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# THE 1998 YANGTZE FLOODS: THE USE OF SHORT-TERM FORECASTS IN THE CONTEXT OF SEASONAL TO INTERANNUAL WATER RESOURCE MANAGEMENT

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**Abstract.** This paper reviews changes in the use of short-term climate information for water management in China after the 1998 Great Flood in the Yangtze River basin. This devastating flood is now believed to have been caused mainly by the 1997–98 El Niño event. Although the short-term climate forecasts and weather forecasts are considered to be useful in planning for flood prevention activities and for making key decisions during combating floods, the gap between the meteorological services (producers of climate forecasts) and water management agencies (users of climate forecasts) has grown in terms of credibility given to climate forecasting: weather services put more efforts on improving the technology for increasing forecast accuracy, whereas water managers put their efforts and investment into upstream ecological restoration and flood control systems. By reviewing the published and 'gray' (unpublished) literature, we found that assessments of the 1998 Great Flood in the Yangtze River basin really helped the central government and water resources agencies to recognize the weaknesses of the existing flood control system, the mismanagement in the ecological systems, and the need for developing a national water resource management plan to deal with the problems of 'too much water, too little water, and very polluted water'.

## 1. Introduction

The Yangtze River basin floods of 1998 were not at all typical in China. It was considered to be among the worst in the century (CNN.com, August 9, 1998). These floods adversely affected the human population, directly and indirectly. At first the blame was placed solely on a stalled weather system in various reaches of the Yangtze Basin. However, closer review showed that water resources mismanagement including human land use activities in the basin contributed to the level of devastation that was finally witnessed there. The Yangtze case study is illustrative of the importance for the use of weather and climate information in the planning of water resources use and sustainable development. It also illustrates the importance of considering both the underlying social processes as well as the use of technology in the prevention of flood-related damage to life and property. In this paper we are going to focus on the improvements of the weather and climate aspects of flood prevention and flood early warning.

Like many developing countries, China has been suffering from an increase in water-related difficulties in recent years. It is a problem of 'too much water', as floods have continuously plagued China. For example, in the Yangtze River Basin with the largest river in China, severe floods have occurred every ten years on average during the last two thousands years. As shown in the following sections, China's topography and climate are considered to be the major natural factors in the frequent occurrence of hydrological hazards (Chen 1993). With more than 70% of its total fixed assets, 44% of its population, one-third of the country's cropland and several hundred cities located in the downstream parts of major rivers and with relative weak flood-control infrastructure, flood losses are expected to increase significantly in the future.

It is also a problem of 'too little water'. Water shortages in China are mainly due to the growing population, particularly in cities, inefficient irrigation systems used in agricultural production and water pollution from industrial, agricultural and municipal use. For example: it has been estimated that China's per capita water resources will drop from a current level of 2,300 to 1,700 $m^3$ by 2030 when the human population reaches 1.6 billion.

The 'very polluted water' problem now causes great concern among the general public. Since the pace of building water treatment facilities for industrial and urban wastewater is far behind industrial and urban development and the high level of discharge of organic water pollutants due to the heavy use of chemical fertilizers in agriculture, the water pollution problem has now become a 'hotspot' in water resource management.

At the top of the list of these problems is the mismanagement of water resources and a lack of knowledge on how to effectively mesh water-sensitive human activities with the natural system. These are among the biggest obstacles for turning China into a sustainable society.

Climate and weather both play a determinant role in the hydrological cycle. Floods and droughts in China are associated to varying degree with anomalous climate. Correctly understanding and efficiently using climate information can be very helpful for improving water resource management. In this chapter, using the 1998 Great Flood in the Yangtze River basin as an example, the use of climate information in water resource management is examined, based on reviewing published literature (e.g., reports, books, articles) and gray literature (unpublished reports written in Chinese and published publicly but only circulated either to a small group of organizations or published only in scientific and engineering journals).

