Hydrological monitoring and flood management in China

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Abstract Flood disasters have been recognized as the most severe natural hazard in China. Strenuous efforts have been made in flood control since 1949. The Chinese government has developed a series of policies and measures for flood control and management. On the one hand, the importance of structural measures such as dyke reinforcement, river regulation, construction of reservoirs, and the building of flood detention and storage basins, has been emphasized. On the other hand, non-structural measures such as hydrological monitoring and forecasting, development of flood control operation pre-schemes, formulating and modifying laws and regulations, and flood risk management have been strengthened as well. Hydrological monitoring and flood forecasting are key non-structural measures for flood control, especially in the case of over-standard floods in China. Based on the powerful database management system and the fast Wide Area Network, a series of operational hydrology software systems have been developed for flood monitoring, warning and forecasting.

Key words flood control and management; flood disaster; flood forecasting; hydrological monitoring

Technologie de la prévision hydrologique et des crues en Chine

Résumé Dans cet article on abordera brièvement les caractéristiques générales de l’hydrologie et des crues en Chine, on présentera le développement d’une technologie de prévision hydrologique à travers les méthodes, les modèles, le calage des paramètres et les systèmes de prévision opérationnels et on discutera un modèle chinois (Le modèle Xin-An-Jiang) et ses applications. Enfin on discutera également de la prospective et du développement de techniques nouvelles pour le futur.

Mots clefs hydrologie des crues; technologie de prévision hydrologique; systèmes de prévision opérationnels.

INTRODUCTION

Due to its special geographical location and climate conditions, China has frequently been hit by floods and suffered from flood disasters. With the population growth and fast socio-economic development, the economic losses due to flood disasters have increased rapidly since the 1990s, and have become one of the constraints for sustainable development. Strenuous efforts including structural and non-structural measures have been made in flood disaster prevention and mitigation since 1949. China has formed a flood control engineering system with the focus on dyke reinforcement, river regulation, construction of reservoirs, and building of flood detention and storage basins. This engineering system has provided a basic guarantee for economic development, the improvement of living standards, social stability and ecological and environmental improvement. Meanwhile, since the devastating floods of 1998, non-structural measures such as hydrological monitoring and forecasting, the development of flood control operation pre-schemes, formulation and modification of laws and regulations, and flood risk management, have been significantly strengthened as well. Hydrological monitoring and flood forecasting are of key importance as non-structural measures for flood control. They play a very important role in flood control and management, especially in the case of the over-standard flood in China. In this contribution, flooding and flood disasters in China will be introduced, the Chinese experience of flood control and management will be shared, and in particular, the hydrological monitoring, flood forecasting and warning techniques and operational systems employed in flood management in China will be presented.

FLOODS AND FLOOD DISASTERS IN CHINA

The vast area of East China and most of South China are dominated by the Eastern Asia monsoon, which results in dry winters and wet summers. Precipitation is distributed quite unevenly temporally and spatially in China. Annual precipitation is over 1600 mm in the southeast, while this figure drops to only dozens of millimetres in the northwest. In most parts of China, the rainfall is of high intensity and concentration in time; about 60~80% of the annual precipitation falls during the rainy season, which normally lasts for about four months. All these features lead to the concurrent occurrence of high severity flood and drought disasters in China.

According to the historical record, 1092 large flood disaster events have occurred since 206 BC in China, i.e. over a period of 2155 years, which means that there is one in every two years on average. At the beginning of the 20th century, the major rivers in China were struck by a number of disastrous floods. In 1931, disastrous floods hit the Huaihe River basin and the Yangtze River basin. Over 51 million people were affected, of which 400 000 died. However, since 1949 the loss of life due to floods has declined more and more compared with that before 1949 because of the flood control projects put in place and efforts made in flood preparedness (Fig. 1). Taking the Yangtze

