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# **Flood Management in China: The Huaihe River Basin as a Case Study**

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Additional information is available at the end of the chapter

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## **Abstract**

The Huaihe River Basin (HRB) is a transitional river located in the transitional climate zone in China, and it has been frequently hit by big floods and suffered from flood disasters. Flood control and management of the areas are of vital importance of the Huaihe River Basin in its social and economic development. In this chapter, pioneer works of summarizing the flood management have been done for the Huaihe River in China. It first introduces flood and flood disasters of the River basin. In addition, this chapter summarizes achievements in flood control and management. Furthermore, it discusses experiences and enlightenment in flood control and management and draws conclusions for the research.

**Keywords:** flood management, flood control, the Huaihe River, transitional river, China

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## **1. Introduction**

China is located in eastern Asia. It is impacted by monsoonal climate and the temporal, and therefore, spatial distribution of precipitation is uneven. The terrain in China is high in the west and low in the east with mountains, plateaus, and humps, which account 67% of China's areas and basins and 33% plains. Special geographical and climatic conditions result in very serious flood and drought disasters in China. Since 1949, great efforts have been made for flood control in China. A series of policies and regulations has been formulated for flood control and management. Furthermore, numerous structural measures such as construction of reservoirs, flood detention areas and lakes, building of dykes, water gates and hydro junctions have been constructed. In addition, non-structural measures of hydrological monitoring system and flood forecasting system have been made for flood control in China.

The Huaihe River Basin (HRB) is located in the transitional climate zone in China (**Figure 1**), which is known as the transitional river of China [1]. It has been frequently hit by big floods and suffered from flood disasters, and the frequency of disaster is one time in 10 years on average [2–5]. The critical issue is that about two-third of the middle and downstream of the major rivers are prone to floods, where is inhabited 13% of people of China, 12% of cultivated land area of China, one-sixth of food product of China, and one-fourth of the food as commodity of China. Flood control and management of the areas are of vital importance for the Huaihe River Basin in its social and economic development. Strenuous efforts have been made in fighting against floods; however, there is still a long way to go.

This chapter is organized as follows: Section 1 introduces general situation of flood management in China and the Huaihe River Basin, Sections 2 and 3 summarize the study area of the Huaihe River Basin. Section 4 presents floods and flood disasters of the River basin and concerns achievements in flood control. Section 5 discusses experiences and enlightenment in flood control and management. Section 6 draws conclusions for the research.

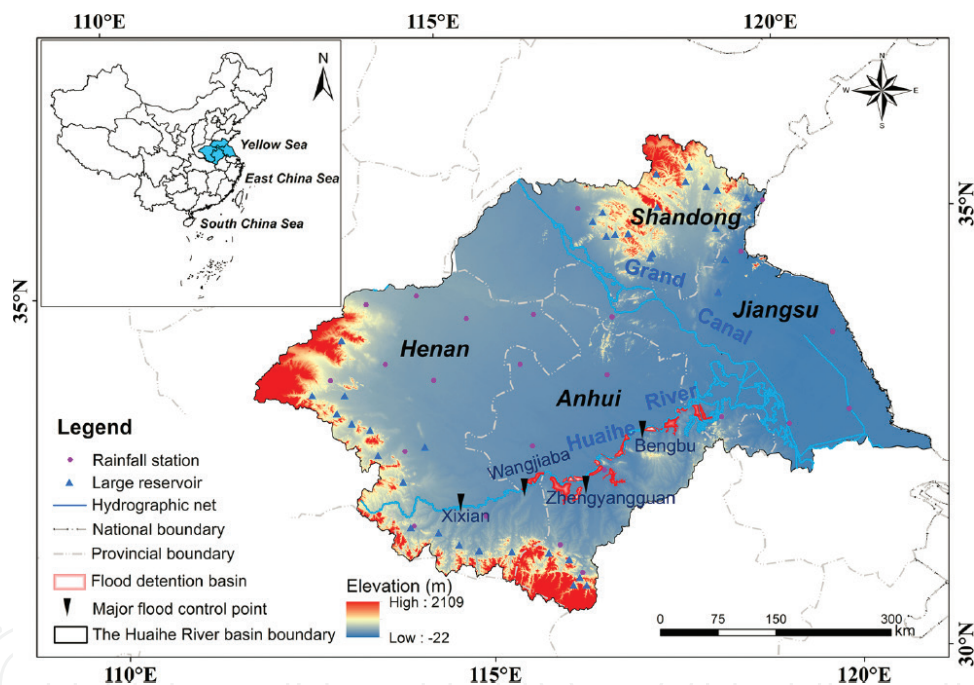


Figure 1. Location map of the study area.

## 2. Geographical features

The Huaihe River Basin is located in the east China, with the Yellow River in the north and the Yangtze River in the south, and its catchment area is 270,000 km<sup>2</sup>. Starting in the Tongbai Mountains of Henan province, it flows from west to east. The upper reaches of the river are located in Henan and Hubei Provinces, the middle of the river is located in Anhui Province, and the downstream of the river is located in the Jiangsu Province. The length of the trunk stream is about 1000 km. The upper reaches of Huai river flow from the river head to the

mouth of Honghe River between Henan and Anhui provinces, and the total length of the upper reaches is 360 km; the middle reaches, from Honghe River to Hongze Lake, are 490 km in length; and the lower reaches have a total length of 150 km. In the lower part of the Huaihe River Basin, there are four major outlets for floods, i.e., the Floodway to the Yangtze River, the Floodway to the Yellow Sea, the Northern Jiangsu Irrigation Canal to the Yellow Sea, and diversion waterway from the Huaihe River to new Yi River, then to the Yellow Sea.

The average annual precipitation of basin is about 875 mm, of which 50–80% precipitation is concentrated in the rainy season (June–September). Located in the north-south climate transition zone, with uneven spatial-temporal distribution of precipitation and the capture of the headwaters of Yellow river into the Huaihe River, Huaihe River flood disasters occurred very frequently. The basin-wide floods hit the Huaihe River in 2003 and 2007 of this century.

Due to the frequent flood disasters in the Huaihe River Basin, the State attaches great importance to harness of the Huaihe River. For nearly half a century, many flood control buildings have been built, including 38 large reservoirs, 21 flood storage areas, 1716 km embankment of grade I, diversion rivers such as Huaihongxinhe canal, Ruhaishuidao canal (floodway to the sea), as well as large lakes such as Hongze Lake. In addition, non-structural measures such as communication systems, hydrological forecasting system, the remote monitoring system of flood control works, remote consultation system, and flood control system have also been built. All these measures have played a positive role in the defence of floods.

### 3. Outstanding characteristics of the HRB

Compared with other rivers all over the world, the Huaihe River has its own outstanding characteristics:

1. HRB is located in the transitional zone from southern to northern climate of China, the weather system changes dramatically, and precipitation varies greatly in both space and time. Therefore, it is prone to flood and drought disaster. The average annual precipitation of HRB is 875 mm, the average annual precipitation in the northern area is 600–700 mm, and in the southern area reaches to 1400–1600 mm. The precipitation is concentrated in flood season (from June to September) and accounts for 70% of the annual amount.
2. The Huaihe River Basin is short of water resources, and water pollution problems have not been effectively solved yet. The total amount of average annual water resources in the Huaihe River Basin is 79.4 billion m<sup>3</sup>, and the average amount of water resources per capita and per mu only accounts for one-fourth and one-fifth of that of China (1 mu = 1/15 ha). Water is unevenly distributed in time and space, unmatched with the production and population pattern. River regulation capacity is weak, and development and utilization of water resources are difficult.
3. The Huaihe River Basin is with flat terrain, where mountainous area is less with poor flood incept and storage condition. It has a broad plain area accounting for two-third of the total area, which has flat terrain and small gradient ratio in the middle-low stream. The total

fall-head of the Huaihe River is 200 m (gradient ratio is 0.2‰). In the upstream, the gradient ratio is greater, with a fall-head of 178 m (gradient ratio is 0.5‰), and flood concentrates rapidly. In the middle reach, the gradient ratio and the fall-head of the midstream are 0.03‰ and 16 m, respectively. The river channel is curved and flat, and several parts of the river even have inverse slopes. The floods cannot flow smoothly and freely, which can easily cause flood disaster. In the middle reach, the gradient ratio and the fall-head of the midstream are 0.04‰ and 6 m, respectively.