The paper is organized as follows: In Section 2, we briefly describe the case of the 1998 Great Flood in the Yangtze River basin and its impacts. Section 3 summarizes the basic setting of China and provides some background information on water management practices. In Section 4, using the 1997–98 El Niño forecast as an example, the processes of weather and climate forecasting and then use in China are discussed. In Section 5, the major issues in China's water resource management activities are reviewed and the changes on water resource management made after the 1998 Great Flood are documented based on both literature reviews and inter-


*Figure 1.* Map of People's Republic of China (Source: http://www.lib.utexas.edu/maps/china.html).

views with forecasters and policy makers. Section 6 summarizes the assessment's key findings.

## 2. The 1997–98 El Niño and its Impacts in China

The Yangtze is China's largest river, 6,300 km long with a basin covering nearly 2 million square km or about one-fifth of China's territory (Figure 2.1). More than half a billion people or 45 percent of China's total population live in the basin and produce about 42 percent of its GDP. Along the river and in the basin, it is also the most developed region in China with over 43 percent of the country's total investment in fixed assets.

From the end of June to the beginning of September 1998, there were persistent torrential rains in the Yangtze River basin, which led to a serious deluge in the form of a continuous overflow with high water levels, lasting more than 70 days in the middle and lower reaches of the river. The most threatened areas were the low-lying basins surrounding the Dongting and Poyang lakes, and their surrounding counties in Hubei and Hunan provinces. In terms of the number of raging flood peaks, the flooding time of high-level inundation and affected farmland acreage and economic losses, the 1998 Great Flood in the Yangtze River basin is now considered to be one of the most devastating floods in Chinese history. In spite of the fact that the nationwide effort was a complete success in preventing the dikes from collapsing, with the army dispatched directly to the frontiers of the surging flood, about 5 million hectares of cropland were inundated. The official death toll was as high as 3,600 with 13.2 million people made homeless. The flood also destroyed or damaged much infrastructure and social services facilities. Economic losses were estimated at over US$ 36 billion.

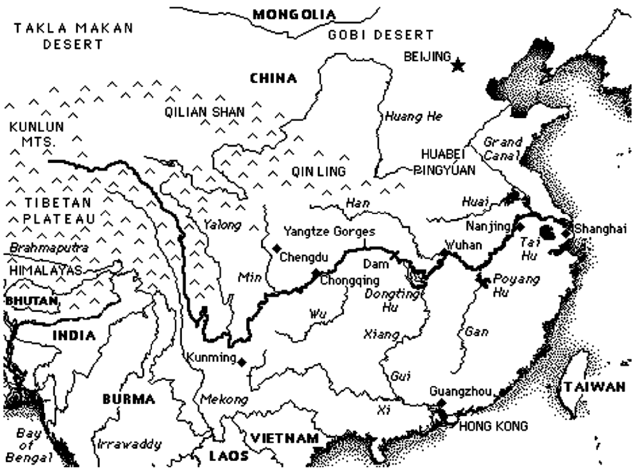


*Figure 2.1.* The Yangtze River basin (Source: http://www.ibiblio.org).

## 2.1. Climate anomalies in China during the 1997–98 El Niño event

Since the beginning of the winter in 1997, the subtropical high in the western Pacific Ocean developed anomalously, and its intensity was the strongest since 1949. Intense rainfall events occurred frequently to the south of the Yangtze River basin. The total amount of precipitation ranged from 300 to 600 mm in most places, which was much more than the climatological averages. In fact, in many places, precipitation levels broke historical records. Recorded precipitation amounts at most weather stations in this region were the biggest for the same time period during the past 40 years. In the basin, some rivers and lakes exceeded the cautionary water level, reaching their highest water levels in regional history (Figures 2.2 and 2.3).

During the main rainy season (June–August in China), the main centers of precipitation were in the following locations: the Yangtze River basin, west of Northeast China and the east of Inner Mongolia. Precipitation in most regions was well over the expected normal amount with continuous, strong rainfall events in some places. For example, there was about 700–900 mm of rainfall north of the Yangtze River Basin, southwest of Hubei Province, in the City of Chongqing and to the east and southwest of Sichuan Province.

