

# Study on flood control operation of Jinsha River cascade reservoirs combined with the Three Gorges along the Yangtze River

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**Abstract.** The middle and lower reaches of the Yangtze River were the main flood control points of the Yangtze River Basin, which had greatly improved after the completion and operation of the Three Gorges and Jinsha River cascade reservoirs. In order to enhance the flood control effect of those reservoirs, a combined operation rule named equal water storage method was studied in this paper, and taking the floods of 1954 and 1998 as examples, the flood control effect of cascade reservoirs was analysed. The results show that under the dispatching action of Jinsha River cascade reservoirs combined with the Three Gorges reservoir with this method, the excess flooding in Jingjiang area and Chenglingji area can be reduced, with better effect and practicality, which can be used in the flood controlling in the Changjiang river basin.

## 1. Introduction

The middle and lower reaches of the Changjiang River is one of developed areas in China, with a mild climate, fertile land and rich products. It is an important area of China because there are Yichang, Jingzhou, Yueyang, Wuhan and other large and medium-sized cities along the river, and Wuhan Iron and Steel Company, Baosteel, Hanjiang Oilfield and other important industrial enterprises. But because of low-lying, this area is always serious threat to the flood, and become the focus of flood control in the Changjiang River basin [1].

After the construction of the Three Gorges Reservoir and Jinsha River cascade reservoirs, the huge regulation capacity of those reservoirs will greatly improve the flood control situation in the middle and lower reaches of Yangtze River. At the same time have a huge effect in power generation, shipping, water resources allocation, water ecology and water environment protection and so on.

Currently, the Xiluodu, Xiangjiaba and the Three Gorges Reservoir mainly run independently [2]. Some scholars have carried out the joint scheduling research by setting up joint operation model based on the hydrology forecasting [3]. But because of the period of hydrological forecast is short, the application effect is limited, and the control condition is not clear enough, it is difficult to be transformed into easy-to-use flood control scheme [4].

Taking the Jinsha River cascade reservoirs, Wudongde, Baihetan, Xiluodu and Xiangjiaba as example, this paper analysed the methods of flood control operation rules in the Jinsha River cascade reservoir and the Three Gorges Reservoir, and chooses the actual flood as an example. Middle and



lower reaches of Jingjiang area and Chenglingji area as flood control targets, the scientific and practical of equal water storage method was analysed.

## 2. Flood Control Reservoirs and Objects

### 2.1. The Three Gorges Reservoir

Three Gorges Reservoir is located in Yichang City, Hubei Province, in the middle of China [5]. About 44km away from the Yichang hydrological station. The control area is about 1 million km<sup>2</sup>, with an average annual flow of 14300m<sup>3</sup>/s. The normal reservoir water level is 175m, flood control limited level is 145m, and the total capacity is 39.3 billion m<sup>3</sup>, flood control capacity is 22.15 billion m<sup>3</sup>, and with a power plant installed capacity of 22400MW, which is the largest reservoir by power installed capacity in the world [6].

The main task of the Three Gorges reservoir is flood control, power generation and shipping, and has a certain water supply benefits [7]. The main flood prevention task to ensure that the Jingjiang area in the event of a hundred years of flooding without flood, and conditional Chenglingji region compensation scheduling.

### 2.2. Jinsha River cascade reservoirs

The Wudongde, Baihetan, Xiluodu and Xiangjiaba reservoirs, which are located in the Jinsha River reach of the Yangtze River, are called by Jinsha River cascade reservoirs as usual. The project development is mainly based on power generation, and also includes flood control, improving shipping conditions and so on [8]. The reservoirs characteristics parameters are shown in Table 1.

The reservoirs along the Jinsha River can significantly improve the flood control standards of Yibin, Luzhou, Chongqing and other cities along the Jinsha River, and reduce the amount of flood flow directly into the Three Gorges Reservoir [9]. With the implementation of joint scheduling, they can further improve the Yangtze River flood control standards in the middle and lower reaches of the Yangtze River.

**Table 1.** Characteristic parameters of Jinsha River cascade reservoirs

Name	Control area (million km <sup>2</sup> )	Flood control level (m)	Top level of flood control (m)	Flood control capacity (billion m <sup>3</sup> )
Wudongde	0.41	960.8	975	2.44
Baihetan	0.43	780	820	7.50
Xiluodu	0.45	560	600	4.65
Xiangjiaba	0.46	370	380	0.90

### 2.3. Flood control objects

The main flood control targets in the middle and lower reaches of the Yangtze River are Jingzhou, Yueyang, Wuhan, Hukou and other important cities along the Yangtze River [10]. The Three Gorges Reservoir and the upper reaches cascade reservoirs can play the role of flood control, mainly in Jingjiang and Chenglingji areas, their location is shown in Figure 1. So Jingjiang area and Chenglingji area are chosen as the flood control objects of the Three Gorges Reservoir and Jinsha River cascade reservoirs.