4. Historically, with the diversion (capture) of the headwaters of Yellow river into the Huaihe River dramatically changes the natural water system, aggravates flood burden on the one hand, and increases the difficulties in harnessing the Huaihe River on the other hand. Originally, the Huaihe River is a separate river flowing into the East Sea; however, from the end of twelfth century to the middle of nineteenth century, in the 700 years of the Yellow river capture into the Huaihe River, a large number of sediments silted up the middle-low channel of the Huaihe River and made the Huaihe River lose its outlet to the Sea. It changes the natural water system to a great extent and has profound influences. It aggravated flood burden on the one hand and increased the difficulties in harnessing the Huaihe River on the other hand.
5. The Huaihe River Basin is densely populated, contradictions between human and water are sharp, and coordinated development is difficult. The Huaihe River Basin has a population of 0.178 billion, which accounts for 13% of that of China. Moreover, the Huaihe River Basin is also a main grain production area in China, with a cultivated land area of 0.19 billion mu accounting for 10.5% of the total amount of China; grain yield of the Huaihe River Basin takes up 17% of the total amount of China, and commodity grain of the Huaihe River Basin constitutes 25% of that of China. There are so many trans-boundary rivers that numerous conflicts of interests between different regions occur in terms of drainage and water resources utilization and protection. As a result, water affairs and conflicts are complex, and therefore, it increases the difficulties in river harness and management.

## 4. Floods and flood disasters

### 4.1. Floods characteristics

The Huaihe River Basin is located in the transitional zone from southern to northern climate of China, the weather system changes dramatically, and precipitation varies greatly in both space and time. Therefore, it is prone to flood and drought disasters. The average annual precipitation of HRB is 875 mm, the average annual precipitation in the northern area is 600–700 mm, and in the southern area reaches to 1400–1600 mm. The precipitation is concentrated in flood season (from June to September) and accounts for 70% of the annual amount. The maximum records of point rainfall of different durations in the Huaihe River Basin are close to or higher than the corresponding maximum records of China and the world. Extremely large flood peaks caused by such high intensity and extensive coverage rainstorms result in serious flood disasters (**Figure 2**)

The magnitude of the maximum floods varies greatly from one area to another over the whole basin, and the important events are given in **Table 1**.

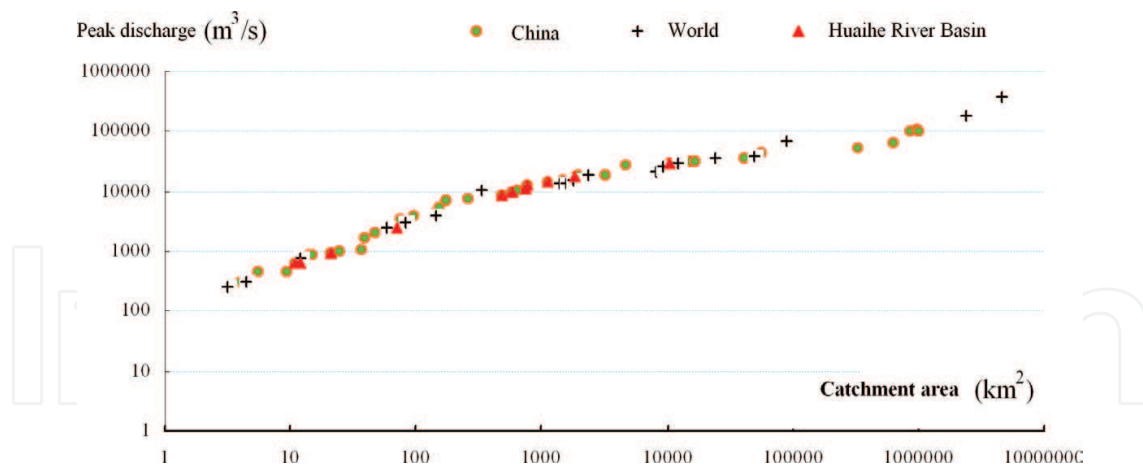


Figure 2. The relationship between catchment area and peak discharge in the Huaihe River Basin, China, and the world.

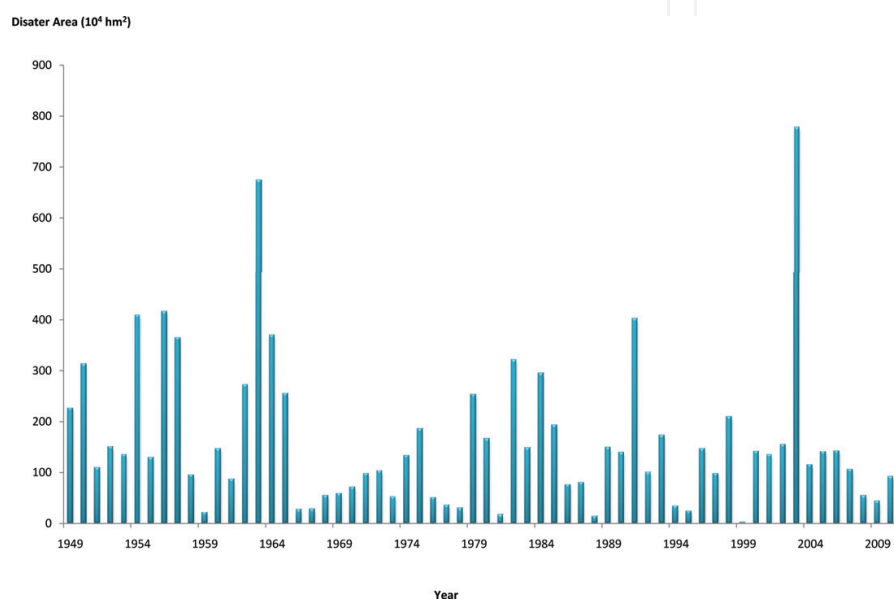
River	Gauged station	Catchment area (km <sup>2</sup> )	Observed	
			Discharge	Year
Huaihe mainstream	Wangjiaba	30,630	17,600	1968
Huaihe mainstream	Lutaizi	88,630	12,700	1954
Huaihe mainstream	Bengbu	121,330	11,600	1954
Huaihe mainstream	Sanhe	158,160	10,700	1954
Shihe southern major tributary	Jiangjiaji	5930	4550	1968
Pihe southern major tributary	Hengpaitou	4370	6420	1969
Shayinghe northern major tributary	Fuyang	36,606	3310	1965
Guohe northern major tributary	Mengcheng	15,475	2080	1963
Yihe major tributary	Linyi	10,315	15,400	1957
Shuhe major tributary	Daguanzhuang	4529	4250	1974

Table 1. The maximum flood discharge for major rivers in HRB (Unit m<sup>3</sup>/s).

#### 4.2. Flood disasters

According to statistics, during the 2256 years from 246 B.C. to 2010, totally 1946 flood and drought disasters had occurred in the Huaihe River Basin, among which, number of flood disaster is 1008, while number of drought disaster is 938, which means disaster almost happens every year. Number of basin-wide flood and drought disasters is 340 (number of flood disaster is 268 and number of drought disaster is 72), and frequency is approximately once every 6.6 years on average. From the diversion (capture) of the Yellow river into the Huaihe River in 1194, flood disasters became more frequently. From the thirteenth century to the nineteenth century, there were 165 flood and drought disasters occurred in the HRB, one time in every 4.2 years on average.