## 2.2. The 1998 Great Flood in the Yangtze River basin

At the beginning of the summer of 1998, the subtropical high in the Northwestern Pacific was the strongest one on record (National Climate Center 1998). The convection band became stalled over the middle and lower reaches of the Yangtze River Basin, starting in mid-June. Rainstorms of varying intensity including very heavy ones hit this area continuously. Then, after moving northward for a short

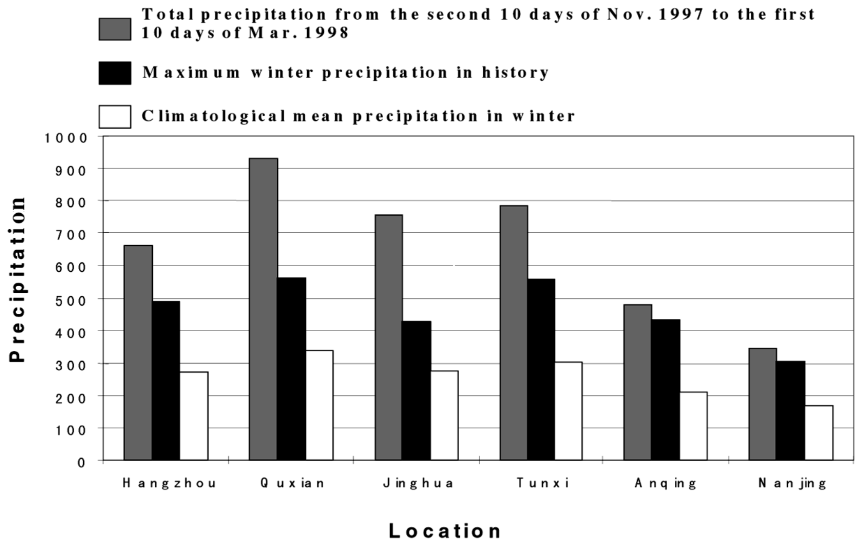


*Figure 2.2.* The comparison between the maximum winter precipitation in history and the total precipitation from the second 10 days of November 1997 to the first 10 days of March 1998 in Hunan and Hubei provinces.

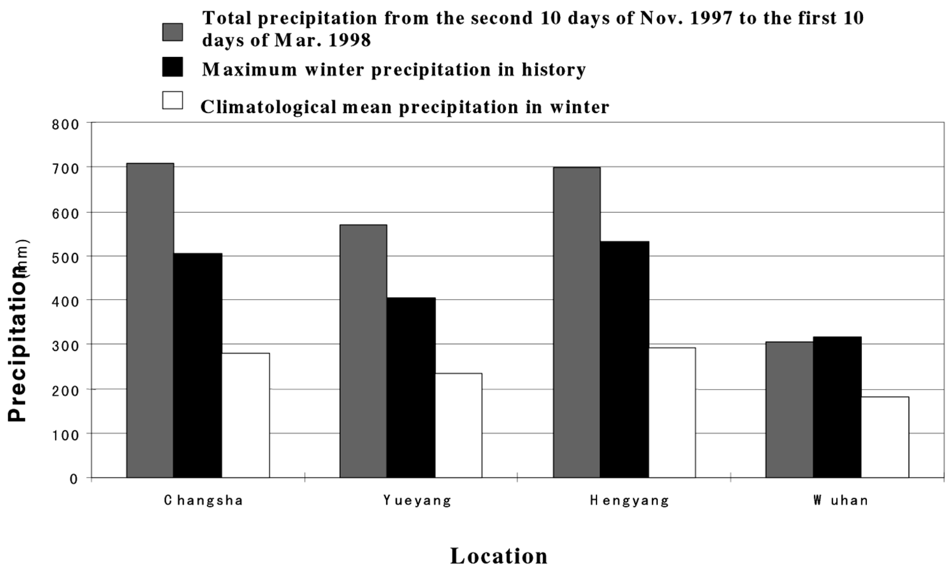


*Figure 2.3.* The comparison between the maximum winter precipitation in history and the total precipitation for several cities in the lower reaches of the Yangtze River from the second 10 days of November 1997 to the first 10 days of March 1998.

period of time, the subtropical high moved back to the Yangtze River Basin in mid-July bringing with it continuous, strong precipitation processes for a second time. Water from Dongtin Lake, Poyang Lake and many small rivers constantly flowed into Yangtze River. The water levels in the middle and lower reaches rose suddenly and at the same time. As a result, the Great Flood occurred in the whole basin.

