheduling calculations for 25 reservoirs upstream of the TGP that have a major flood control effect.

2.2 Analysis of Current Flood Control Capacity in Songli Region

The hydrodynamic mathematical model based on MIKE and self-made program has been used to numerate the excess flood volume in the Songli area under the flood conditions mentioned above, the safe discharge volume of 14000m^3/s for Anxiang+Shiguishan at the corresponding Nanzui guaranteed water level is also taken as the standard. The amount of water exceeding this flow rate is called the excess flood volume, and the results are listed in the Table 1.

Table 1. The excess flood volume in the Songli area (Unit:10^8m^3)

Ranking	Years	Before the operation of the TGP and Li River reservoirs	After the operation of the TGP and Li River reservoirs	The highest water level in the TGP (m)
1	1935	42.5	8.51	158.0
2	1954	8.73	0.87	159.6
3	2003	6	2.74	148.4
4	1998	10.13	3.37	155.0
5	1983	3.3	0	148.2
6	1991	3.1	0	145.8
7	1996	0.66	0	147.9

As shown in the Table 1, after the operation of the TGP and reservoirs in the Li River, there were still 87 to 337 million cubic meters of excess flood to be arranged in the Songli area due to typical annual floods in 1954, 1998, and 2003. The excess flood in 1935 was 851 million cubic meters. The flood situation in the Songli area was still severe.

3 Flood Control and Governance Plans

In order to achieve the planned flood control standards in the Songli area, according to the layout and deployment of the upper-level planning flood control system, an analysis of the flood control effects of the main engineering measures arranged in the plan is

conducted, and a flood control governance plan for the Songli area is proposed. Specifically, it includes plans such as the construction of flood control reservoirs in the Li River Basin, the use of flood storage and detention areas in the Songli area, and the construction of gates at Songzikou.

Considering the flood control capacity of Yichongqiao Reservoir, calculate the flood control effect of the reservoir construction on the Songli area. At present, the cascade development plan for the Li River mainly controls the flood control capacity of reservoirs: Jiangping River (flood control capacity of 200 million m^3), Jiangya (740 million m^3), and Zaoshi (780 million m^3). The Yichongqiao Reservoir is currently undergoing research work and is a controlled flood control reservoir for the Li River. The watershed area above the dam site is 5829 km^2. After the completion of Yichongqiao Reservoir, it was jointly dispatched with Jiangya and Zao City to achieve a flood control standard of once every 20 years in the Songli area. The calculation results show that after the construction of Yichongqiao Reservoir, except for 1954, the excess flood volume in Songli area decreased by 115-120 million cubic meters. In 1954, the inflow of water from the Li River was not significant, while the inflow of water from the Songzi River was large. Therefore, the construction of the Yichongqiao Reservoir did not have a significant effect on reducing the excess flood volume in the Songli area. After considering the construction of Yichongqiao Reservoir, the excess flood volume for four typical years is 84 to 731 million cubic meters; The excess flood volume in the Songli area during the 1954 and 1998 floods alone was 829 million cubic meters and 283 million cubic meters, respectively. Therefore, the construction of the Yichongqiao Reservoir cannot completely tackle the flood control problem in the Songli area.

The Linan Embankment and Xiguan Embankment, located at the tail end of the Li River, are key embankments. It is necessary to use the Linan Embankment and Xiguan Embankment to divert floodwater to ensure the safety of the tail end of the Li River. After using the Linan embankment and Xiguan embankment, the excess flood volume of Anxiang+Shiguishan in typical years of 1935, 1998, and 2003 decreased by 120-240 million cubic meters, but there were still 153-611 million cubic meters of excess flood volume that could not be solved. Due to the typical mountainous flood in the Li River, which has the characteristics of steep rise and fall, and small peak height, it is still difficult to solve the excess flood in the Songli area. The use of flood storage and detention areas for flood diversion in the Songli area may not affect the flood control of the main stream, but the loss of flood diversion is significant, and it also has a significant impact on the economic and livelihood aspects of the flood storage and detention areas. Therefore, the use of engineering measures such as flood storage and detention zones to ensure safety in the Songli area is not suitable as a preferred solution.