Due to the unique natural features of the HRB, in recent years, large-area flood and drought disasters happen frequently, and local flood and drought disasters happen annually. According to statistics, from 1949 to 2008, average annual flood disaster area of the HRB is 25.29 million mu (**Figure 3**), among which, number of annual flood disaster area above 30 million mu reaches to 15 accounting for 25% of the number of statistical years; number of annual flood disaster area higher than 40 million mu reaches to 11 accounting for 18.3% of the number of statistical years; and number of annual flood disaster area above 50 million mu reaches to 8 accounting for 13.3% of the number of statistical years. **Table 2** shows statistics of flood disasters for three basin-wide floods in the HRB.



**Figure 3.** Disaster area in different years in the Huaihe River Basin.

Year	Disaster area (10 <sup>4</sup> hm <sup>2</sup> )	Affected people (10 <sup>4</sup> )	Destroyed houses (10 <sup>4</sup> )	Immigrant (10 <sup>4</sup> )	Direct economic losses (10 <sup>8</sup> RMB)
1991	401.6	5423	196	226.1	339.6
2003	259.1	3730	77	207	286
2007	158.7	2472	11.53	80.9	155.2

**Table 2.** Statistics of flood disasters in 1991, 2003, and 2007 in HRB.

## 5. Achievements in flood control

Since the foundation of the new China, for the purpose of effectively reacting to flood and drought disasters and reducing losses, under the guidance of “jointly considering storage and discharge of floodwater” principle for harnessing the Huaihe River, with 60-year continuous river harness, tremendous achievements have been made in engineering construction of

the Huaihe River harness. Laws and regulations, i.e., “Flood Control Law of The People’s Republic of China,” “Flood Control Regulation of The People’s Republic of China,” “Drought relief regulation of The People’s Republic of China,” and “Administrative regulation for flood storage and detention areas,” have been established, and basin flood prevention and dispatching programs have been improved, and all these play a vital role in reducing flood and drought disasters.

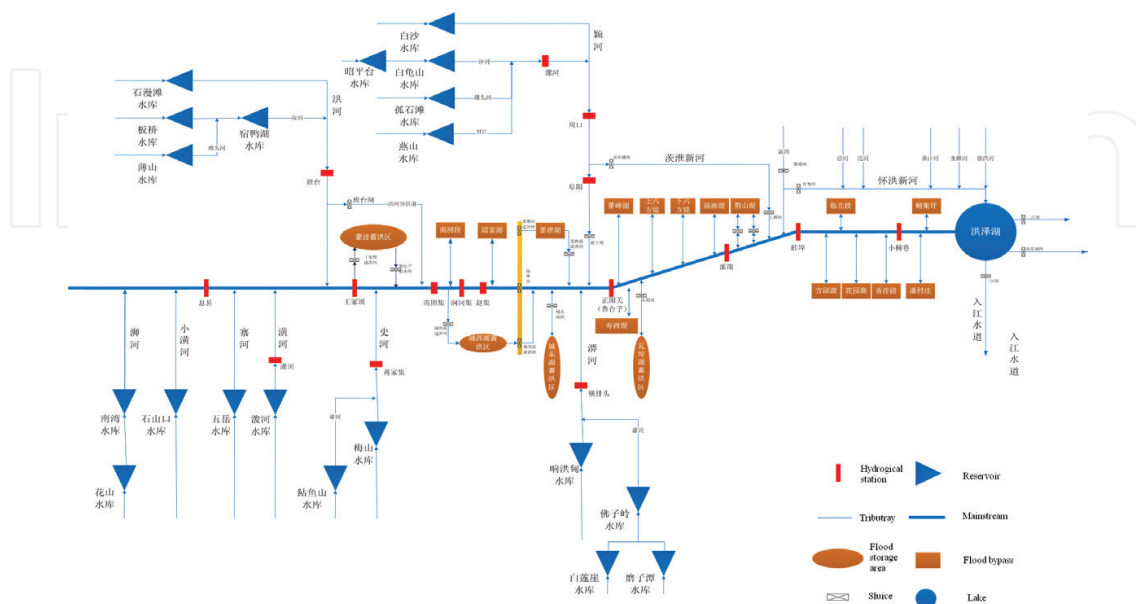
### 5.1. Structural measures

Overall arrangement: In the upper reaches, carrying out water-soil conservation and constructing reservoirs are important to intercept and store floods. In the middle reaches, taking structural measures to dredge & broaden river course, construct dykes and flood diversion & storage areas to increase channel flood discharge capacity. In the lower reaches, taking structural measures to excavate river channels for enlarging flood discharge capacity. The overall layout of structural measures is shown in **Figure 4**.

Water and soil loss have accumulatively been harnessed with an area of 40,000 km<sup>2</sup>.

About 6300 reservoirs have been constructed, with a total storage capacity of 30 billion m<sup>3</sup>, and 40 of them are large reservoirs, with a total storage capacity of 20 billion m<sup>3</sup> and a flood control capacity of 6.2 billion m<sup>3</sup>. Seventeen flood detention areas and large lakes for controlling flood have been constructed, with a total storage capacity of 3.59 billion m<sup>3</sup> and a flood storage capacity of 2.63 billion m<sup>3</sup>. **Figure 3** illustrates the major structures in the Huaihe River Basin.

Artificial channels have been constructed with a length of 2100 km. Different types of dikes have been constructed with a length of 50,000 km, and the length of key dike is 11,000 km. River channel discharge capacity has been significantly promoted, channel discharge capacity of the



**Figure 4.** Simplification of major water conservancy projects of the Huaihe River.



upper mainstream has been enhanced from 2000 to 7000 m<sup>3</sup>/s, channel discharge capacity of the middle mainstream has been enhanced from 5000 to 7000 m<sup>3</sup>/s to 7000 to 13,000 m<sup>3</sup>/s, and channel discharge capacity of the lower mainstream has been enhanced from 8000 to 18,270 m<sup>3</sup>/s. In addition, 1200 sluices have been constructed.

At present, flood control standard of the mainstream in the upstream is once-10-years, and flood control standards of the key flood protection areas and important cities in the middle and lower reaches were promoted to once-100-years. Flood control standards of the important tributaries can reach to once-20-years to once-50-years. Specifically, in the upper mainstream, channel discharge capacity has been enhanced from 2000 to 7000 m<sup>3</sup>/s. In the middle mainstream, channel discharge capacity has been enhanced from 5000–7000 to 7000–13,000 m<sup>3</sup>/s. In the lower mainstream, channel discharge capacity has been enhanced from 8000 to 18,270 m<sup>3</sup>/s.

## 5.2. Non-structural measures

So far, non-structural measures of flood prevention regulation command system jointly form system mechanism for flood prevention and disaster reduction.

### 5.2.1. Legal and institutional system for flood control

China has already promulgated laws and regulations concerning water, e.g., water law, flood control law, regulation on river channel, regulation on flood control, etc.

#### (1) Flood control law

The Law of Flood Control was adopted at the 27th Meeting of the Standing Committee of the Eighth National People's Congress on August 29, 1997, and promulgated by Order No. 88 of the President of the People's Republic of China on August 29, 1997. It is the first law on the prevention and control of natural disasters in China. It is also a very important law following the Water Law and the Law of Soil and Water Conservation in water domain in China.

Numerous administrative regulations were promulgated to clarify the responsibilities of responsible parties concerned in the flood control, such as flood Control Regulation of the People's Republic of China (2005 Revision), Regulation of the People's Republic of China on the Administration of River Courses, Guidelines for safety and construction of flood detention areas and flood control operation plan, etc., which have played an vital role in flood control and management in China. However, with the rapid socio-economic development, population growth, and acceleration of urbanization, numerous problems and new challenges have risen in terms of flood control, which can be summarized as follows: (a) Lack of legal consciousness on the importance of flood planning and at the same time the approved flood plan was not fully observed or strictly enforced; (b) Flood protection standard was relatively low; (c) There was no effective means for river channels management, e.g., sand excavation; (d) No effective management of flood plains area; and (e) Lack of funds in flood control and infrastructure construction. Therefore, there is an urgent call for specific law on flood control to ensure that necessary measures could be implemented legally.

