# Retrospective Analysis of Flood Operations for 2020 Floods in the Yangtze River Basin Under Water Engineering Projects Conditions in 2023

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**Abstract.** Based on the current conditions of the joint operation of water projects in the Yangtze River Basin (as of 2023), this study aims to conduct retrospective operations using 2020 Yangtze River Basin flood events. Operations are regulated by “2023 Joint Operation Plan for Water Projects in the Yangtze River Basin”. The outcomes of operations are analyzed to demonstrate the effectiveness of current water engineering conditions when tacking with 2020 floods, which provide valuable references and insights for future flood operation and management.

**Keywords:** 2020 Floods in the Yangtze River; Basin-wide Flood; Joint Operation of Water Engineering Projects; Flood Operation Procedures.

## 1. Introduction

The reservoir operation procedures refer to the technical guideline developed to ensure the safety of flood control and maximize the comprehensive benefits of the reservoir. These regulations serve as a guide for reservoir operations[1]. At present, the authorities of main control reservoirs in the Yangtze River Basin (YRB) are required to report their annual operation and utilization plans to the Yangtze River Water Conservancy Commission (YRWCC) before the flood season each year. All plans need to be officially approved by YRWCC before implementation. Since 2012, YRWCC has organized and implemented a joint operation plan for the water engineering projects in the YRB. The number of reservoirs included in joint operation has expanded yearly. Compared to 2020, 12 more major reservoirs has been added to the joint operation plan[2], such as Lianghekou on the Yalong River and Baihetan on the Jinsha River, increasing the total operation capacity by 28.5 billion m3 and flood control capacity by 10.8 billion m3. This has significantly enhanced the flood control capacity of the basin.

In 2020, the Yangtze River experienced basin-wide flood events, which is the third largest since the establishment of the People’s Republic of China, only after the floods of 1954 and 1998[3]. Through implementation of joint operation, approximately 49 billion m3 of floodwater were retained during the flood season, yielding substantial flood control benefits. In the practice of operation, YRWCC made several amendments of initial operation plan based on the evolution of rainstorm and hydrological conditions. Such practice broke through the limits of pre-approved operation procedures, however, it achieved effective and posotive outcomes. Such practice reduced the peak water level of the upper and middle reaches by 2.9~3.3m and the middle and lower reaches by 0.3~3.6m, respectively, avoiding the water level exceeding the guaranteed levels in key sections, and shortening the flood warning period by 8~22 days in several stations downstream[4].

The climate, geographical, and geomorphological conditions of the basin determine that there is a probability of historical heavy rainstorms and floods recurring. The impact of underlying surface conditions and human activities, such as land use changes and the construction and operation of water conservancy projects, can also alter runoff patterns. As a result, the development process of historical floods will also undergo significant changes when regulated by current engineering projects. Following the operation procedures, this paper simulates the operation of the Yangtze River floods in 2020 based on the conditions of water engineering project sin 2023 and then analyze the operation outcomes, which provides support for further understanding the flood control capacity of the current engineering conditions in the Yangtze River Basin and for managing basin-wide major floods.

## 2. Data and Methods

### 2.1 Overview of the Current Engineering Projects

As of 2023, 125 projects are included in the joint operation in YRB, which comprises major controlling reservoirs (e.g. Three Gorges, Wudongde, Baihetan, Xiluodu, and Xiangjiaba reservoirs); retention and storage areas (e.g. Jingjiang flood diversion area); important drainage pumping stations (e.g. Xintankou pumping station); major water gates (e.g. Hanheji sluice); and large water diversion projects (e.g. the first phase of the South-to-North Water Transfer Project's eastern and central routes). Specifically:

Controlling reservoirs: 53 reservoirs with a total operation storage capacity of 1,169 billion m³ and a total flood control capacity of 706 billion m³.

Retention areas: 46 areas with a total retention capacity of 583.68 billion m³.

Drainage pumping stations: 11 stations with a total drainage capacity of approximately 1,880 m³/s.

Water gates: 9 gates with a total designed discharge capacity of about 8,078 m³/s.

Water diversion projects: 6 projects with an annual design water diversion capacity of 284 billion m³.