After the joint operation of the TGP and the Reservoir in Li River, the typical flood process is achieved through the staggered operation of the Songzi Gate, and the effect is as follows. As shown in the Table 2, in the typical annual floods of 1935, 1954, 1998, and 2003, after the peak shifting of the Songli River, the water levels in Anxiang and Shiguishan can be basically controlled at the guaranteed water level, and the effect of the peak shifting of the Songli River is obvious. With the use of Songzi Gate, the amount of water retained through the TGP is greatly reduced. Compared with the situation where no gates were built, the storage capacity of the TGP decreased to 1/9-1/6

of its capacity, and the reservoir water level only increased by 0.50-0.73m, leaving great room for ensuring safety in the basin. In 1935 and 1954, the water level of the TGP was slightly higher than 158m, exceeding the highest water level specified in the Three Gorges regulation for compensation scheduling in the Chenglingji area. However, actual scheduling has room for scheduling in the Songli area, especially in recent years. In order to reduce the use of flood storage and detention areas, the water level for supplementary scheduling in the Chenglingji area is often higher than 158m. In 1998 and 2003, the water level of the TGP was both below 155m. It can be considered that staggered scheduling has a relatively small impact on main stream, and the plan is basically feasible. Since 1949, considering the flood control effect of the TGP and Li River Basin reservoirs on the Songli area, and encountering three typical floods such as 1954, 1998, and 2003, it is still necessary to consider the staggered operation of the Songzi Gate to ensure the safety of the Songli area, which is equivalent to the average operation of the Songzi Gate every 20-30 years.

Table 2. The Three Gorges Reservoir cooperates with the Songzi Gate for staggered regulation of storage capacity and changes in reservoir water level

Years	Scheduling demand start and end time	Three Gorges Reservoir water level(m)	Need to increase flood detention capacity (billion m^3)	Scheduling space
1935	5-7, July	158.04	18.16	No
1954	29-30, July	158.30	3.81	No
1998	23-24, July	154.88	4.77	Staggered scheduling
2003	9-11, July	148.44	6.92	Staggered scheduling

After calculation, it is found that relying solely on the Yichongqiao Reservoir, or using the Songli area flood storage and detention area are difficult to completely solve the excess flood volume in the Songli area. However, as one of the key engineering measures for flood control construction in the Songli area, the staggered scheduling of the flood-gates at Songzikou plays an important role in reducing flood water levels and alleviating flood control pressure in the Songli area.

4 Conclusions

This article establishes a coupled hydrodynamic model based on one-dimensional and two-dimensional on a new terrain, analyzes the current situation of flood control in the Songli area, and conducts an analysis of the effectiveness of possible flood control measures.

The analysis results indicate that under the current operation of the TGP and upstream reservoirs, there is still a risk of flood disasters in the Songli area. This article analyzes three possible solutions separately. Research has shown that using the Yichongqiao Reservoir and flood storage and detention areas is difficult to solve flood

disasters in the Songliao region. The use of Songzi Gate staggered scheduling can effectively reduce the flood level in Songli area and alleviate the flood control pressure in Songli area. Therefore, it is necessary to construct the Songzi Gate to improve the flood control engineering system in the Songli area, meet the planned flood control standards, and provide response measures for the Songli area to cope with the 1935 flood and avoid catastrophic disasters.

The research results of this article can serve as a reference for subsequent com-prehensive governance projects in the Songli area of Dongting Lake. But, in order to achieve the flood control standard of once every 50 years in the Songli area, the overall flood control layout of the Songli area still need to increase the embankment of the Jinshi City. This article argues that the staggered scheduling considered by Songzi Gate is based on hydrological predictions made 7 days in advance, which is difficult to achieve in reality. The following research will conduct sensitivity analysis based on different hydrological prediction days to further demonstrate the feasibility of Songzi Gate staggered scheduling.

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