The process of the 1998 Great Yangtze Flood can be divided into three periods. The first period was from mid-June to the end of June. At the beginning of June, the Meiyu season[1] started in the Dongtin Lake and the Poyang Lake areas. In mid-June, continuous rainstorms occurred in Jiangxi, Hunan, Zhejiang, Guangxi and Fujiang provinces. In these provinces, the *total* precipitation from June 12 to June 27 ranged from 200 to 500 mm which was two to three times more than normal. To the north of Jiangxi, north of Hunan, southwest of Zhejiang, south of Anhui, northwest of Fujian and northeast of Guangxi, precipitation reached 600–900 mm, and in some locations it exceeded 1000 mm. It was rare in the country's history that so much precipitation fell in so short a time. The rainfall amount was about 2 times more than average.

As early as in February, winter floods occurred in the Xingjiang River and the Fuhe River, which made the water levels of rivers and lakes in the middle and lower reaches of the Yangtze River basin dangerously high, later reaching their highest summer levels in history.

After June 28, the subtropical high moved to the west and shifted to the north. Rainfall in the middle and lower reaches of the Yangtze River basin decreased, and the flooding of the Yangtze subsided.

The second period was in late July, from July 20 to 31. Because the strength of the subtropical high had been reduced, it retreated to the south and to the east. Large-scale rainstorm processes occurred in the middle and lower reaches of the Yangtze basin. Compared to the first period, the rainy area was smaller and the rainy period was shorter. The rainfall, however, was heavier and came in downpours. As a result, the water level rose very rapidly.

In this period, precipitation in most areas of the Yangtze River basin fell in amounts from 90 to 300 mm. Northwest of Hunan, north of Jiangxi, and south of Hubei, precipitation amounts reached 300–500 mm, and in some locations exceeded 800 mm with a maximum of 911 mm. Since the water level in the Yangtze was already very high in the previous period, it exceeded the damage level. So, continuous precipitation in this period was really disastrous.

The third period started from the beginning of August. Although precipitation in the middle and lower reaches of the Yangtze River decreased greatly in August, precipitation increased continuously in the upper reaches of the Yangtze River in Sichuan Province, Chongqing, the Three Gorges area, the Qingjiang River basin

[1] The Meiyu season is defined by the China Meteorological Administration as the season when the lower reaches of the Yangtze River enter its summer rainy season.

and in the Hanjiang River basin. The total amount of monthly precipitation ranged from 150 to 250 mm, and in some areas exceeded 300 mm.

Frequent precipitation in the upper reaches led to the repeated occurrence of flood peaks. There were five peaks in August. On August 7, the dike in the Jiujiang segment was broken and torrential water swarmed into cities, villages and agricultural fields, causing severe damage to property and loss of life (Zheng 1998).

The Yangtze flood did not subside until late August. The total time of the floods was about three months. It proved to be one of the most disastrous floods in the $20^{th}$ century, and had severe impacts on society.

## 3. Natural and Social Setting

China is one of the countries suffering the most from many kinds of meteorological hazards. These include but are not limited to floods, droughts, typhoons, and severe storms, due to its geographic location and topography. The increasing losses associated with these natural hazards during recent years, however, are in no small measure due to human activities. This section briefly describes the baseline natural and social settings for the causes of the 1998 Great Flood.

### 3.1. Physical Setting

#### 3.1.1. *Topography*

China has a total area of $9.6 \times 10^6$ km$^{-2}$. With such a broad area, China's topography is very complex. The percentage of various topographic elements in China is as follows: mountainous regions 33%, plateaus 26%, basins 19%, plains 12%, and hills and low mountains 10%. The mountainous area, which includes mountainous regions, hills and comparatively rugged plateaus, takes up 65 percent of the total area. The Bohai Sea, East China Sea, Yellow Sea and South China Sea embrace the east and southeast coast.