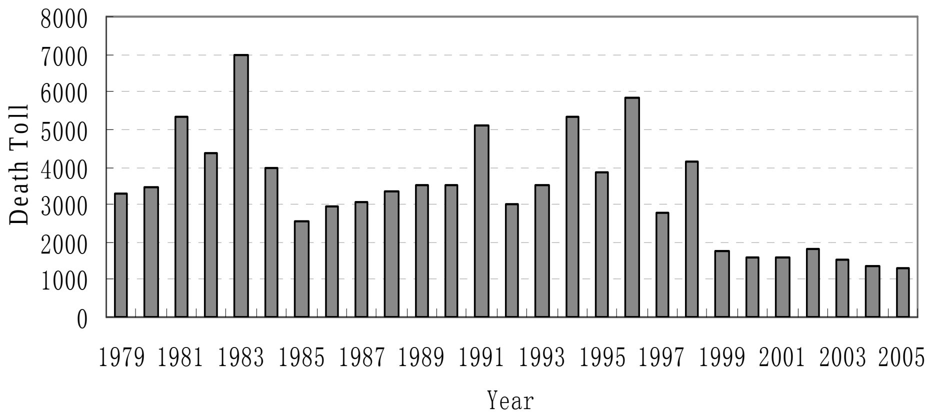

Fig. 1 Loss of life due to flood disasters in China since 1979.

River as an example, the flood of 1998, which was close to the maximum since 1949, only caused 1320 deaths, while the disastrous flood of 1954 caused 37 000 deaths.

However, with the population growth, rapid urban-expansion and economic development, the economic losses due to flood disasters have increased rapidly (Fig. 2). Statistics show that since the 1990s, the national averaged economic loss directly caused by floods has exceeded RMB 110 billion every year, equivalent to 2% of the national GDP in the same period. On average, about 10 million ha, which accounts for about 10% of China’s total farmland, was affected annually by floods during the period since 1949. Flood control and management are of vital importance to China for its social and economic development.

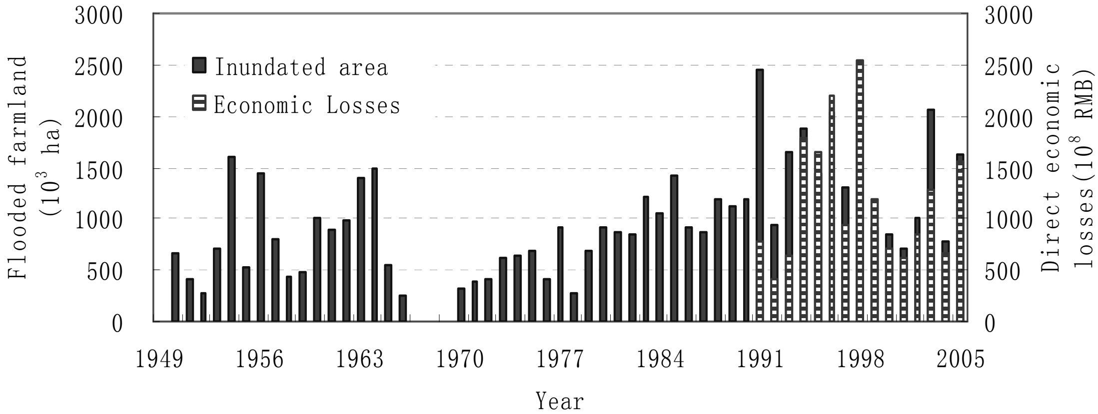

Fig. 2 Flood disaster damage in China since 1949.

FLOOD CONTROL AND MANAGEMENT IN CHINA

Since 1949, the Chinese government has attached more and more importance to flood disaster prevention and reduction. On the one hand, structural measures, such as dyke reinforcement, river regulation, construction of reservoirs, and the building of flood detention and storage basins, have been increased. On the other hand, non-structural measures such as hydrological monitoring and forecasting, developing flood control operation pre-schemes, management of flood storage and retardation basins, flood risk management and flood insurance systems have also been strengthened. The major structural and non-structural measures of the flood control system in China are shown in Fig. 3.

The Water Law of the People’s Republic of China, which was adopted in 1988 and revised in 2002, is the first basic law on water since 1949 (Zhang, 2005). It marked the beginning of the new period of development, utilization, protection and management of water resources as well as control of water disasters in the country. The Law of Flood Control, adopted in 1997 and enforced in 1998 (http://www.mwr.gov.cn/english1/laws.asp, 2004), was formulated on the basis of rules and regulations of flood prevention, river management and the *Guideline on Safety Building of Flood Storage and Detention Basins*. Moreover, a number of administrative

