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Current Flood Control Countermeasures of the Yangtze River Basin

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Synopsis

The 1998 flood attacked Central and Northeast China and caused the most serious flood damage, which is estimated as the biggest one since the foundation of China in 1949. To enhance the flood control of major rivers and lakes, structural measures, such as constructing and consolidating river levees, are emphasized as the measures taken in previous flood damage years. Through brief description and analysis to current flood control measures in the Yangtze River Basin, some problems concerned are presented. Since the United States and Japan have successful experiences on flood control, their measures concerning comprehensive flood control including structural and non-structural measures are introduced. Consequently, the feasibility to implement such measures in the Yangtze River Basin is discussed and some significant measures, which can be taken at present, are proposed.

Keywords : *flood control measures; the Yangtze River Basin; comprehensive flood control*

1. Introduction

Devastating floods hit Central and Northeast China in the summer of 1998 and caused the most severe flood disaster losses since the foundation of China in 1949. During the period, various comments on flood reasons and flood control measures were reported through mass media. Low flood control standard system, ecological environment damage and special climate conditions were treated as major reasons for 1998 flood disasters in China by most people. Also, based on such viewpoints, some suggestions such as improving levees, banning illegal land reclamation, enhancing soil and water conservation, and constructing large-scale flood control projects are proposed.

Following 1998 summer floods, Chinese government has set to improve flood control ability of the Yangtze and Yellow Rivers and of China's other major rivers and lakes in a short period. The construction and reinforcement of levees have become a matter of top priority in China. The goal is to build major river levees into first-class ones with the standard designed to withstand the worst flood with one hundred-year return period. However, compared with previous flood damage years, structural flood control measures such as improving levees and constructing reservoirs are still emphasized than non-structural ones.

Looking back on the Yangtze River flood control history of the recent 50 years from 1949 to 1999, there is a contradictory evidence. On one hand, unprecedented progresses on Chinese water conservancy construction have been made. For instance, major levees and branch levees have been constructed and improved; a large number of reservoirs were built; many flood diversion and detention areas were constructed along the middle and lower reaches of the Yangtze River. On the other hand, flood damages remain increasing according to the statistics from the Ministry of Water Resources of China. The evidence indicates that the structural projects alone have not effectively reduced flood damages. Current situation of flood prevention and disaster reduction in China is very similar to that in the developed countries such as the United States, Japan and the Netherlands during the period from the 1960's to the 1980's. At that time, flood damages remained high even with the addition of flood control investment on structural projects.

With rapid economic development after the 1980's in China, the process of urbanization results in increasing concentration of property and population in flood-prone areas since there are convenient conditions and abundant resources. Consequently, even if the same level disastrous floods occur, more severe flood damage is possibly caused. China is a developing country, it is very difficult or unrealistic to require higher standards to all structural projects for flood control in a limited period although it may be necessary. Whereas lacking effective flood control measures, flood damage will impede social and economic development severely. In this case, it is much necessary to study more effective flood control countermeasures.

Comprehensive flood control including structural and non-structural measures have been put forward firstly by the United States around the 1960's and then were taken as a reference by other countries such as Japan, France, Canada to make their respective flood control strategies according to each national conditions. In spite of the different conditions from those countries, China still has many similar problems on flood control with them. Considering these factors appropriately, it may be possible or effective to apply their experiences on flood control into China.

For the above-mentioned purposes, in this paper, firstly, the authors analyze current flood control measures in the Yangtze River Basin and their problems, since the Yangtze River is the biggest river and suffered much flood damage in 1998 flood. Then, some achievements made by the United States and Japan on their flood control measures are introduced. Finally, the feasibility to implement comprehensive flood control measures in the Yangtze River Basin is discussed and some significant measures, which can be promoted as soon as possible based on the authors' opinions, are proposed.