**Figure 1.** Location of reservoirs and flood control objects

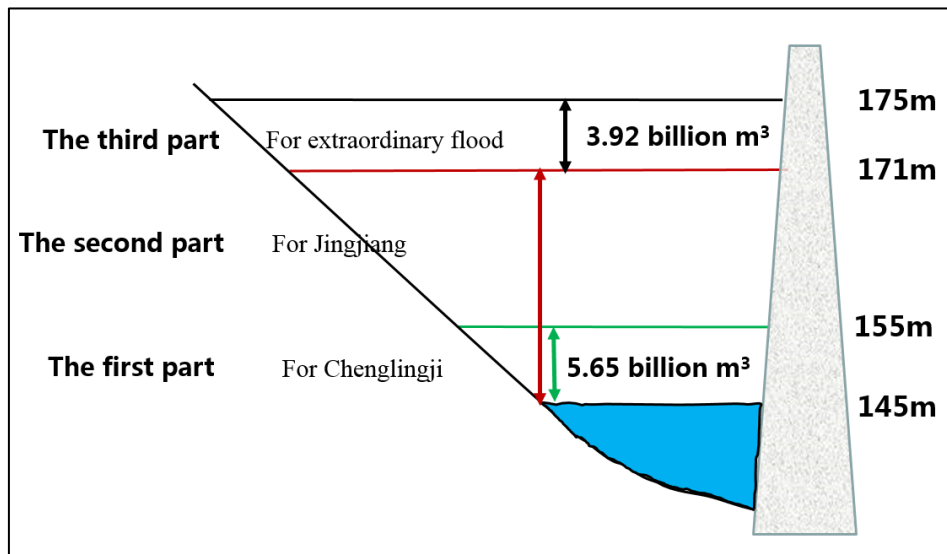
Jingjiang area is a nickname of area from Zhicheng city to Chenglingji section in the Yueyang city along the Changjiang River, with a total length of 360 km [11]. The north shore of Jingjiang area is the Jiangnan plain, and the south bank is the Dongting Lake plain. Due to sediment deposition, the river bed is higher than the plains, and becomes an aboveground river, which is very easy to burst flood disaster.

Chenglingji area is located in the intersection of the Yangtze River and Dongting Lake, 7.5 kilometres away from the downtown of Yueyang City. It is the only channel of Dongting Lake out to the Yangtze River, and the flood is affected by both Dongting Lake and the mainstream of Changjiang River, the flood control situation is complex. At the same time, due to the flat terrain, the flood control standards is low. In 1954 and 1998, it had occurred in the larger floods, resulting in great casualties and property damages.

### 3. Joint Flood Control Operation method analyze

#### 3.1. The Three Gorges Reservoir

The flood control targets of the Three Gorges Reservoir are mainly Jingjiang and Chenglingji [12]. The 22.15 billion  $\text{m}^3$  flood control capacity of the Three Gorges Project is divided into three parts from bottom to top as figure 2. The first part is 5.65 billion  $\text{m}^3$ , which is used to control the maximum flow of Chenglingji station is not more than  $60000\text{m}^3/\text{s}$ , at the same time control the maximum flow of Jingjiang station is less than  $56700\text{m}^3/\text{s}$ . The second part is 8.55 billion  $\text{m}^3$ , which is used to control the maximum flow of Jingjiang station is not more than  $56700\text{m}^3/\text{s}$ . The third part is 3.92 billion  $\text{m}^3$ , is reserved for the regulation of Jingjiang flood, and control the maximum flow of Jingjiang station is not more than  $80000\text{m}^3/\text{s}$ . When encounters a flood up to a thousand year frequency or the Three Gorges reservoir water level has reached 175m, in order to ensure the safety of the dam, the output flow of the Three Gorges reservoir determines by discharge capacity, no longer consider the flood control requirements of downstream.



**Figure 2.** The three parts of the flood control capacity of the Three Gorges Reservoir

The outflow of the Three Gorges Reservoir can be calculated by formula (1).

$$q_{s,t} = \begin{cases} \max(\min(Q_z - (1+e_1) \cdot r_{z,t}, Q_c - (1+e_1) \cdot r_{z,t} - (1+e_2) \cdot r_{c,t+2}), \min(p_{s,t}, Q_s)) & 0 \leq w_{s,t} \leq W_{s1} \\ \max(Q_z - (1+e_1) \cdot r_{z,t}, \min(p_{s,t}, Q_s)) & W_{s1} < w_{s,t} \leq W_{s2} \\ 80000 - (1+e_1) \cdot r_{z,t} & W_{s2} < w_{s,t} < W_{s3} \\ \max(p_{s,t}, 80000 - (1+e_1) \cdot r_{z,t}) & w_{s,t} \geq W_{s3} \end{cases} \quad (1)$$