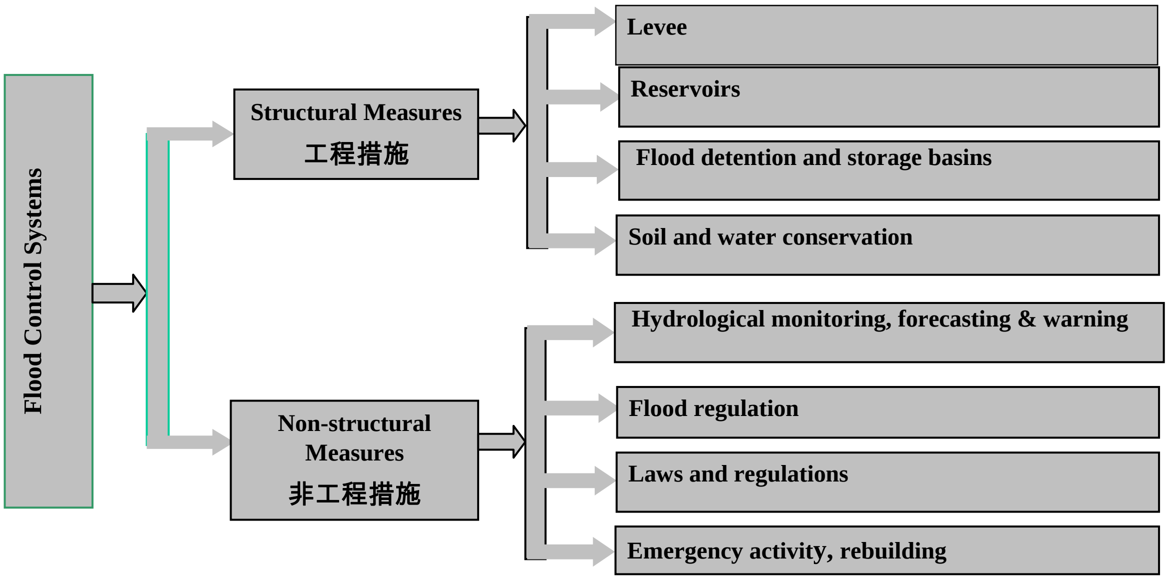

Fig. 3 Major structural and non-structural measures of flood controlling systems in China.

regulations were issued by the central government to regulate the activities of the parties concerned in flood control, such as the *Rules and Regulation of Flood Prevention* (1991), the *Regulation of River Course Management* (1998) and the *Guide to the Safety Building of Flood Storage and Retarding Basin* (1988), etc. These laws and regulations have played an important role in flood management in China.

However, with the rapid economic development, population growth and the urbanization process, many problems arose in facing the new challenge. Since the devastating floods in 1998, the central government has worked out a series of new policies and measures on flood control. The new policy of flood management that is being implemented emphasizes the need to provide adequate space for floods by restraining human activities. Guided by this concept, China will execute scientific management of rivers, lakes, flood detention areas and flood storage facilities, in order to enlarge the flood storage and discharge capacity. To obtain a better flood mitigation result, flood warning and hydrological forecasting systems and risk management should also be strengthened. Meanwhile, due to the shortage of water, rational use of rainwater and floodwater resources is encouraged both in research and practice.

Structural measures for flood controlling and management

In the 1950s, comprehensive basin planning was worked out for all the major rivers, in which flood control was regarded as the priority issue. Modification and revision were later made on the basis of flood control practice and with consideration of the social and economic development. The major flood control works operating in China by 2004 (MWR, 2005) can be summarized as follows:

Levees The total length of river embankments is about 277 000 km, which protects 531 million people and 43.9×10^6 ha of farmland. According to the requirements of the flood control plans for river basins, 95 000 km of embankments which meet the flood control standards, have been constructed. Meanwhile, river dredging and training works were carried out together with the opening of new flood diversion passages to the sea for the Huaihe, the Haihe and other rivers.

Reservoirs Over 85 000 reservoirs have been constructed with a total storage capacity of 554×10^9 m^3 and a flood-control storage capacity of 100×10^9 m^3, and have played a significant role in the control of floods. Among these, there are 460 large-sized reservoirs (storage capacity $\geq 1 \times 10^8$ m^3) with a total capacity of 414.7 $\times 10^9$ m^3.