2. The Yangtze River Basin and Its Flood Control

2.1 General situation

As the biggest river in China, the Yangtze River has a total length of about 6,300 km and a total watershed area of about 1.8×10^6km^2. As shown in **Fig. 1**, Yichang and Hukou divide the whole river into three parts: the upper, middle

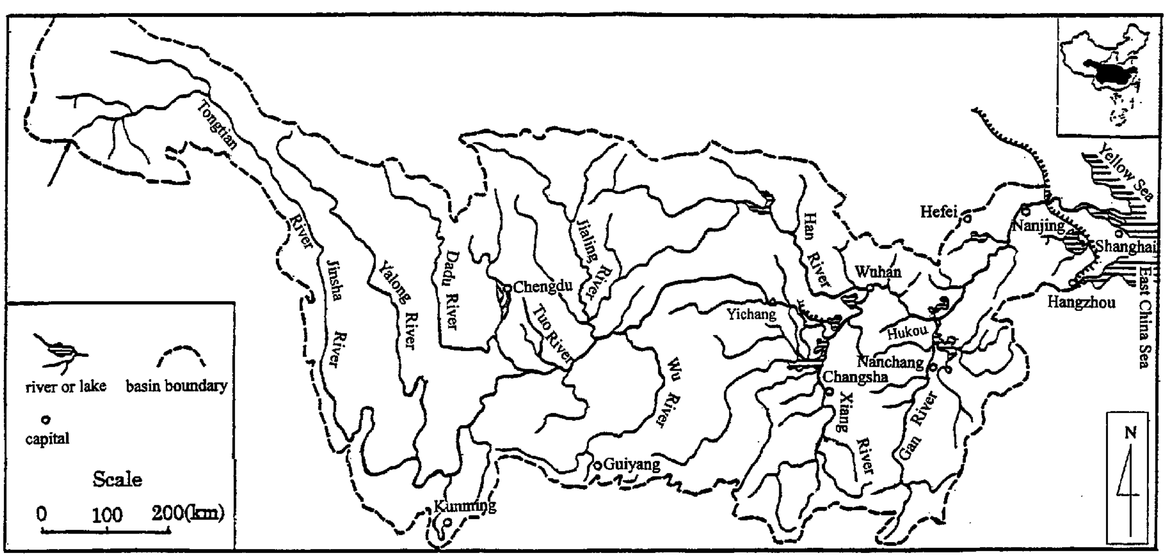

Fig. 1 The sketch map of the Yangtze River Basin

and lower reaches. The area along the middle and lower reaches is usually called the middle and lower floodplain of the Yangtze River since the river slope is very mild and both bank side plains are mainly alluvial, in which population of 1/4 of total China is concentrated. Compared with total river basin, the middle and lower floodplain has an area of about 126,000 km^2, however, in which flood damages are frequent through history.

The middle and lower floodplain of the Yangtze River is flooded regularly due to heavy rainstorms. Because of vast catchment area, flood seasons of local areas and tributaries of the Yangtze River are quite different and generally appearing earlier in the middle and lower basin than in the upper basin, earlier in the southern area than in the northern area. Consequently, water stages of the middle and lower reaches are usually raised before floodwater coming from the upper reaches. Such flood combinations is very disadvantageous for flood control. High water stages of the middle and lower reaches reduce the discharging capacity of the river greatly, whereas floods from the upper reaches have high peak discharge and much volume. In addition, because of low water velocity and sediment deposition due to mild slopes of the middle and lower reaches, the discharge capacity of the middle and lower reaches is low.

The situation is especially severe along the Jingjiang River Reach from Zhicheng to Chenglingji as seen in **Fig. 2**. Therefore, it is said that flood control of the Yangtze River Basin primarily deals with disastrous floods, which occurred in the middle and lower basins. Accordingly, flood control of the middle and lower reaches principally copes with floods around the Jingjiang region.

Since the foundation of China in 1949, the biggest flood in the Yangtze River Basin occurred in 1954 with an occurrence frequency of 1%. This flood was a standard to formulate the flood control planning in the Yangtze River Basin. According to the latest version of flood control planning made in 1980, a design flood with an frequency of 1% is treated as the worst one, which should be withstood through the combined usage of river levees, flood control reservoirs, and flood diversion and detention areas.

Once such a design flood occurs, under the condition of full use of river levees, which are improved according to the 1980 standard, excess floodwater of $50\times10^9 m^3$ cannot be safely carried by river channel, and it still must be diverted into flood diversion areas to avert the destructive flood disasters. The diversion or detention areas for excess floodwater of about $50\times10^9 m^3$ are shown in **Table 1**.