## (2) Institutional Arrangement

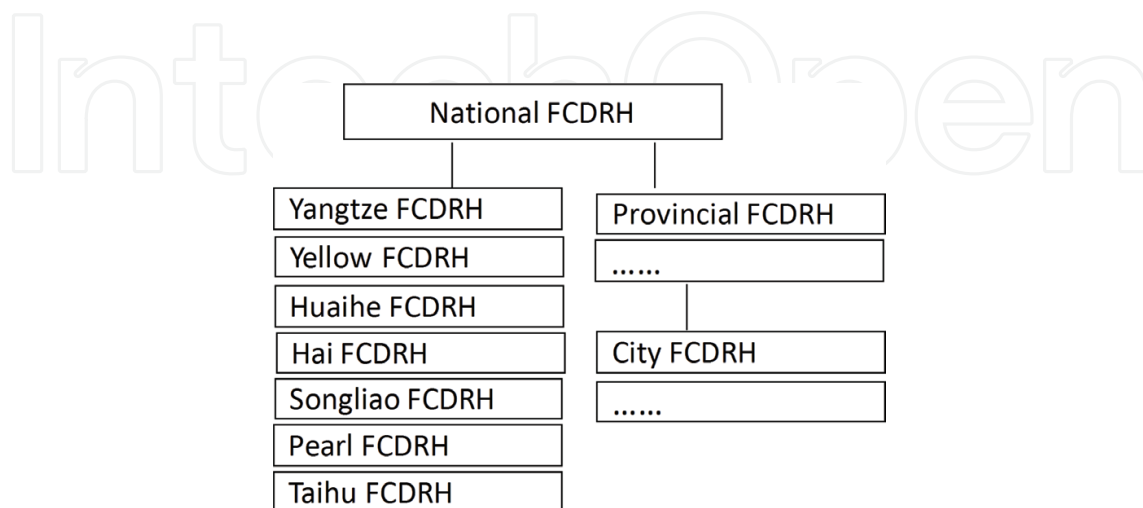
### (a) Ministry of Water Resources (MWR)

Ministry of Water Resources (MWR), the Chinese Government Department responsible for water administration, was founded in October 1949. In order to clarify the responsibilities among different ministries/departments under the State Council, Ministry of Water Resources was reorganized on July 22, 1988. In accordance with the stipulations of the State Council of the People's Republic of China, the function and responsibility of the department were summarized as follows:

- ensure rational development and utilization of water resources in China,
- formulate water resources development strategies, plans, and policies in China,
- provide draft legislations,
- promulgate water administrative rules and regulations,
- undertake integrated water resources management and supervision,
- take charge of water resource protection and water conservation,
- organize, coordinate, and supervise the work of flood control and drought relief, and be responsible for control of soil and water losses.

### (b) Flood control and drought relief commanding headquarters (FCDRH)

The flood control and drought relief commanding system has been constructed at national, river basin, and local levels (**Figure 5**). On a national level, the General Commander is a vice premier of the State Council. Its members are from administrative leaders of governmental departments and the military, who are responsible for organizing and guiding efforts in flood control and drought relief throughout the whole country [6–9]. In the six major river basins, namely, the Yangtze River, Yellow River, Huai River, Hai River, Songhua River, and Pearl River, Flood Control and Drought Relief Headquarters are constructed, and they take the



**Figure 5.** Institutional framework of Flood Control and Drought Relief Commanding Headquarters.

same responsibility of flood control and drought relief on a river basin level. In local governments that undertake flood and drought tasks, flood control and drought relief commanding headquarters are constructed as part of the local governments.

#### (c) The Huaihe River Basin Commission

The Huaihe River Commission is a river basin authority dispatched by the Ministry of Water Resources of China to exercise water administrative functions in the Huaihe River Basin and Shandong Peninsula, which is responsible for basin design and planning, flood control and drought relief, integrated water resources management, etc.

In accordance with the stipulations of the Ministry of Water Resources (MWR), the Commission is given the following major mandates in Huaihe River Basin (HRB):

1. It is in charge of making the integrated planning and related professional planning for HRB, such as water resources developing planning, annual water projects construction implementing planning, and so on.
2. It is in charge of HRB's water resources management and supervising.
3. It is in charge of checking the water body acceptance capacity for pollutant, and monitoring the water quality for the water functional areas located in the boundary of provinces.
4. It is in charge of dealing with routine work of the Huaihe River Flood Control and Drought Relief Headquarters. This includes the organization, coordination, supervision, and direction of flood control for HRB, and execution of operations of flood control and drought prevention for major river basins and key water projects.
5. It is in charge of building, managing, and operating for important water projects.
6. It is in charge of enforcing the laws and regulations relative to water administration.
7. It is in charge of organizing water and soil conservation in HRB, including development of engineering measures for water and soil conservation, and organization of the monitoring and overall prevention and control of soil and water losses.

#### (d) The local water resources management agency

The local water resources management comprises four levels, i.e., the provincial, prefecture, country, and the village (town). Overall, it has the most of main functions and responsibilities as that of the central government. Specifically, there are also direct legal duties of flood control and drought relief.

### 5.2.2. *The flood forecasting and warning system*

#### (1) The flood monitoring system

Hydrological information and flood forecasting provide basic information for flood control. By 2014, totally 329 hydrological stations (hydrologic information including information of precipitation, water level, and discharge), 220 stage gauging stations, and 2488 rain gauges

had been constructed. For those stationary gauging stations, they collect rainfall information using rainfall recorder, water level information using telemetering stage recorder, and discharge information using acoustic doppler current profilers (ADCP) or current meter. In addition, 1489 water quality monitoring stations, 324 moisture stations, and 3024 ground water monitoring stations had been constructed; all of these constitute the hydrological network and also the flooding monitoring system over the Huaihe River Basin. During flood period, with the aid of water information transmission system, 1250 stations (including important hydrological stations, stage gauging stations, and rain gauges) are mandated to collect, transmit, and share hydrological information from single state level to provincial, river basin, and the national levels. It runs at a regular time interval ranging from 6 minutes to 6 hours as stipulated on the basis of the requirement of flood forecasting for the river system [2].

### (2) Information transmission

The hydrological information is transmitted through the national telecommunication system. Most of the hydrological information collected are transmitted using client software of the transmission system. For those river reaches and water projects of special importance, short wave radio stations were established to ensure more effective information transmission. Furthermore, data collection and management have been computerized in the real-time flood forecasts on the state level, the river basin level, the province level, and the municipal level.

### (3) Flood forecasting and warning

Flood forecasting and warning were made by hydrological bureau or flood control office, which is the member of the Flood Control and Drought Relief Headquarters (FCDRH) at various levels ranging from municipal level to the country level. Faced with emergence, the FCDRH will issue warning via government at different levels. Before the flood season in every year, annual meeting of FCDRH at different levels is held to ensure preparatory work is well organized. In addition, on a national level, there are about 1000 hydrological stations that conduct river flood forecast as requested, and there are 66 hydrological stations conducting river flood forecast in the Huaihe River Basin. Numerous models, e.g., the Antecedent precipitation index (API) model, the Xinanjiang model, and tank model, have been employed for flood forecasting (Table 3) [9–13]. Most of the hydrological bureau above municipal – level established flood forecasting system in the flood forecasting [14] (Figure 6). In addition, a new real-time flood forecasting platform FEWS\_HUAIHE has also been established for probability forecasting (Figure 7).