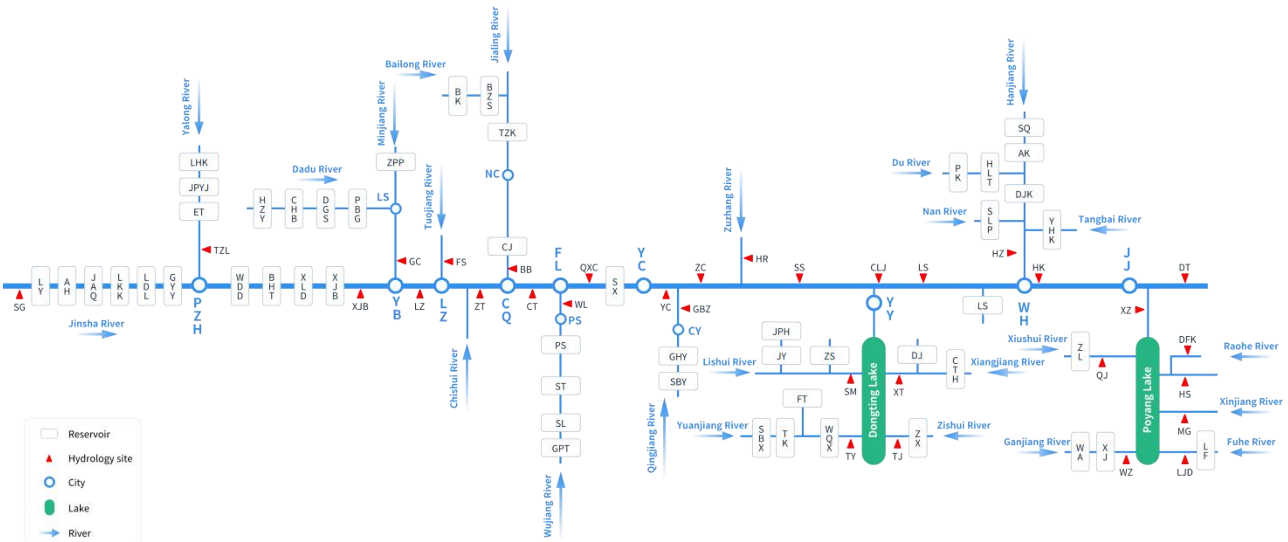
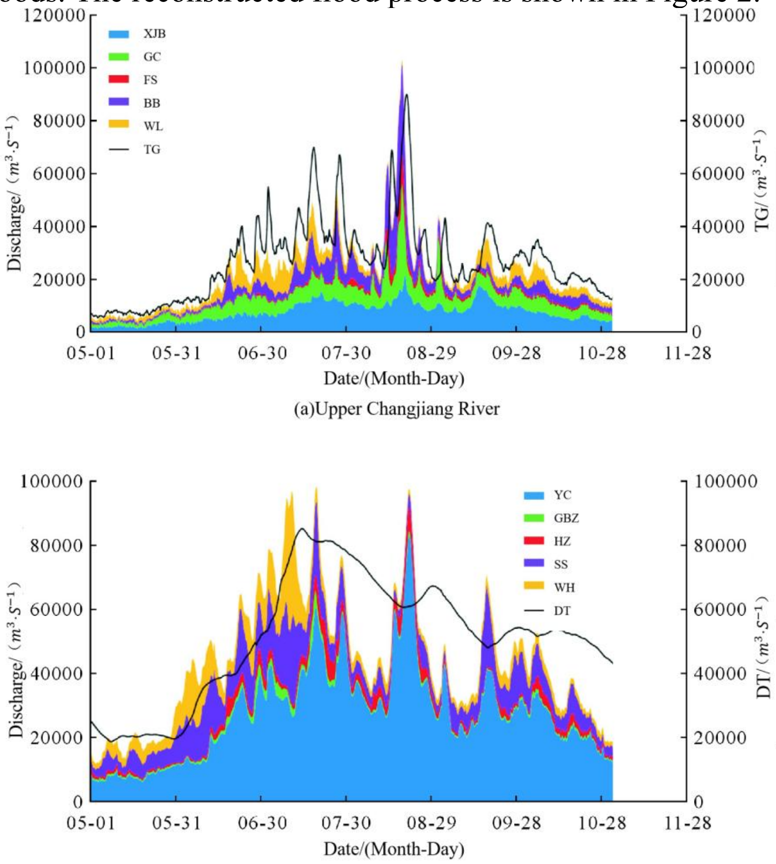


Fig. 1 Main Control Reservoirs Included in 2023 Joint Operation in the Yangtze River Basin

### 2.2 Reconstruction of 2020 Yangtze River Basin Floods

Zhang et, al[5] reconstructed and analyze the typical historical floods in YRB. In this paper, results from Zhang et,al [5] were used for further analysis.