Besides this, if an exceptional flood with a frequency of less than 1% occurs, no suitable countermeasures can be taken to withstand it by the current flood control measures. Such a kind of flood has occurred in 1870. However, it is said that the completion of the Three-Gorge Dam will

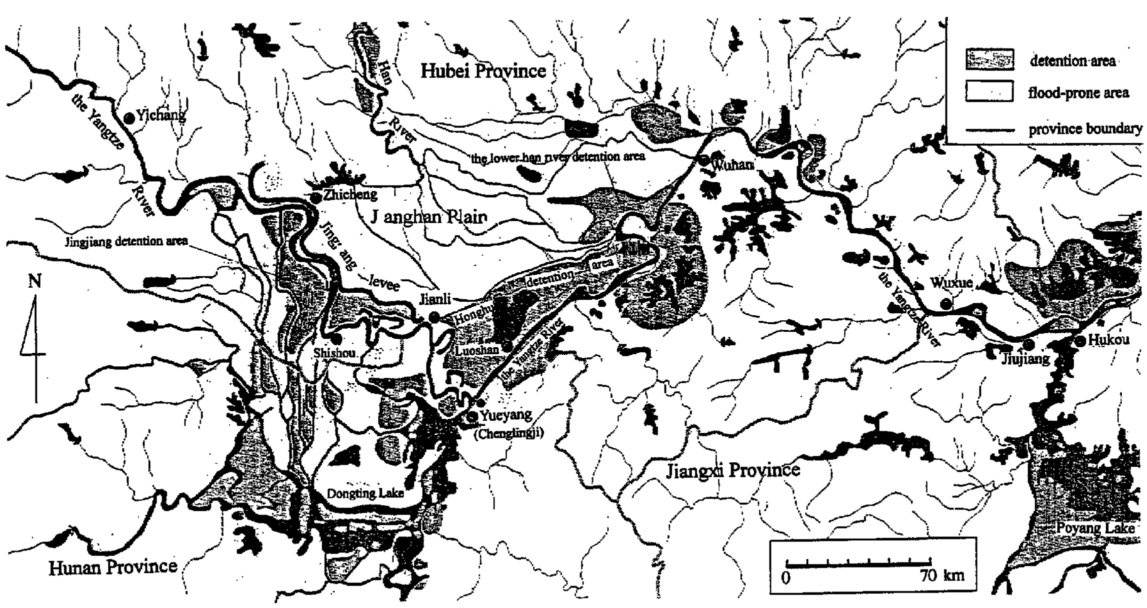

Fig. 2 The sketch map of the Jingjiang Region

Table 1 Major flood detention areas for diverting excess floodwater

Detention Areas for Flood Diversion	Flood Diversion Volume ($\times 10^9 m^3$)
Jingjiang	5.4
Dongting Lake area[1]	16.0
Honghu	16.0
Wuhan area[2]	11.0
Hukou area[3]	5.0

Notes:[1] including 24 polders* located around the Dongting Lake area; [2] including 6 polders around the Wuhan area; [3] including $2.5\times 10^9 m^3$ of Huayanghe detention area, Anhui Province and $2.5\times 10^9 m^3$ of Poyang Lake, Jiangxi Province, respectively.
* A kind of small-scale flood detention area in the Yangtze River Basin, which is surrounded by low standard embankments.

improve the current flood control standard of the middle and lower floodplain of the Yangtze River from 1% to 0.1%. In addition, the dam will assure that flood diversion and detention areas will not be used even in the occurrence of a flood of 1%.

2.2 Flood control measures and problems

To defend from exceptional floods, since 1949, about 3,500 km major levees and 30,000 km branch levees, 48,000 reservoirs and 14 major flood diversion and detention areas have been built for flood control and other objectives in the Yangtze River Basin (Yu, H.Q., et al, 1998). In addition, river regulation works such as river cutoffs and revetment construction were also made in past years. Moreover, non-structural measures such as flood forecasting and warning, flood fighting and flood relief systems have been established although they are very limited. Structural projects mainly including levees, flood diversion and detention areas, and reservoirs play a leading role in flood control as discussed below.

(1) Reservoirs

As shown in **Table 2**, presently there are nearly 48,000 reservoirs constructed in the Yangtze River Basin and they provide a total storage capacity of $122.2\times 10^9 m^3$. Unfortunately, their storage capacity for flood control is very limited and cannot be much effective. Because most of middle and small reservoirs are generally designed for irrigation, power generation and fishery, they have no or little capacity for flood control. In addition, there is no flood control reservoir along the main channel of the Yangtze River except the Three-Gorge Dam that is now under construction. Most of large reservoirs are constructed for multipurpose use, and they can only protect the middle and lower reaches of tributaries on which they are located, but they are almost impossible to provide an effective protection to the middle and lower floodplain of the Yangtze River.