Flood detention and storage basins There are 97 flood detention and storage basins along the major rivers with a storage and retardation capacity of 103×10^9 m^3. These handle floodwaters exceeding the design standard. These flood control systems are capable of controlling the ordinary flood (under-standard flood) for the major rivers in China. When big floods occur, the flood disasters in the plain areas are restricted within the planned flood detention and storage basins, and so the flood damage in the basin can be greatly mitigated, particularly in the middle and downstream areas.

Soil and water conservation By the end of 2004, the total area affected comprehensively by soil erosion had amounted to 920 000 km^2, in which small watersheds occupied 360 000 km^2. However, the Chinese government has spent huge amounts to fund the planting of trees, and forbid farming and pasture destruction in mountainous areas, in order to control and reduce the soil loss, and to improve the ecology of the environment. Meanwhile, dynamic monitoring of soil erosion was implemented in key areas, for guiding and evaluating the soil conservation work. Some monitoring projects have been implemented in important regions, for example, in the Jialing River basin, the source areas and regions of rich and coarse sands of the Yellow River basin and the Haihe River basin (MWR, 2005).

Non-structural measures

Non-structural measures refer to laws and regulations, administrative management and economic levers, and other technical measures such as hydrological monitoring and flood forecasting, and development of flood operation pre-schemes for the purpose of flood disaster mitigation.

Generally speaking, non-structural measures for flood control in China can be classified into four steps (Fig. 4): data collection (hydrological monitoring and data transmission), flood forecasting and prediction, decision making and emergency response plus rebuilding activities. Regarding data collection, China’s effort is focused on using advanced monitoring and measuring technologies to equip hydrological stations and realize automatic data collection so as to raise the quality and speed of hydrological data collection. As for communication, based on wide use of the national public communications network, technical measures such as satellite, microwave and integrated communication have been adopted to supplement and improve the flood control communication network so as to strengthen its function. With regard to flood

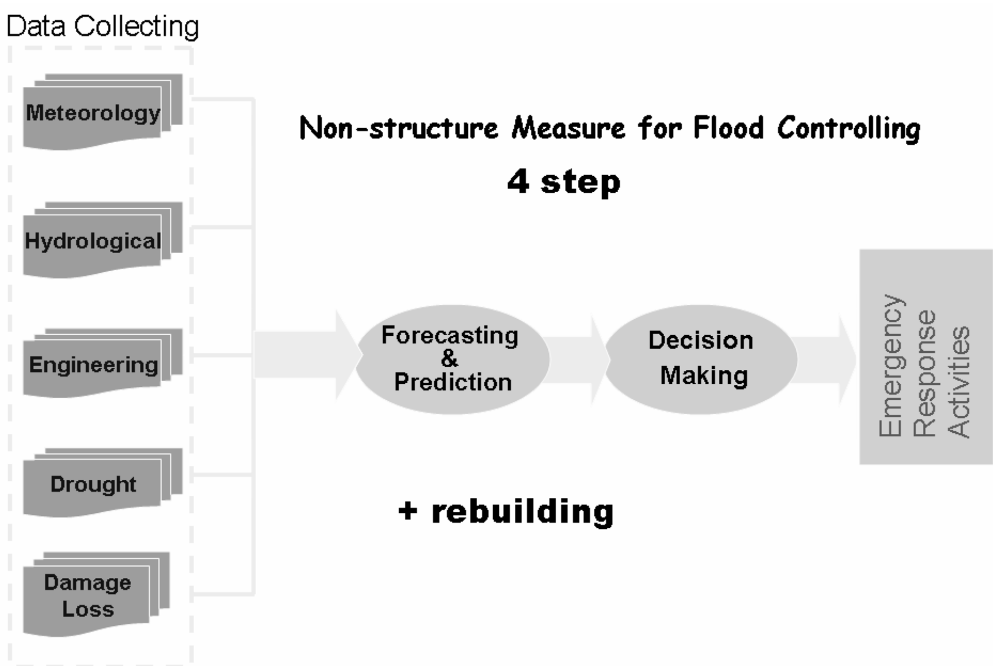

Fig. 4 Non-structural measures for flood control in China.

forecasting and prediction, the National Flood Forecasting System was developed by the Bureau of Hydrology, Ministry of Water Resources, China, in the late 1990s, and has been applied widely over the country by the central government, river basin committees, provincial and city level hydrology agencies. A decision support system based on hydro-meteorological information with a GIS platform for flood control and drought relief has been developed and since 2000 it has been used by the Ministry of Water Resources. It will be established in all the flood control agencies, river basin committees and provinces through the on-going project of State Flood Control and Drought Relief Commanding System.