1	P-Pa-R relation curve	7	Xinanjiang Model
2	P+Pa-R relation curve	8	Grid-xinanjiang Model
3	Z <sub>m</sub> ~Q <sub>m</sub> , Z~Q	9	Tank Model
4	Unit hydrograph	10	TOPMODEL
5	Muskingum	11	TOPKAPI
6	Tacit knowledge	12	HBV

**Table 3.** Flood forecasting models applied in the Huaihe River Basin.

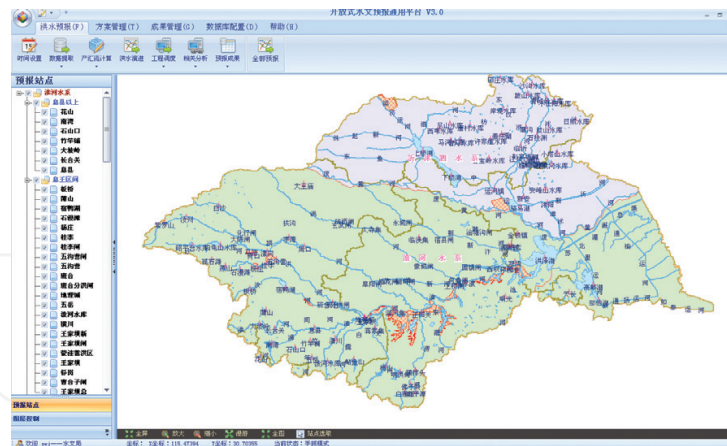


Figure 6. Real-time flood monitoring, forecasting, and warning system for the Huaihe River Basin.

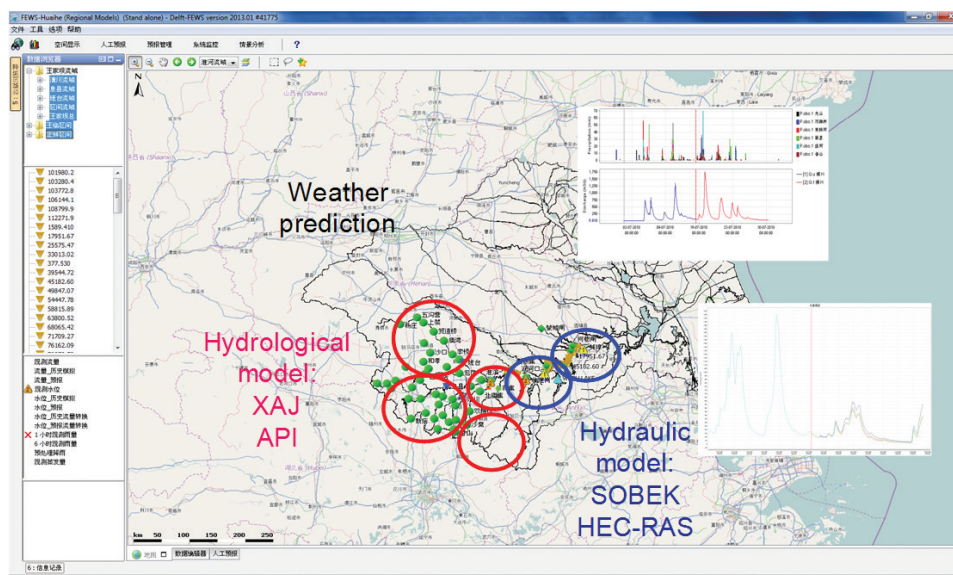


Figure 7. Probability flood forecasting system for the Huaihe River Basin.

#### (4) Decision support system for flood control

The major flood control measures can be summarized as “upper-stream storage, middle-stream passage, and lower-stream discharge” in accordance with the principle of flood prevention and regulation. Decision support system for flood control was designed for real-time control of structures in the Huaihe River Basin in case that big floods hit the basin (Figure 8). It has the following functions: reservoir regulation (Figure 9), flood bypass regulation (Figure 10), sluice regulation, hydrojunction regulation as well as joint dispatching of hydraulic structures, etc.

#### (5) Flood disaster assessment system

Flood disaster assessment system is designed for evaluating losses of flood disasters during the whole process in several key flood-prone areas in the Huaihe River Basin. It has the major function of pre-disaster evaluation, real-time evaluation, and post disaster assessment (Figure 11).

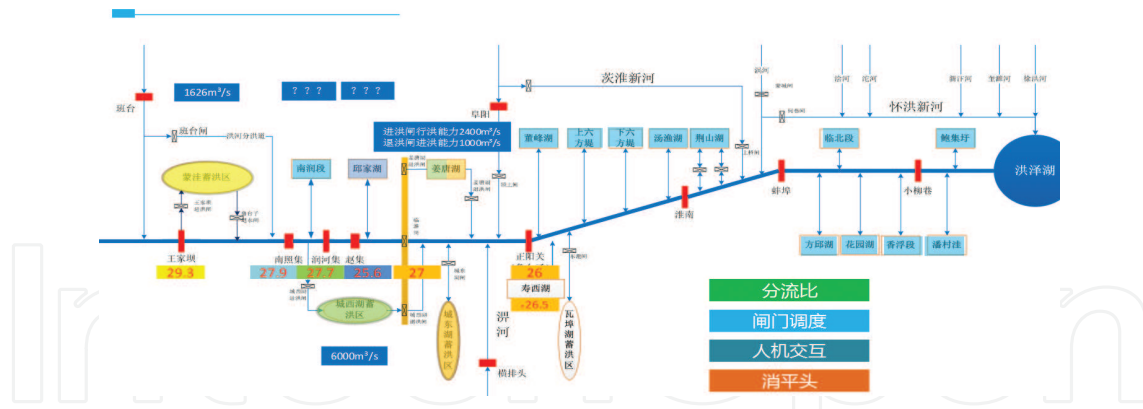


Figure 8. Topological diagram of hydraulic structures for the Huaihe River Basin.

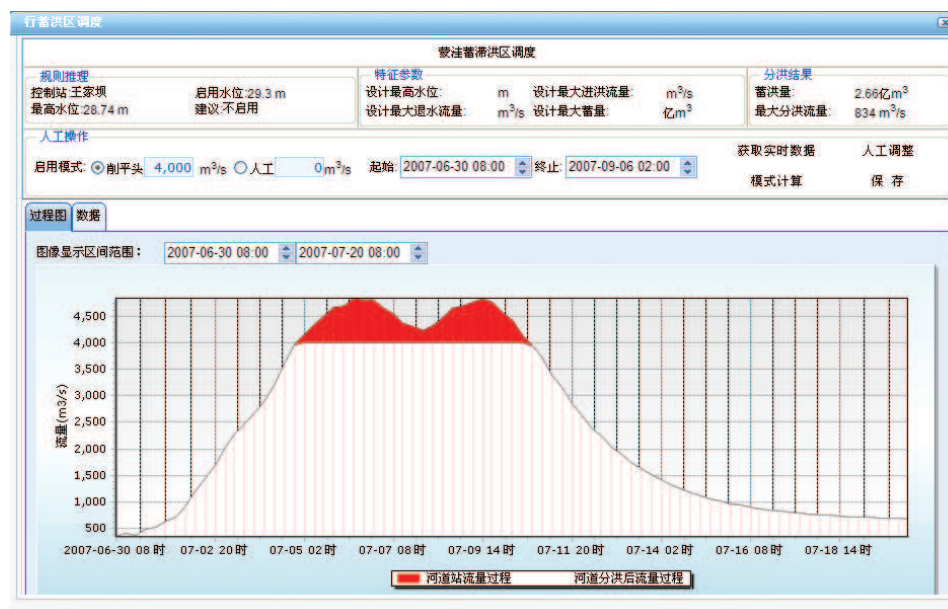


Figure 9. Interface of flood bypass regulation.

### (6) Flood risk mapping

Flood risk mapping identifies flood hazards, assesses flood risks, and partners with provinces and communities to provide accurate flood hazard and risk data to guide them to mitigation actions. Flood risk mapping is an important part of flood regulations and flood insurance requirements. It maintains and updates data through Flood Insurance Rate Maps (FIRMs) and risk assessments. FIRMs include statistical information such as data for river flow, storm tides, hydrologic/hydraulic analyses, and rainfall and topographic surveys (Figure 12).

In summary, an integrated system of flood monitoring, forecasting, and warning system, including weather prediction, flood monitoring and forecasting, flood dispatching, and flood control discussion, has been preliminarily established in the Huaihe River Basin (Figure 13), which plays a vital role in basin flood control. However, system for flood risk management, e.g., probability flood forecasting system, flood risk dispatching models for reservoirs and hydro-junction, still stays at a starting stage.