Table 2 Reservoirs of the Yangtze river Basin

Reservoir Type	Number	Storage Capacity ($\times 10^9 m^3$)
Large type	105	73.3
Middle type	887	22.4
Small type	47,008	26.5
Total	48,000	122.2

Furthermore, although the Three-Gorge Dam will provide storage capacity of $22.15\times 10^9 m^3$ for flood control but its construction still lasts 10 more years from now. Besides this, the Three-Gorge Dam only controls a catchment area of about $800,000 km^2$ upstream of Yichang which occupies about 44% of total catchment area of the Yangtze River Basin. Therefore, it is difficult to say the completion of the Three-Gorge Dam will solve all flood control problems of the Yangtze River Basin.

Without question, the more dams are constructed the more capacity for flood control is expected. However, except for current economic conditions of China, the problems such as environmental deterioration, population immigration, and farmland submerge, which result from dam construction, must be taken into account.

(2) Flood diversion and detention areas

The construction of flood diversion and detention areas is an expedient measure to give up local interests for the sake of important cities and economically developed-zones located along the middle and lower reaches of the Yangtze River. Until now, about 40 flood diversion and detention areas along the middle and lower reaches of the Yangtze River Basin are constructed. They have a total area of 12,000 km^2, a total population of 5.7×10^6 and a total storage volume of $64\times10^9 m^3$. Among of them, 14 are major flood diversion and detention areas.

However, the usage of flood diversion and detention areas is becoming more difficult than ever due to rapid economic and population growth in those areas. For instance, the population of the Jingjiang flood detention area has increased from 170,000 in 1954 to 510,000 in 1998. In this situation, if the Jingjiang detention area for flood diversion is operated, it is estimated that about 300,000 people need to evacuate for refuge in a short time. It can be easily imaged how much difficult it is for ordinary people to take such a huge refuge action. Therefore, as seen during the 1998 flood, although the water stage at Shashi gauging station has exceeded 45.0 m four times which is a planned water stage for operating the Jingjiang flood detention area, finally the Jingjiang flood detention area could not be put into use. This is by the two major reasons of the difficulty to move a large number of people and the losses due to flooding, besides the correct flood forecasting and regulation as reported by the newspapers.

(3) River levees

The Yangtze River levees were constructed mainly along the middle and lower reaches since flood disasters occurred mainly near these areas through history. By now, about 3,500 km major levees and 30,000 km tributary levees have been built and improved wholly for three times since 1949 through raising, widening and strengthening according to gradually improved standards at different periods as shown in **Table 3**. Until now, most levees have a standard with a frequency of about 10%~5%.

Table 3 The improvement of river levees

Period	Standard for Improvement
1949~1954	The highest water stages of the 1931 or 1949 flood
1954~1972	The highest water stages of the 1954 flood + an extra height of 1.0 m
1972~present	Extra height of 0.5~0.8 m over levee elevations completed in 1972

However, due to the difficulty of usage of flood diversion and detention areas and insufficient flood control capacity of reservoirs as discussed above, river levees actually become the principal means for flood control. In this situation, to defend from the flood with the frequency of 1%, high standard of river levees is required.

Furthermore, if flood diversion and detention areas are not taken into account for diverting excess floodwater of about $50\times10^9 m^3$, floodwater should be carried mainly through the river. In this case, it is estimated that current major levees must be raised 2~3 m more to assure the security of the middle and lower floodplain. In addition, the improvement of levees will bring about additional requirements such as preparing earthwork of about $7.6\times10^9 m^3$, digging out farmlands of 6,480 km^2 and moving population of 1.0×10^6. Besides, tens of thousands of floodgates, pumps, bridges and so on would be reconstructed according to the new levee standard.

Actually, the flood with a frequency of 1% is not the worst through history. Considering much worse one, which occurred in 1870 with a frequency of 0.1% as a reference for the levee, much high levee may be required.

On the other hand, present flood stages of the middle and lower reaches and lower reaches of tributaries have surpassed the ground elevations of the middle and lower floodplains by several to tens meters. The high levees may cause more severe damages when they are broken. This situation indicates that the suitable levee standard is necessary, but does not mean that the higher the river levees are, the safer the floodplains are. Therefore, as concerns levee raising, it seems to be impossible to improve the discharge capacity of river, whereas the construction and reinforcement of levees are necessary to improve levees quality.