In 2020, the floods in the upper reaches of the Yangtze River occurred early, with a wide range of flooding across the basin. Floods in the main stream sections were particularly prominent, with the stream flow from Wu River contributed significantly to the peak of floods from late June to early July. From July to August, heavy rains frequently occurred in the basin, leading to severe encounters between floods in the main stream and its tributaries. This resulted in five successive major floods along the main stream. In August, the inflows from the Jialing and Minjiang rivers contributed more than 25% of the inflows to the Three Gorges Reservoir (TGR), significantly affecting the formation of flood peaks at the reservoir. From June to July, significant floods occurred in the Qingjiang River and the Poyang-Dongting lakes (Two lakes) system in the middle and lower reaches. The rivers and lakes in these regions reached full capacity, and the water levels in the main stream of the middle and lower reaches rose rapidly. The water levels at Luoshan, Hankou, and Datong stations exceeded the warning levels for over 40 days, resulting in a basin-wide major floods. The reconstructed flood process is shown in Figure 2.



(a)Upper Changjiang River

(b)Middle and lower Changjiang River

Fig. 2 Comparison of discharge at control stations on the main and tributary rivers of the Yangtze River in 2020

### 2.3 Reconstruction of 2020 Yangtze River Basin Floods

**(1) Initial Operation Time**

Considering that floods in the Yangtze River mainly occur between June and August, with occasional floods in September, and taking into account that the main control reservoirs in the upper reach typically enter the flood season between June and July, the initial operation time for the reservoirs is set to June 1.

**(2) Initial Water Levels**

The initial water levels are determined by considering the pre-flood drawdown schedule of each reservoir and the actual inflow conditions of tributaries during typical historical floods. For reservoirs in the Jinsha River, Yalong River, Dadu River, Min River, Jialing River, Wu River, Qing River, and Han River cascade, where early inflows are small or for multi-year regulated reservoirs, the initial water levels are set based on the average operational water levels for the same period from 2016 to 2020. For the reservoir cascades in Dongting Lake and Poyang Lake, which enter the flood season earlier, the water levels are set according to their own flood-limited water levels.

**(3) Transition Period Strategy**

From June 1 to the start date of flood season for each reservoir (e.g. July 1 for Xiluodu Reservoir), there is a transition period. During this period, operation is based on the initial water levels, average inflow, and full-load flow(the outflow reaches electricity generation capacity of the reservoir):

1)If the initial water level is higher than the flood-limited water level and the average inflow exceeds the full-load flow, the strategy is to set the outflow as full-load flow first and then lower the water level later. The target is to bring water level down to flood-limited water level by the start of the flood season.

2)If the initial water level is higher than the flood-limited water level but the average inflow is less than the full-load flow, the strategy is to balance the inflow and outflow first, and then to lower the water level controlled by full-load flow. In this case, it is possible to bring water level down to flood-limited water level by the start of the flood season but without releasing excess water.

3)If the initial water level is below the flood-limited water level and the average inflow exceeds the full-load flow, outflow is maintained by full-load flow, and once the flood-limited water level is reached, the outflow is set to balance the inflow, without releasing excess water.

4)If the initial water level is below the flood-limited water level and the average inflow is less than the full-load flow, outflow is set to balance inflow without releasing excess water. The water level can be raised but should not exceed the flood-limited water level by the start of the flood season.

**(4) Flood Season Strategy**

All operations should strictly follow the approved flood season operation plans for each reservoir.

**(5) Effective Lead Time for Hydrometeorological Forecasts**

Based on the performance of hydrometeorological forecasts and their effectiveness in actual flood management operations, the effective lead time for these forecasts is set to be 5 days.

### 2.4 Platform for Retrospective Operation

The platform for retrospective operation utilizes the integrated management system of dominated water conservancy projects in Yangtze River Basin[6]. This system was launched for trial operation in June 2022 and has been tested during the flood seasons of 2022 and 2023. It has also strongly supported the flood management drills organized by the Ministry of Water Resources, including the Yangtze River 1870 Flood Control Drill (2022) and the Yangtze River "1999+" Flood Control Drill (2023). The system's operational functions are relatively mature[7].

## 3. Analysis of Retrospective Operation

### 3.1 Actual Operation Practice of 2020 Floods

During the 2020 flood season, the Yangtze River experienced basin-wide major flooding, with five numbered flood events occurring in succession along the main stream.

1st Flood: The primary objective of water project operation was to control the water level at the Chenglingji hydrological station, ensuring it did not exceed the guaranteed level of 34.4 meters, and to reduce the water levels in the Poyang Lake area.