$p_{s,t}$  —inflow of the Three Gorges Reservoir in  $t$  period;

$q_{s,t}$  —outflow of the Three Gorges Reservoir in  $t$  period;

$Q_z$  —safety limit flow of Zhicheng;

$Q_c$  —safety limit flow of Chenglingji;

$r_{z,t}$  —local inflow from the Three Gorges Reservoir to Zhicheng of  $t$  period;

$e_1$  —prediction error of local inflow from the Three Gorges Reservoir to Zhicheng;

$e_2$  —prediction error of local inflow from Zhicheng to Chenglingji;

$r_{c,t+2}$  —local inflow from Zhicheng to Chenglingji of  $t+2$  period;

$Q_s$  —the power generation rated flow of the Three Gorges Reservoir;

$W_{s1}, W_{s2}, W_{s3}$  —adjustable parameters.

### 3.2. Jinsha River Cascade Reservoirs

According to the distribution of flow, and taking into account of does not affect power generation and economic rational use of reservoir flood control capacity in flood season, the preliminary development of equal water storage method is used in the Jinsha River cascade reservoirs combined with the Three Gorges Reservoir. That is when the middle and lower reaches of the Yangtze River floods, which need the Three Gorges Reservoir flood control operate, the Jinsha River cascade reservoirs storage water at the same time by equal volume of water, reducing the outflow to downstream. When the inflow is less

than  $Q_0(i)$ , the storage capacity of the first stage is  $q_1(i)$ , and when the inflow is more than the first stage control flow  $Q_0(i)$ , the storage capacity is the second stage  $q_2(i)$ .

During the process of reservoir operation, the minimum outflow of each reservoir is not less than the power generation rated flow of the reservoir, such as formula (2).

$$q_i(t) = \begin{cases} \max \{ [Q_i(t) - q_1(i)], q_E(i) \} & Q_i(t) < Q_0(i) \\ \max \{ [Q_i(t) - q_2(i)], q_E(i) \} & Q_i(t) \geq Q_0(i) \end{cases} \quad (2)$$

$Q_0(i)$  is the inflow of reservoir  $i$ , and  $q_E(i)$  if the power generation rated flow of reservoir  $i$ .

#### 4. Case Study

Taking the Floods of 1954 and 1998 as examples, the operation parameters of Wudongde, Baihetan, Xiluodu, and Xiangjiaba reservoirs are shown as table 2. The minimum outflow means the outflow need greater than power generation rated flow.

**Table 2.** Equal Storage Volume parameters and Minimum outflow unit:  $\text{m}^3/\text{s}$

Reservoir's name	Inflow	water storage volume	The minimum outflow
Wudongde	<10000	2000	5000
	>10000	3000	
Baihetan	<10000	2000	6000
	>10000	3000	
Xiluodu	< 10000	2000	4500
	> 10000	3000	
Xiangjiaba	< 10000	1000	7000
	> 10000	2000	

The flood control model of reservoirs in 1954 and 1998 was used to simulate, and calculate the excess floods of Zhicheng and Chenglingji under the condition of no reservoir, reservoirs operated independent and combined operation by equal water storage method, as shown in Table 3.

**Table 3.** Flood control results by reservoirs unit: billion  $\text{m}^3$

Year	Excess flood	Non reservoir	Reservoirs operated independent	combined operation by equal water storage
1954	Zhicheng	9.1	0	0
	Chenglingji	44.1	36.5	35
1998	Zhicheng	3.3	0	0
	Chenglingji	21.1	9.8	9.3

From the table 3, for the flood in 1954 and 1998, under the operation of the Three Gorges Reservoir and Jinsha River cascade reservoirs, the excess flood in Zhicheng reduces to zero. And under the situation of reservoirs operated independent, the excess flood will reduce from 41.1 billion  $\text{m}^3$  to 36.5 billion  $\text{m}^3$  in 1954, and reduce from 21.1 billion  $\text{m}^3$  to 9.8 billion  $\text{m}^3$  in 1998. After using the combined operation method by equal water storage, the exceed flood can further decreases to 35 billion  $\text{m}^3$  in 1954 and 9.3 billion  $\text{m}^3$  in 1998.

#### 5. Conclusion

Based on the characteristics analyse of flood control in the Yangtze River Basin, this paper put forward a flood control joint control method based on the Three Gorges Reservoir inflow as the control condition of the upstream reservoirs. The results show that the combined operation method by equal water storage can further reduce the excess flood amount in Chenglingji area, with advantages of clear control condition and simple application mode, and has great application value in flood prevent practice.

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