Based on the above-mentioned considerations, although flood control level has been improved greatly through constructing a large number of structural projects in the past 50-year, there still exist many problems resulting from rapid social and economic development. To meet the requirement of current flood control, the reinforcement of existing structural projects or the construction of new structural projects may be possible but very difficult to realize them in a short period under Chinese current national conditions. Experiences either from China or other countries indicate that the structural projects are not enough to reduce flood damages. In this situation, it is necessary to develop other measures to control flood disasters more effectively.

3. Flood Control Measures of USA and Japan

3.1 The National Flood Insurance in USA

In the United States, it is estimated that 5% of the land is located in floodplains and coastal areas and about 25% of the population are concentrated in or near these areas. The cities and towns located in the floodplains and coastal areas are flooded regularly due to hurricanes or rains. It is estimated that floods cause about 90% of all property losses in the United States.

In order to lessen flood damages, structural projects such as building dam and levees were taken as the first action. However, because flood damages continued to increase despite the construction of dams and levees, the Congress of the United States determined to establish alternative means of floodplain management to reduce the ever increasing property damage due to floods (Richard W. K., 1996).

In 1966, "A United National-Program for Managing Flood Losses" was issued, non-structural flood control measures were established first. In 1968, the study entitled "Insurance and Other Programs for Financial Assistance to Flood Victims" was passed by the Congress and signed by the President. Since then, the National Flood Insurance, as a previously unavailable flood insurance protection, was provided to property owners in flood-prone areas. Until the 1980's, the National Flood Insurance Project (NFIP) was really implemented in an all-round way and became a principal measure for flood damage reduction(Richard W. K., 1996).

Exactly speaking, the success of the National Flood Insurance Project is a result of mutual incorporation of 4 non-structural measures including: a) flood insurance; b) floodplain development and administration; c) flood control project management; and d) floodplain land regulation (Tan, X.M., 1998). The government provides federal disaster assistance to damaged persons by selling flood insurance. To qualify for the eligibility in the National Flood Insurance Project, a community must adopt and enforce floodplain management regulations formulated by the government.

From the 1930's to now, the meaning of floodplain management of the United States changed several times, until now it has developed into a wide extent of flood control.

3.2 Integrated flood control measures in Japan

Japan is a mountainous country. Compared with other countries in the world, its riverbed slope is extremely steep. Moreover, due to the influence of typhoons, heavy rainfalls occur during a short period with a large amount. Consequently, floods not only flow into downstream rapidly but also last in a relatively short time. River discharge changes significantly in the flood season and in the normal season.

On the other hand, population, property and metropolitan functions tend to concentrate in the so-called floodplain. It is estimated that about 50% of total population and 75% of total property are concentrated in such floodplains that account for about 10% of total land area of Japan. Especially, with the rapid economic growth after the second world war, high-speed urbanization around floodplains caused disorderly urban development and thus resulted in loss of water retention and storage functions and increases river discharges greatly during the flood period than ever. Floodplains became a high-risk area affected from floods.

Under these circumstances, "Integrated Flood Control Measures" was promoted in 1977 at first and mainly applied to highly urbanized areas (Takahashi, Y., and Watanabe, Y., 1996). Its major measures included are shown in **Fig. 3**.

In 1988, "Integrated flood control measures" was used in the Neya River, Osaka Prefecture to defend from flooding due to landside water and became a model flood control plan for other urban river in Japan. Similar plans have been implemented for 17 river basin in Tokyo, Nagoya, and other large cities (Watanabe, Y., 1996).