2nd Flood: The main goal was to control the water level at Chenglingji station, striving to keep it from exceeding the guaranteed level. At the same time, flood control in the Chenglingji area was balanced with ensuring the safety of the Jingjiang River section and the TGR.

3rd Flood: The focus was on ensuring the maximum flood level at the TGR did not exceed 165 meters, controlling the water level at Chenglingji station below 34.9 meters, and avoiding the activation of flood retention areas whenever possible.

Intermittent Flood in Early August: the main objectives were pre-discharge to create storage capacity and ensure the continuous recession of water levels in the middle and lower reaches of the main stream.

4th and 5th Floods: The goals were to reduce the flood control pressure on the Sichuan-Chongqing section (especially the main urban area of Chongqing), lower the risk of inundation at the tail of the TGR, and simultaneously ensure the flood safety of the middle and lower reaches.

### 3.2 Procedures-Based Operation Process of 2020 Floods Under Current Water Engineering Projects

Based on the approved operation procedures, retrospective operations of the 2020 flood were conducted and analyzed. The flood operation processes of the TGR are shown in Figure 3. The operation modes and outcomes, and flood defense processes of the flood control projects are summarized as follows, which can be divided into five phases:

**Phase I**: June 10 to June 29. During this phase, the water level of the TGR was maintained around the flood-limited level of 145 m. Other reservoirs in the basin operated according to the procedures and the water levels at the main control stations in the middle and lower reaches remained below the warning levels.

**Phase II**: June 30 to July 13. To respond to the 1st Flood, the reservoir cascades in the upper and middle reaches,with TGR being the core reservoir, carried out flood compensation operation for the Chenglingji area, controlling the water level at Lianhuatang Station to not exceed the guaranteed level of 34.40 m. During this phase, the reservoir cascades in the upper and middle reaches collectively retained approximately 8.09 billion m3 of floodwater, with the upstream reservoir cascade above the Three Gorges retaining about 2.77 billion m3, and the TGR retaining about 3.08 billion m3, raising its water level to 150.93 m. The middle reach reservoir cascades retained approximately 2.25 billion m3. During this phase, the peak water levels were 42.09 m at Shashi Station, 34.39 m at Lianhuatang Station (close to the guaranteed level of 34.40 meters), and 28.42 mat Hankou Station, exceeding the warning level by 1.12 m. To prevent the water level at Hukou Station from exceeding the guaranteed level, the critical flood detention area of Kangshan was used to divert about 170 million m3 of excess floodwater (without diversion, the peak water level at Hukou Station was expected to reach 22.58 m on July 13).

**Phase III**: July 14 to July 29. To respond to the 2nd and 3rd Floods, the reservoir cascades in the upper and middle reaches shifted from flood compensation operation for the Chenglingji area to compensation operation for the Jingjiang River section (controlling the water level at Shashi Station to not exceed 44.50 m). During this phase, the reservoir cascades in the upper and middle reaches collectively retained approximately 14.9 billion m3 of floodwater, with the upstream reservoir group above the Three Gorges retaining about 7.83 billion m3, and the water level of the TGR rising from 150.93 meters to a maximum of 158.61 m, retaining about 5.02 billion m3 of floodwater. The middle reach reservoir group retained approximately 2.05 billion m3. During this period, the peak water level at Shashi Station reached 42.56 m, 0.44 m below the warning level, and the peak water level at Lianhuatang Station was 34.33 m close to the guaranteed level. The water level at Hankou Station fluctuated and receded, dropping to 27.22 m by 8 a.m. on July 29, below the warning level. The water level at Hukou Station also fluctuated and receded, dropping to 20.35 m by 8 a.m. on July 29, 2.15 m below the guaranteed level.

**Phase IV**: July 30 to August 13. During the interim between floods, the TGR partially released flood. By the end of this phase, the water level of the TGR had receded to a minimum of 149.11 m releasing about 6 billion m3 of flood storage capacity. The water levels at the control stations in the middle and lower reaches and the outlets of the two lakes showed a fluctuating downward trend.