Non-structural measures are crucial to reap the full benefits from structural flood control systems and to achieve the desired results of flood control and disaster reduction. They also provide risk management for flood control zones, especially the areas suffering from frequent floods, and enable adoption of the management mode that will have the smallest impact and cause least losses to human survival and development.

HYDROLOGICAL MONITORING AND FLOOD FORECASTING IN CHINA

Hydrological monitoring

Hydrological monitoring and flood forecasting are the basis of flood prevention and disaster mitigation during the rainy season. By the year of 2004 (MWR, 2005), there were 3182 national essential hydrological stations (most of those stations gauge precipitation, water level, discharge and sediment), 1134 water stage stations, 14 108 raingauges, 3946 water quality stations, 11 757 groundwater stations and 358 evaporation stations in the whole country; these constitute the hydrological network as well as the flooding monitoring system across China. Of these, about 7600 hydrometric stations are mandated to report/release hydrological information at a regular time interval stipulated on the basis of the requirements of flood forecasting and water resources management for the river system.

Discharge is normally measured using cableways and hydrometric boats. The current-meter method is commonly used for discharge measurement, while alternatives including the float method, discharge calculation by the hydraulic method, and flow measurement by hydraulic structures, are used when ordinary hydrometric facilities at the gauging stations are destroyed due to floods. Currently, some new techniques and methods, such as the Acoustic Doppler Current Profiler (ADCP), are being applied to measure flow in China.

Generally speaking, more than 600 million pieces of data about hydrology and water resources are collected per year in China. These provide a reliable basis for flood control, drought relief, water resources management, water environment protection, planning of water-related works, and national economic planning and development.

Data transmission

Rainfall, discharge and other flood information are first transmitted from hydrometric stations to the hydrological data sub-centres by means of telephone, GPRS, radio (microwave, short-wave, ultra-short wave, etc.), ground satellite stations and cable, and are then transferred to the provincial-level data centres, river management committees and Ministry of Water Resources through the WAN (Wide Area Network) of 2 Mbps, which was specially constructed for hydrological data transmission.

The central government has approved the project to set-up a National Flood Control Command System. Under that project, 224 hydrological information sub-centres will be established using advanced sensor and communication techniques, in order to improve the data quality and to increase the speed of data transmission. When the system is operational, all data from the system will be transmitted to the data centres at province, river basin committee, and the Ministry of Water Resources within 30 minutes. It is planned that 125 sub-centres will be completed by the end of 2006.

Flood forecasting and warning

In China, flood forecasts and warnings are made by the Flood Control and Drought Relief Headquarters (FCDRH) at various levels; for example, the central government, the river basin commissions, and the province level. At the central government level, the Bureau of Hydrology, MWR, as the technical support department to the State Flood Control and Drought Relief Headquarters (SFCDRH), is in charge of the flood forecasting and warning for important river reaches and reservoirs. At present, there are 1052 hydrological stations issuing flood forecasts.

According to the Law of Flood Control, the forecasting and warning information will be issued to the public via radio, TV, newspapers, and other media only by different levels of government, which depends upon the seriousness of the flood situation. In the extreme emergency case, for example the use of a large flood-detention area within which there are thousands of people and many properties, the warning information and the decision should only be made by central government, i.e. by the chief of the SFCDRH (who is usually one of the vice-premiers).

Based on the powerful database management system, GIS platform, and the WAN, a series of hydro-meteorological operational systems have been developed and widely applied, such as the SkyEye-2000 Hydro-meteorology Information System, China National Flood Forecasting System (CNFFS), and the Hydrological Information Consultation System (HICS) for supporting the decision making for flood controlling, the Hydrological Information Service System, etc. All of these systems play an important role and significant benefits in flood management have been gained.

The hydrological modelling techniques (Liu & Zhang, 2005) for flood forecasting have been developed since the early 1950s, on the basis of the conventional methods of runoff yield analysis and flood routing, the Chinese Xin'anjiang Model (Zhao *et al*., 1980; Zhao, 1992; Zhao & Liu, 1995), and other models such as API, Sacramento, Tank, SMAR and SCLS (Liu & Zhang, 1996; Wang, 2000) are also employed in many river basins' forecasting systems (Table 1).