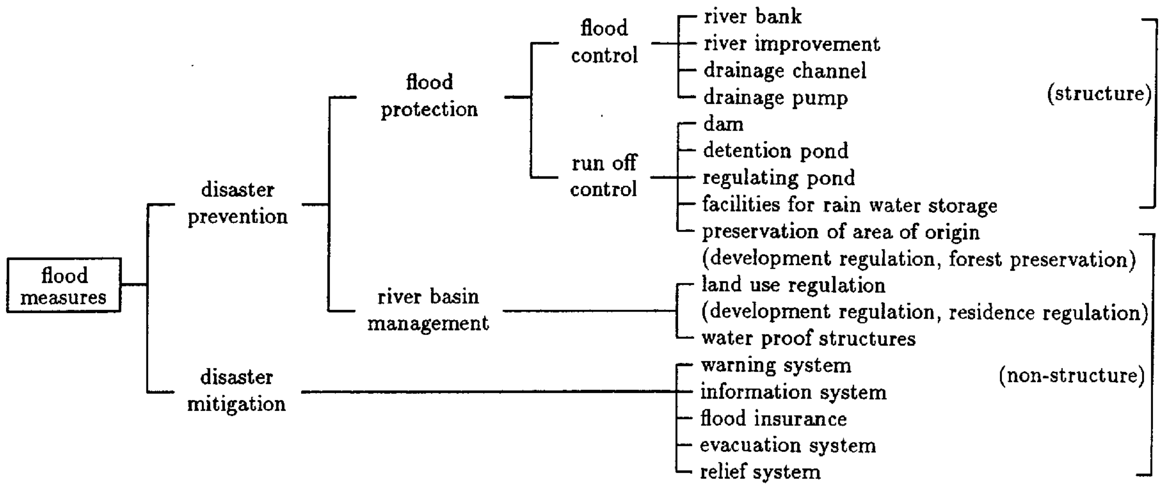

Fig. 3 Framework of comprehensive flood control measures in Japan

According to the 9th Flood Project 5-Year Plan executed from 1997, a new approach for flood control countermeasures is formulated. New countermeasures are presently under study including several aspects as follows: a) Integrating flood control countermeasures for the entire catchment area; b) Improving the reliability of flood control facilities; and c) Making rivers suit the natural environment.

4. Implementing Comprehensive Flood Control Countermeasures in the Yangtze River Basin

4.1 Feasibility

Current flood control measures of the Yangtze River Basin are very difficult to withstand great floods effectively. Whereas improving existing structural measures such as reservoirs, flood diversion and detention areas, and levees, there are many problems to be faced. Under these circumstances, it is necessary to implement comprehensive flood control measures consisting of structural measures and non-structural measures in the Yangtze River Basin to mitigate increasing flood damages.

(1) To operate flood diversion and detention areas smoothly

Although the usage of flood diversion and detention areas are becoming difficult, they will be continuously kept for use in case floods of less than 1% occur, according to the flood control planning made by the Yangtze River Committee, even after the completion of the Three-Gorge Dam. This means that flood risk will continuously exist around these areas.

Restricted by natural conditions, $500 \sim 600 \times 10^6$ of people, which account for 40%~50% of Chinese population, live in or near the flood-prone areas. The situation is very similar with that of Japan but very different from that of the United States in which only about 12% of the national population live in such areas. Therefore in the United States, people can choose safer places for living, whereas many Chinese people have to live in flood risk areas without any choices.

Furthermore, flood diversion and detention areas occupy a wide land, but they are operated in very limited times. Vacating them only for flood diversion that may be used once per hundred years may be unreasonable for present situation of vast population and limited farmlands in China.

In addition, in the flood diversion and detention areas, the local interests were originally given up for the sake of important cities and economically developed-zones of the lower reaches. People living around these areas did not obtain any compensation from benefited or protected areas, but they are attacked by social opinions due to difficult usage of diversion and detention areas. This is unreasonable to some extent. The balance of the interests between the affected areas and the benefited areas is a very important problem.

Therefore, in order to operate flood diversion and detention areas smoothly, it is desirable to apply non-structural measures to coordinate the requirements of flood control and the interests of residents living in such areas.

(2) To control the magnitude of floods

Current flood control measures of the Yangtze River Basin emphasize to reduce flood peak discharge and volume along the trunk river, but pay little attention to control flood magnitude on tributaries and in river basin. Although the former is an immediate way to minimize flood peak discharge and volume, but it is still limited to the areas along the Yangtze River.

Therefore, the management of the total river basin should be kept in mind. Especially, with rapid economic development, illegal land reclamation and deforestation destroy rainwater retention and runoff retardation seriously, which had been maintained by natural topographical features and vegetation. Consequently, flood peak discharge is raised, and flood lag time is shortened. This situation is also aggravating the potential of flood damages.

4.2 Significant countermeasures

The comprehensive flood control measures in the Yangtze River Basin needs to consider present socio-economic conditions. However, some measures discussed below can be taken at first through combining existing structural measures.

(1) Rainwater retention and runoff retardation

In the Yangtze River Basin, high peak discharge and much volume are the main reasons to cause flood disasters. Also, such floods result from insufficient flood regulating facilities such as reservoirs located on the upper reaches.