Figure 10. Interface of reservoir regulation.

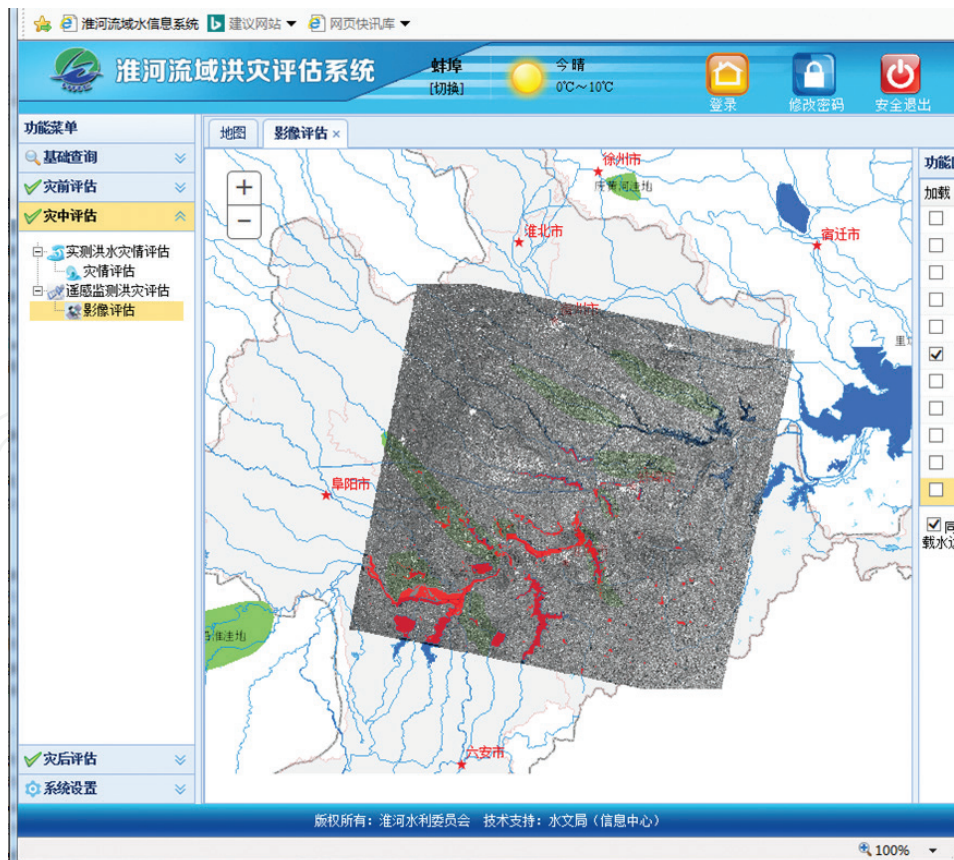


Figure 11. Flood disaster assessment decision support system.





## 6. Case study

### 6.1. Flood management for the Huaihe Basin-wide flood in 2007

#### 6.1.1. Floods in 2007 in the Huaihe River Basin

In 2007, a long-time, wide-range, and high-intensity rainfall occurred in the Huaihe basin, in which area average rainfall reached to 465 mm. Influenced by the rainfall, a multi-peak flood appeared in the mainstream of the Huaihe River. Among them, four flood peaks have been found in the upstream of Wangjiaba of Huaihe River, three peaks in the Wangjiaba-Linhuaigang section, two peaks in the Linhuaigang-Huainan section, and one peak in downstream of Huainan.

The water level of the Wangjiaba-Runheji section rose over the guaranteed stage, and the water level of the Runheji-Wangji section rose to a historically high value. According to a preliminary analysis, the return period of the Mid-Huaihe River is about once-in-15-years to once-in-20-years, while that of the downstream is about once-in-25-years.

The fierce flood lasted for a long time, affected 2.5 million hectares crops, and caused a direct economic loss of 15.5 billion Yuan. However, compared with floods in 1991 and 2003, the loss was reduced by 54.3 and 45.7%, respectively. Why did the same magnitude floods make such differences? It is primarily resulted from scientific regulation of the Huaihe River flood.

#### 6.1.2. Flood management

Flood regulation is an important part of the Huaihe River flood Management work. In 2007, all levels and branches of government facing a serious flood situation took many measures comprising of “intercept, discharge, store, divert” in accordance with “the programs for the defenses of the Huaihe River floods.”

##### (1) Intercept flood with the reservoirs on upstream

In the general flood defense process, the first step is to discharge flood with river channels, and the second step is to intercept water with reservoirs and then to store flood by detention basins. In 2007, the 18 large reservoirs in the Huaihe River upstream, such as Suyahu, Nianyushan, Meishan, and Xianghongdian, totally stored flood with an amount of nearly 2.1 billion cubic meters, which greatly released the flood defense pressure.

Although the reservoir played a significant role in the Huaihe River flood in 2007, in actual operation, it also faced many difficulties. At first, the Suyahu Reservoir and Meishan Reservoir, which are closely related to the flood control and prevention, are facing different levels of safety problems. Reservoir regulations are subject to the safety of reservoir projects, if a reservoir has safety problems, which means that the project itself is prone to the flood, and it cannot intercept flood according to design standards. The second is the difficulty of forecasting. At present, it is difficult to accurately and timely forecast sudden heavy rain in Huaihe Basin for our technology. Third, the provincial conflicts need to be coordinated. Most of the

reservoirs in the upstream of the Huaihe River are located in Henan Province. How to weigh the pros and cons has always been a difficult issue.

Suyahu Reservoir regulation is a typical example. The reservoir is located in Henan Province. On July 15, the reservoir water level reached to 54.76 m, over the flood control water level 12.26 m, and a lot of land was flooded and therefore reservoir operation was facing great pressure. At the same time, as the downstream part of the river exceeded the guaranteed stage, flood situation was very tense. The Flood Control and Drought Relief Headquarter (FCDRH) of Huaihe River, Henan Province, and Anhui Province launched flood consultations repeatedly and regulated Suyahu Reservoir carefully, and finally intercept 500 million cubic meters for downstream on the premise of guaranteeing projects safety, and thus the masses in this reservoir area have paid a heavy price.

## (2) Pre-discharge capacity of rivers and lakes

Under normal circumstances, it takes 2 days for the formation of flood peak in mainstream of the Huaihe River from the beginning of rainfall to a flood peak appears. Short-term weather forecasts can basically predict the location and quantity of rainfall. It provides an opportunity to use the project ahead of time. The Bengbu Gate is the important control hydro-junction in the middle reaches of Huaihe River. When rainfall started in upstream and a large flood forecast was reported, the Bengbu Gate opened all 40-hole gates to pre-discharge the water. As a result, when the flood arrived, the water level can be reduced from 17.85 to 16.03 m. The reduction of 1.82 m of water level provided an opportunity to receive the upstream runoff and drainage.

Hongze Lake is the largest lake in the Huaihe Basin, and Sanhe Gate is the largest controlling gate of the lake. On July 4, before the floods arrived at Hongze Lake, the FCDRH of Huaihe River coordinated with the FCDRH of Jiangsu Province and opened Sanhe Gate and began to discharge water. When flood discharge and water level reach to a warning value in the upstream, open Sanhe Gate of Hongze Lake in the lower stream in advance to decrease water level for discharging flood freely. Through analysis and calculation, Sanhe Gate discharged a cumulative capacity of 16.8 billion cubic meters for flood prevention from July 4 to July 31 for totally 28 days and reduced the water level of the lake by 0.2 m, all of which win an advantageous opportunity in flood prevention.

## (3) Make full use of detention basins for flood storage

The detention basins are important parts of the Huaihe River flood control system. When large floods occur, the use of the floodplain detention can reduce the flood volume, decrease flood peak, and lower the water level of rivers, which is a major feature of the flood prevention of the Huaihe River. The Mengwa Detention Basin is the first one in the Huaihe Basin. Due to the important location that involves the two provinces, it is scheduled by State Flood Control and Drought Relief Headquarters (FCDRH).