**Phase V**: August 14 to August 31. To respond to the 4th and 5th Floods, the reservoir cascades in the upper reaches implemented joint operation, with the goal of reducing the flood pressure on the Sichuan-Chongqing river section (especially around Chongqing), lowering the backwater flooding risk at the tail of the TGR, and reducing the flood pressure in the middle and lower reaches. The upstream reservoir cascades above the Three Gorges (excluding the TGR) retained approximately 7.5 billion m3 of floodwater, with the peak water level at Cuntan Station reaching

192.30 m (the guaranteed level is 183.50 m) and the peak flow reaching 73,200 m3/s. After flood retention by the upstream reservoir cascades, the peak inflow to the TGR was 74,400 m3/s. The TGR carried out compensation operation for the Jingjiang River section, with the water level rising to a maximum of 160.77 m, retaining about 7.53 billion m3 of floodwater. The middle reach reservoir cascades retained approximately 2.09 billion m3. During this phase, the water levels at the control stations in the middle and lower reaches and the two lakes continued to recede, with peak water levels of 43.20 m at Shashi Station, 33.22 m at Lianhuatang Station, 26.58 mat Hankou Station, and 19.82 m at Hukou Station. The peak water level at Lianhuatang Station was 1.18 m below the guaranteed level, while the peak water levels at Shashi and Hukou Stations exceeded the warning levels by 0.20 m and 0.32 m, respectively.

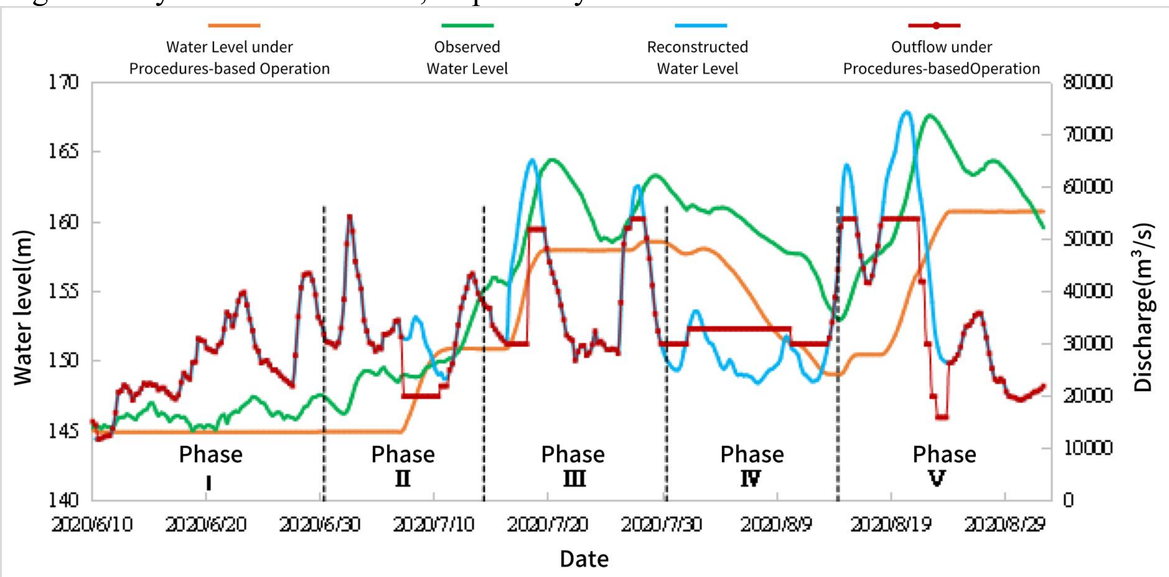


Figure 3 Operation Processes of the Three Gorges Reservoir in 2020 Flood Season

### 3.3 Procedures-Based Operation Outcomes of 2020 Floods Under Current Water Engineering Projects

According to the approved operation procedures, during the retrospective operation of the floods in 2020 (June 29 to September 1), the storage of the reservoirs in the YRB increased by about 47.78 billion $m^3$ , of which the storage of the upstream reservoirs above the TGR (excluding the TGR) increased by about 24.69 billion $m^3$ , effectively reducing the flood volume entering the TGR. The highest flood level of the TGR is 160.77m, and the cumulative flood storage volume is about 15.88 billion $m^3$ .

Under the joint operation of the reservoir cascades, the peak water level in the Sichuan-Chongqing river section was effectively reduced by nearly 3 m, significantly reducing the flood control pressure in the Sichuan-Chongqing river section; the peak water level in the Shashi river section was reduced by about 3.6 m, and the highest water level at the Shashi station was controlled within 44.50 m, avoiding the use of the Jingjiang flood diversion area; the peak water level in the Chenglingji area was reduced by about 1.7m, and the highest water level at the Lianhuatang station was controlled within 34.40 m; the peak water level in the Hukou area was reduced by about 0.5 m, and the excess flood volume above the guaranteed water level at the Hukou station was about 170 million $m^3$ . See Table 1 for more details.