Table 1 Flood forecasting models applied in China.

1	Xin'anjiang Model	10	SMAR Model
2	API Model	11	NAM Model
3	Jaingwan Runoff Model	12	Tank Model
4	Hebei Storm Flood Model	13	Sacramento Model
5	Shanbei Model	14	SCLS Model
6	Xin'anjiang Model for Semiarid Areas	15	Index Recession Method
7	Liaoning Model	16	Recession Curve Method
8	Double Attenuation Curve Model	17	Unit Hydrograph Method
9	Double Excess Runoff Yield Model		

The Xin'anjiang model was developed at Hohai University in Nanjing in the 1960s, and was revised into different versions during the 1970s and 1980s. The Xin'anjiang model has three components:

(1) runoff generation, the model considers the pervious area and the impervious area, and in the pervious area, one curve which reflects the features of the soil's capacity to hold water is employed with a three-layer evaporation model;

(2) the generated runoff is divided into surface runoff (RS), sub-surface runoff (RI), and underground water (RG) according to the geological features of the basin and its infiltration capacity; and

(3) the routing part, the RS can be routed into discharge into the river using the unit hydrograph or Nash routing model, the RI and RG can be routed into discharge using the Nash Linear Reservoirs model or other methods.

The Xin'anjiang model is now widely applied in China, and in particular works quite well for middle and large river basins in humid regions. A flow chart of the model structure of the Xin'anjiang Model is shown in Fig. 5.

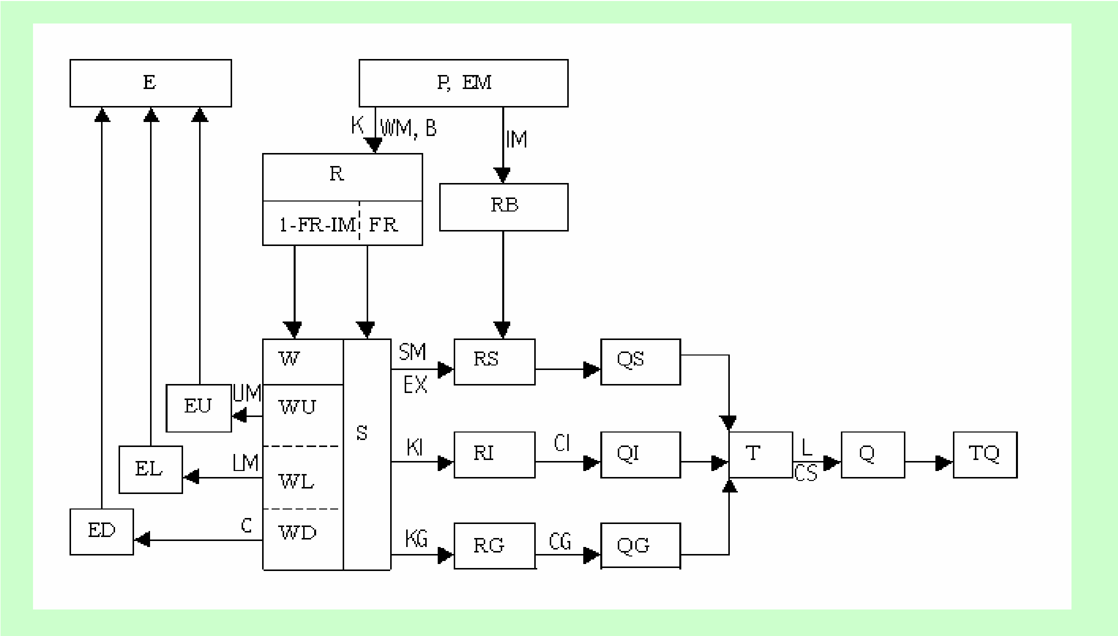

Fig. 5 Flowchart of the Xin'anjiang model (after Zhao & Liu, 1995).

CONCLUSIONS

China is a country that suffers from frequent floods. Nowadays flood and drought disasters have become a major restraint in China's economic development. The Chinese Government have given a very high priority of flood management and drought relief, both through structural measures to increase the ability for flood prevention and control, and non-structural measures to improve the precision of flood forecasting and regulation, and to improve the quality of the decision making.

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.

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