On July 8, the water level raised rapidly due to a heavy rain. The water level of Wangjiaba hydrological station, which is known as the Huaihe River Flood Control barometer and flood weathervane, reached quickly to 29.3 m, the guaranteed stage. At this point, the 18 large reservoirs in Huaihe River upstream were in full load operation, and the flood control

capacity was exerted to the most, many rivers exceeded the guaranteed water level, and the dangers of embankment appeared ceaselessly.

Facing the severe situation, the FCDRH promoted the flood emergency response level to grade II on July 9 and to the highest level I on July 10. This is the first time to start the highest level of flood emergency response. In accordance with request of the grade I response, the Mengwa Detention Basin was operated timely when the water level of Wangjiaba of the Huaihe River reached 29.3 m.

However, there are several real problems in storing floodwater, namely the migrant relocation and resettlement, inundated farmland, heavy loss of property, and waste of human and material resources. To operate, or not to operate? That's the question. At that time, the SFCDRH made an analysis and found that there would be three negative results when not using detention basin or using not properly. At first, inundated farmland in the upstream would be increased to 2530 hectares, with an increased area of 1340 hectares more than the use of the Mengwa Detention Basin. The second is the raising of the Huaihe River water level, which would increase the difficulty of flood prevention and threaten safety of the mainstream embankment. Lastly, probability of the use of the detention basins in downstream would be increased. However, the use of the Mengwa Detention Basin means that more than 3000 people have to be transferred, 12,000 hectares farmland would be flooded, and the part of the infrastructure in the region to be destroyed. After the five consultations by the relevant authorities, it was determined finally that the Mengwa Detention Basin would be opened. According to analysis, the basin had diverted water for 46 hours, stored flood with a volume of 250 million cubic meters, lowered the Wangjiaba water level by 0.2 m, reduced the water level of the downstream of the Zhengyangguan pass by 0.1 m, and has played a significant role in clipping flood peak. Subsequently, the Huaihe River Basin started using nine more detention basins diverted floodwater with a total capacity of 1.5 billion cubic meters. The use of these detention basins shorten the duration of Wangjiaba stage at high level nearly 20 hours.

#### (4) Divert water with the channels timely

It can relieve the pressure of flood prevention in the main stream by regulating diversion rivers to discharge a part of the flood water. Both Huaihongxinhe canal and Ruyaishuidao canal (canal to the sea) played the role of accelerating flood discharge in the Huaihe River flood prevention in 2007.

Huaihongxinhe canal is an artificial diversion river that passes through Jiangsu and Anhui provinces. In late July, the Huaihe River water level was still high. After soaking in high level water, much more dangerous situation of the embankments appeared. On the one hand, the rescue personnel were tired due to the long struggle; on the other hand, the high temperatures of 38°C caused inconvenience for the rescue team and relocated people. In order to reduce the water level of Huaihe River and relieve the defensive pressure of the downstream from Bengbu city as soon as possible, the FCDRH of the Huaihe River actively coordinated Jiangsu and Anhui provinces for reasonable operation of Huaihongxinhe canal, thereby reducing the dike defense and emergency pressure, and 110,000 metastatic masses returned home 2–4 days ahead of time and returned to a normal production and living order.

## 6.2. Room for river project in the Huaihe River Basin

### 6.2.1. Development of "Room for river" idea in the Huaihe River Basin

From 1950 to 1969, there were 10 flood storage areas (total area is 3788 km<sup>2</sup> and flood storage capacity is 10.18 billion m<sup>3</sup>) and 21 flood bypasses (total area is 1301 km<sup>2</sup> and flood discharge capacity is 1000~3500 m<sup>3</sup>/s when fully open).

The HRB has constructed five flood storage areas (total area is 3300 km<sup>2</sup>, and flood storage capacity is 9.3 billion m<sup>3</sup>) and totally 21 flood bypasses. These flood diversion and storage areas constitute as part of the flood control engineering system and played important roles in preventing basin-wide floods in the past.

However, there are also outstanding problems, e.g., too many flood bypasses occupy river's room, evacuation of 1.8 million people is a hard work, etc.

Since mid-1980s to the twentieth century, problems of flood diversion and storage areas have received a great deal of attention, new ideas about the Huaihe harness have progressively formed, i.e., properly reducing number and area of flood diversion and storage areas, enhancing river channel discharge capacity, reducing the probability of using flood bypasses, and reinforcing security construction of people's safety.

By 2010, number of flood bypasses along the Huaihe mainstream reduced from 21 to 17, of which four flood bypasses were abandoned and returned room to river with an area of 24.3 km<sup>2</sup>, other flood diversion and storage areas returned room to river with an area of 96.4 km<sup>2</sup> by partial dike retreat, and totally returned 120.7 km<sup>2</sup> area to river.

By the plan completion in 2020, only six of the 17 flood bypasses will be preserved, among which two of them will be abandoned, three of them will be changed to flood storage areas, and five of them will be adjusted to flood protection areas (**Figure 14**).

Totally, 230 km<sup>2</sup> will be returned to river, width of river channels will be increased 100~2500 m, and flood discharge capacity will be increased from 800 to 1200 m<sup>3</sup>/s. The operation standard of the preserved flood bypasses will be promoted to once in 10–20 years (**Figure 15**).

From the start time of the flood diversion and storage areas construction to now, flood diversion and storage areas have experienced from "conflicts between human & water", to "co-existence of human & water" and finally to "harmony between human & water", which also reflects development of idea about "Room for river" in the HRB.

What follows take Jingshanhu flood bypass as a case study.

### 6.2.2. Room for river: Jingshanhu flood bypass as a case study

Jingshanhu flood bypass is about 4 km long from east to west, and 17 km wide in south-north direction, with an area of 72.0 km<sup>2</sup>. It plays a vital role in raising the flood-diversion capacity and decreasing water levels of Bengbu and Huainan cities.

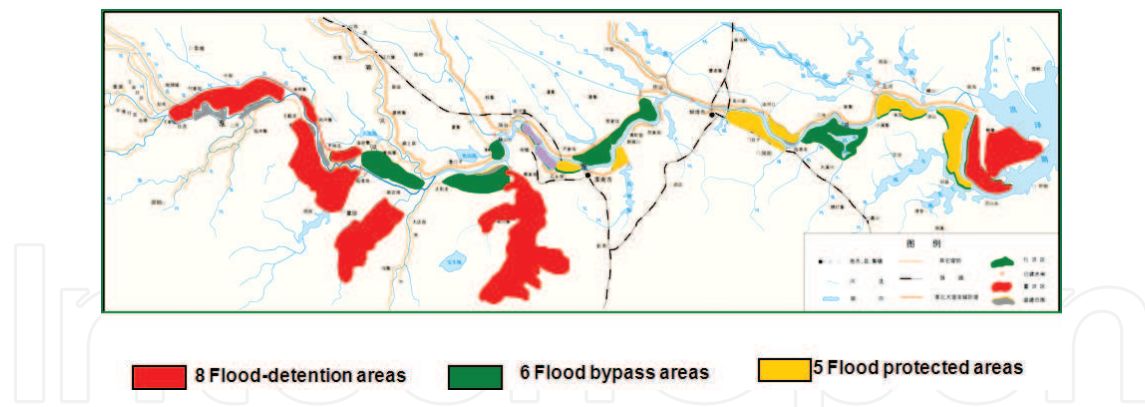


Figure 14. Adjustment of flood detention areas and flood bypass in 2020.