In general, if the operations of reservoirs were strictly implemented according to approved operation procedures, the flood control pressure in the YRB would have been significantly reduced through joint operations. However, due to severe floods in the mainstream of the middle and lower reaches there is still excess flood volume in the Hukou area. At the end of the 2020 floods (September 1), the available storage (storage below the normal water storage level) of the control reservoir cascades in YRB was still nearly 38.5 billion $m^3$, of which the available storage (below 175 m) of the TGR was about 12.5 billion $m^3$. Such available storage has the ability to further reduce the flood control pressure in the basin and optimize the reservoir cascades operation process.

The comparison of the observed, reconstructed and post-operation flood process of Shashi, Lianhuatang, Hankou and Hukou stations in the middle and lower reaches are shown in Figures 4 to 7.

Table 1 Analysis results of water levels at main stations in the middle and lower reaches of the main stream during the 2020 flood

| Category | Item | Cuntan | Shashi | Lianhuatang | Hankou | Hukou |
|---|---|---|---|---|---|---|
| Eigenvalue | Warning water level (m） | 180.5 | 43 | 32.5 | 27.3 | 19.5 |
| | Guarantee water level (m） | 183.5 | 45 | 34.4 | 29.73 | 22.5 |
| Observed | Maximum water level (m） | 191.62 | 43.38 | 34.59 | 28.77 | 22.49 |
| | Maximum amplitude of water level beyond Warning water level (m） | 11.12 | 0.38 | 2.09 | 1.47 | 2.99 |
| Reconstructed | Maximum water level (m） | 194.60 | 46.80 | 36.10 | 29.70 | 23.00 |
| | Maximum amplitude of water level beyond Warning water level (m） | 14.10 | 3.80 | 3.60 | 2.40 | 3.50 |
| Post-operation | Maximum water level (m） | 192.30 | 43.20 | 34.39 | 28.42 | 22.5 |
| | Maximum amplitude of water level beyond Warning water level (m） | 11.80 | 0.20 | 1.89 | 1.12 | 3.00 |