In the comprehensive flood control plan of Japan, rainwater retention and storage measures are parks, school grounds and retarding basins/ponds and infiltration facilities such as high permeable pavement and channels. The Yangtze River Basin is very big compared with Japanese river basin, therefore, similar facilities with different scale facilities may be considered. Some existing facilities such as the middle and small reservoirs, which should be suitably reconstructed, ponds, low-lying land can be used for rainwater retention and runoff retardation.

Compared with large water conservancy works such as reservoirs, a single pond has only limited effect to collect rainwater or cut runoff discharge. However, a series of small ponds in total river basin will produce a considerable effect. In addition, such a measure is advantageous to conserve water resources.

(2) Flood insurance

Compared with the United States, there is a high population density in flood-prone areas of the Yangtze River. Once flooded, there may be a wide extension of damaged people to be supported by flood insurance. If the government is responsible for all expenditure of flood insurance, it will become a big problem.

According to the authors' opinions, at first, the Yangtze River Basin is to be taken as a unit for flood insurance, and if successful, flood insurance should be spread to other river basins of China. Gradual spreading of flood insurance system might be a cautious method.

(3) Land use and flood-proofing regulation

Either to establish a successful flood insurance system or to reduce flood damages purely, land use regulation and flood-proofing should be promoted as soon as possible.

In flood-prone areas, flood-proofed buildings and suitable land use should be encouraged through financial assistance provided by the government and local government. In those areas, which have suffered flood damages, further development should be regulated by means of laws, taxes and others, and suitable structure standard, for example building base height, should be established.

(4) Flood information announcement

Until now, the study of so-called flood risk maps has started for nearly 12 years (Liu, S. K., 1990) in

China. However, the flood risk maps are still limited in a few river basin areas or urban areas, and mainly work for the goal of flood decision support, scientific research and flood control planning and regulation. Ordinary people, however, have little knowledge to flood and its threat, although they live in such flood risk areas.

Whereas in Japan, as of November 1988, there are 333 rivers, in which the flood risk maps have been published(Seki, K. 1989). Such maps can make residents more conscious of the importance of flood risk and management. The maps facilitate flood fighting and evacuation activities and also provide guidance for flood-proofed structure and land development. Although in present China, flood information announcement may cause somewhat influence to the local benefit, it will be very valuable from a long-term point of view.

(5) Evacuation system

Because flood risk areas exist extensively, the study on evacuation system is required.

In Japan, numerical models on evacuation are developed to analyze the factors affecting the safe evacuation and how to decide suitable paths and places for refuge. In the Yangtze River Basin, the more realistic problems are about the determination of suitable refuge paths, refuge places and organization to transfer many people to safe places in a limited period.

5. Conclusions

The 1998 flood attacked the Yangtze River Basin and other river basins of China. After summing up the experience and the lessons of past flood control works, the most important task is to establish appropriate flood control countermeasures to improve the ability to withstand an exceptional flood as soon as possible.

The United States, Japan and other countries have developed very effective flood control and damage mitigation countermeasures through continuous efforts. To develop a flood control system, which suits Chinese national conditions, experiences from these countries can be taken as a reference.

Flood control construction of China in past 50 years made an unprecedented achievement. Structural measures such as levees, reservoirs and flood diversion and detention areas occupy the important position in flood control strategy. Although flood control investment from government is increased continuously, flood damage losses remain high. At the same time, some problems such as low standard of levees, insufficient flood control reservoirs, and the difficulty of the usage of flood diversion and detention areas have actually appeared with rapid socio-economic development.

Through surveying current flood control measures and problems in the Yangtze River Basin, some specific measures, as parts of comprehensive flood control measures in the Yangtze River Basin, are proposed.

Finally, based on the authors' own opinions, any measures alone are difficult to avoid flood disasters, however, combination of the comprehensive measures will contribute to reduce flood damage as far as possible.

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長江流域における洪水対策の現況

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要　旨

1998年，中国の華中部および東北部において大きい洪水が発生し，1949年の建国以来最大の被害をもたらした．洪水防御策としてこれまではおもに築堤や堤防強化といったハード的対策がとられてきた．本報では，長江流域におけるそれらの洪水防御策の現状を概観し，問題点を論ずる．また，米国や日本における洪水防御策，とくに構造的方法および非構造的方法からなる総合的治水対策が，長江流域にも適用可能かどうかを考察するとともに，それに基づいて現在とるべき対策を提案する．

キーワード :洪水防御，長江流域，総合的治水対策