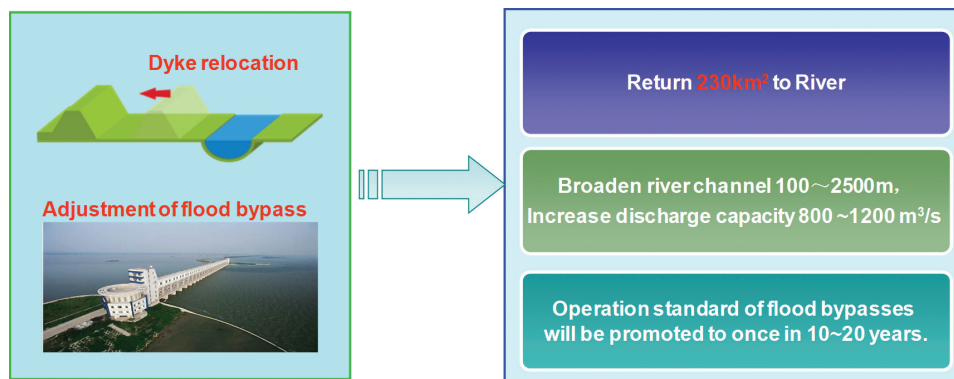


Figure 15. Achievements after completion of adjustment of flood detention areas and flood bypass.

The major problems before the harness were as follows: (1) The river channel is narrow, river channel for flood discharge is only 500 m wide, and maximum discharge capacity is only 5700 m<sup>3</sup>/s. (2) There are 10,000 people in the Jingshanhu flood bypass and most of them live in the plain area, which involves a large amount of works when carrying out immigration. (3) The flood bypass operates so frequently that it causes serious property losses. (4) The controlling gates of the flood bypass are so inconvenient that it cannot be timely and effectively operated. (5) Reconstruction after disaster involves hard works.

By retreating, reinforcing, and newly constructing dykes with a length of 42 km, constructing one withdrawal sluice and one intake sluice, and security construction, e.g., retreat road construction, reinforcement of Zhuangtai (small villages on raised ground with higher elevation), communication and warning facilities, etc., the chance of flood diversion was promoted from once-in-7-years to once-in-15-years, and it has significant effects.

After the control measures were implemented, the following achievements have been made:

1. The problems of local people's security have been solved. There are only 855 people living in the flood-protected villages.

2. The flood dispatching measures have been strengthened. In 2007, the Huaihe River Basin was hit by a basin-wide large flood event again and the newly-built intake and withdrawal sluices firstly came into use and showed good effects.
3. The flood passage of the mainstream has been enlarged. After the implementation of dike reconstruction and reinforcement, the width of the dike inside reached to 600 m, and the release discharge of the reaches lower than Zhengyangguan pass in the mainstream can reach to 8000 m<sup>3</sup>/s without using the flood bypass.
4. Probability of using the flood bypasses has been promoted from once-in-7-years to once-in-15-years.
5. If inundated, economic losses of peasants have been compensated by our country and it is conducive to resume production.

**Table 4** summarizes control measures and achievements of Jingshanhu flood bypass.

Control measures	Achievements
Relocating, strengthening, and newly constructing 42 km dykes and dredging 3.7 km river channels	Returning 4.5 km <sup>2</sup> lands and enlarging river channels with a width of 600 m, and thus discharge capacity of these reaches has been increased to 800 m <sup>3</sup> /s
Constructing one withdrawal sluice and one intake sluice	Intake and escape sluices have been constructed for timely and effective operation
Constructing inside security facilities	Inside security facilities, e.g., retreat road and Zhuangtai (village on raised ground), etc., have been constructed
Most of the people living inside have been relocated to other safe areas outside	A total of 800 people have been relocated to safe villages on raised ground and the rest 9000 people have immigrated to flood protection areas and got rid of flood threat
Constructing drainage pumping stations and improving drainage system inside	Two drainage pumping stations and improving drainage system inside have been constructed

**Table 4.** Control measures and achievements of Jingshanhu flood bypass.

## 7. Experiences and enlightenment

China is a flood-prone country, and flood disasters occur frequently. The Chinese Government attaches great importance to flood management and drought relief, and great efforts and achievements have been made with aid of the structural and non-structural measures. However, flooding is still a big issue in China. The ability to control floods needs further improvement of the non-structural measures, including the relevant laws, monitoring networks, warning and forecasting, and social management [14].

Both the structural and non-structural measures are very important for flood control and management. However, for the over-standard flood cases, the non-structural measures, such as the hydrological monitoring and flood forecasting, become much more important.

Flooding is still a big issue in China. The ability to control floods needs further improvement of the non-structural measures, including the relevant laws, monitoring networks, warning and forecasting, and social management.

### 7.1. Experiences in flood management

Flood disaster, which occurred suddenly and inevitably, is different from the general emergency disasters. It is determined by the natural conditions of the Huaihe Basin. By review of the Huaihe River flood regulation, it is found that the keys of success are still dependent on the following factors:

1. The complete flood control structural system is the foundation of flood regulation and management. The standard and quality of the flood control works are directly related to flood management and projects operation. Although the standard of the flood control system in Huaihe Basin is not high enough, it is compounded by a wide range of works with high correlation. Their operation is very flexible, especially the flood regulation of detention basins and diversion channels like Huaihongxinhe canal and Rahaishuidao canal (floodway to the sea), and plays a vital role in flood control. In future, we should strengthen the construction of structural system for flood prevention and increase the flood control standard appropriately.
2. Accurate hydrologic forecasting is the prerequisite of the flood regulation. The forecast accuracy and the lead time will directly affect the correctness and timeliness of the flood regulation decision. In recent years, the extreme weather events have increased significantly from global perspective. The sudden strong rainfall is unforeseeable, and it becomes a new issue for flood prevention work. In the future, we should continue to strengthen early warning system, to optimize flood forecasting model, and to improve forecast accuracy and quality. Particularly, there is an urgent call for constructing an ensemble flood forecasting system integrating with numerical weather models, distributed hydrologic models, hydraulic models, and real-time control models.
3. Scientific analysis and judgment of the flood are the key to flood regulation. Flood regulation should consider all factors as an integrated system, including upstream and the downstream, both sides of river, global and local, flood control and drought relief, as well as economy and society. To balance different interests is a hard nut to crack in decision-making. In future, we need to continue to strengthen the flood management and risk management and to resolve the problems in laws and regulation, mechanism, technology, and other issues.
4. Advanced technology and perfect plan are the effective support for flood regulation. Huaihe River floods in 2003 and 2007 are not only a test of the flood structural system, but also a full inspection of the Huaihe River non-structural system. All of advanced technology and comprehensive plan of flood monitoring and forecasting, flood control scheduling, emergency management mechanism, and the joint regulation of the flood engineering system play an important role in joint operation of flood control structural system. In future, we should learn from domestic and international flood management experience, promote the application of high technology, constantly improve the flood control, and strive to reduce disaster losses.

## 7.2. Outlook on flood management in the Huaihe River Basin

In the future, we have to change from flood control to flood management and finally achieve the goal of flood risk management.

1. Room for River. In terms of river planning and training, it is necessary to make more room for flood and formulate relevant schemes and measures by comprehensive analysis of flood. Based on the structural system comprising of reservoirs, dykes, and flood detention areas, we have to enlarge passageway for small and middle magnitude floods in river harness for the purpose of releasing such kind of floods. To construct flood detention areas to receive extra floods that exceed the river channel capacity aims to solve the big flood issues.
2. Live with floods. In order to realize harmony between human and nature, first and foremost, an integrated flood control and management system should be well established on an operational level. In addition, in order to achieve a shift from flood control, flood management to flood risk management, there is urgent call for raising awareness of flood risk management both for the leader and the public.
3. Flood risk management. We do not have to control all floods of different magnitude, and we cannot bear enormous flood disaster risk. We have to avoid risks actively, take preventive measures as high priority, live far from flood disasters, and control flood disaster risk to a certain extend. We have to determine reasonable flood protection standards, and the standards should not be too high or too low. We have to classify function of flood structures in a reasonable way, because flood disaster risks could propagate if function of flood structures is not classified correctly or properly. We have to share risks. Construction of flood structures can absolutely cause risk propagation; therefore, we have to treat risk propagation in a right way and different regions have to share flood risk and construct flood risk compensation mechanism and flood insurance system.

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