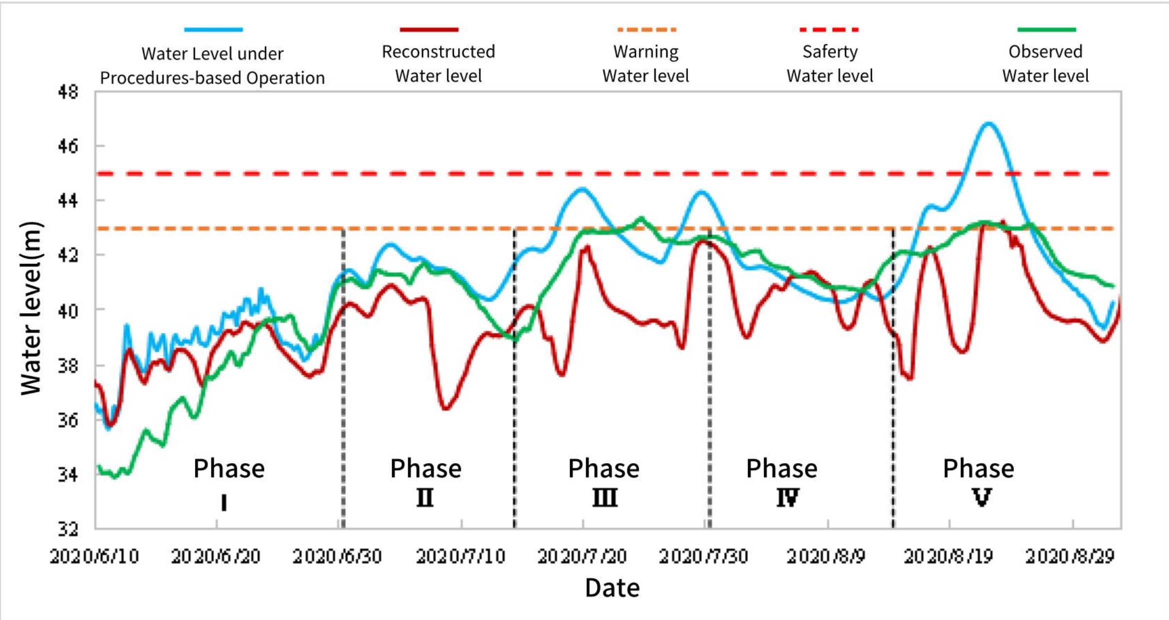


Fig. 4 Water level of Shashi after procedures-based operation in 2020

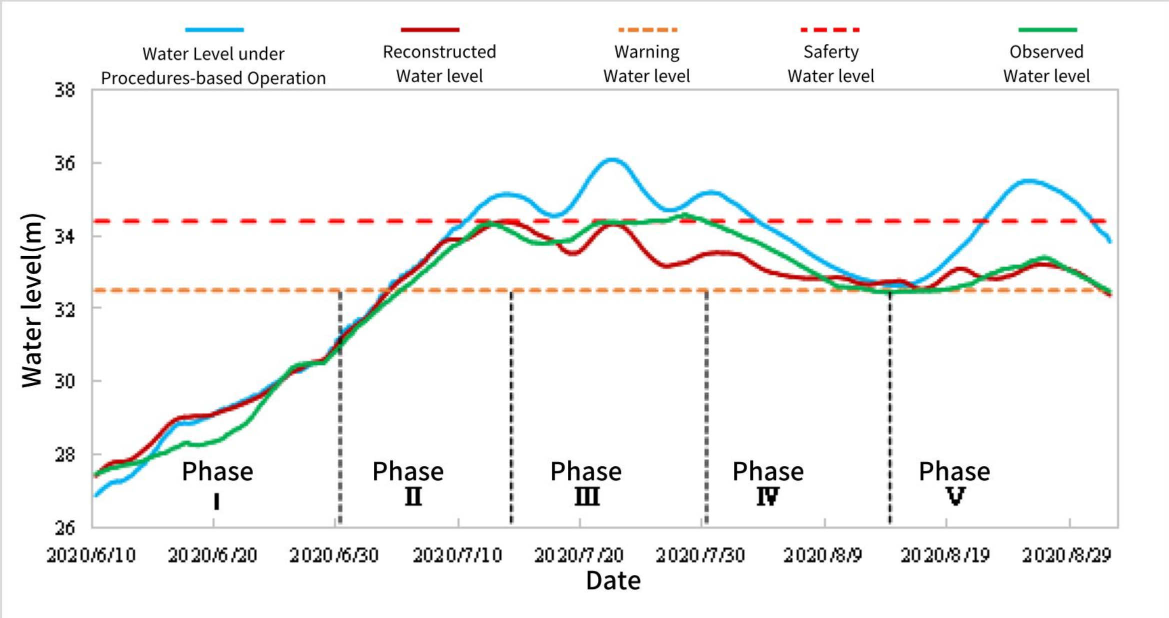


Fig. 5 Water level of Lianhuatang after procedures-based operation in 2020

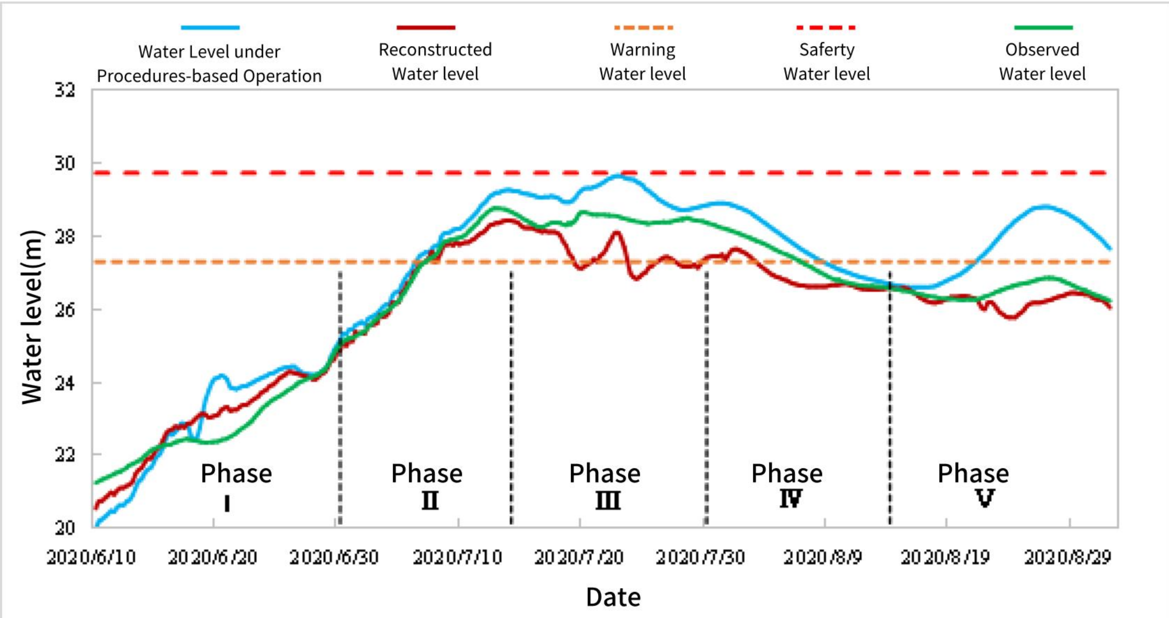


Fig. 6 Water level of Hankou after procedures-based operation in 2020

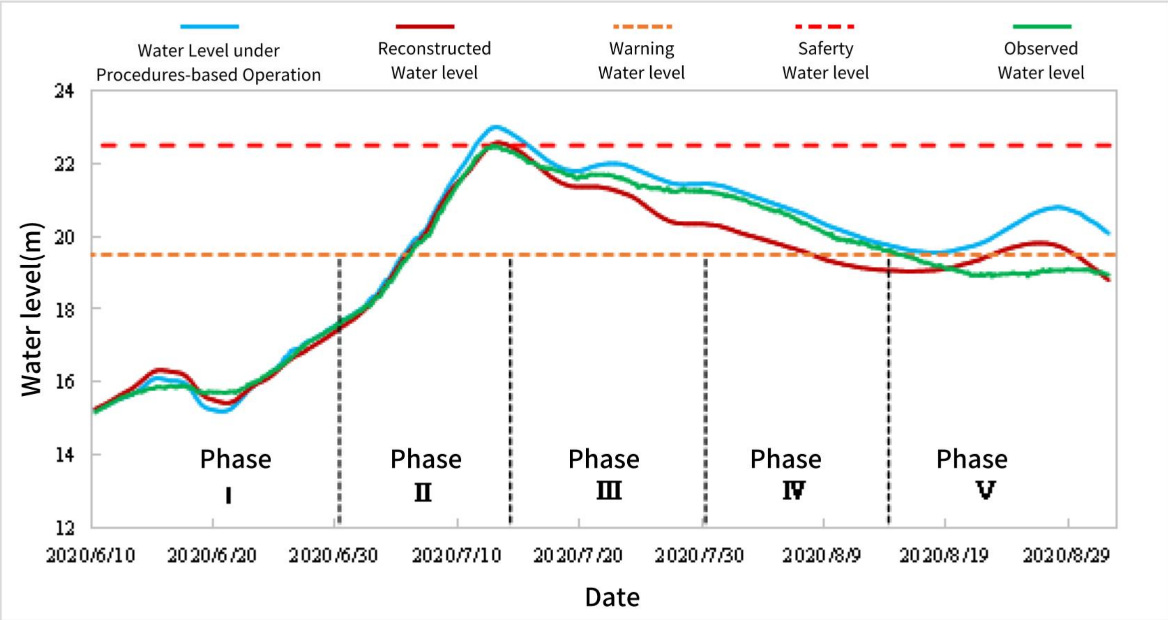



Fig. 7 Water level of Hukou after procedures-based operation in 2020

# 4. Conclusion and Outlook

## 4.1 Conclusion

Following "2023 Yangtze River Basin Water Engineering Projects Joint Operation Plan", retrospective flood operations were carried out based on the reconstructed major floods of 2020 and engineering conditions of 2023 in the Yangtze River Basin. The analysis made use of the integrated management system of dominated water conservancy projects in Yangtze River Basin. The main conclusions are as follows:

(1)If 2020 major floods in the Yangtze River Basin were to reoccur under current conditions, the implementation of the joint operation plan for the Yangtze River Basin's water projects, including the operation of 12 key reservoirs such as Lianghekou on the Yalong River and Baihetan on the Jinsha River, could essentially achieve the same optimized operation outcomes as observed in 2020.

(2)As of the end of the 2020 flood season (September 1), the available storage capacity below the normal water levels of the key reservoirs in the Yangtze River Basin was nearly 38.5 billion m3, including approximately 12.5 billion m3 of available storage capacity below 175 meters in the Three Gorges Reservoir. By appropriately and scientifically breaking through the limitations of the current regulations and optimizing operation, the overall flood control pressure in the basin could be further alleviated.

## 4.2 Outlook

Reference [5] conducted research on historical typical floods in the Yangtze River Basin, generating a relatively complete database of historical typical floods in the basin. Based on the technical approach proposed in this paper, retrospective analysis s can be performed for all historical typical floods, leading to the development of a case library for regulated operation and optimized operation. By integrating current artificial intelligence and data mining technologies, further extraction of knowledge on historical typical floods and operation can provide support for decision making for flood control.

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