Generally, the outline of China's terrain descends in four steps from west to east (Figure 3.1). At the top (1), it is the so called the 'roof of the world' – the Qinghai-Tibet Plateau – with an elevation averaging more than 4,000 m above mean sea level. The second step (2) has an average elevation of between 1,000 m and 2,000 m and includes Inner Mongolia, the Loess and Yunnan-Guizhou plateaus, and the Tarim, Junggar and Sichuan basins. Then, the third step (3) drops in elevation down to about 500–1,000 m. This step begins at a line drawn around the Greater Hinggan, Taihang, Wushan and Xuefeng mountain ranges and extends eastward to the coast. The fourth and last step extends out into the ocean, as the country's shelf.

Because of this 'four-step' topography with sharp drops in elevation in the upper- and middle-reaches of the Yangtze River but relative flat in the lower reaches, the speed of flood water flow upstream is always faster than it is downstream. This is one reason for the frequent floods in the Yangtze River basin (Ministry of Water Resources 1999).

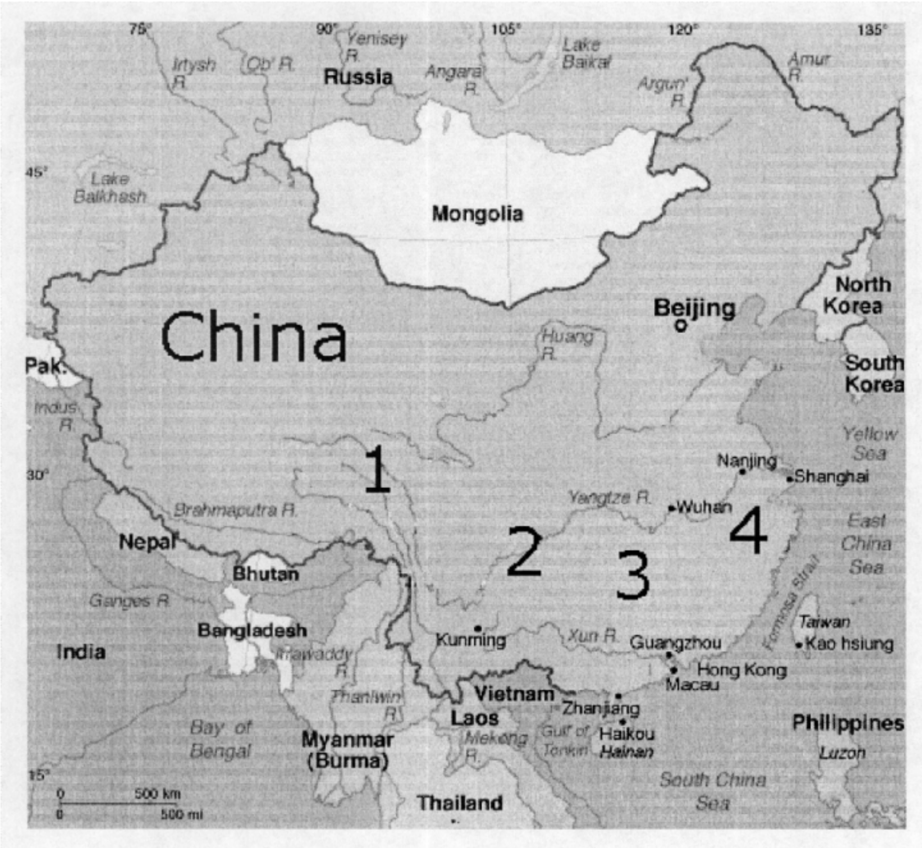


*Figure 3.1.* The 'four-step' topography in China (Source: USDA).

### 3.1.2. *Climate*

The climates of China vary considerably from south to north. They include tropical, subtropical and temperate zones as well as colder climates. Climate in China is dominated by the Asian monsoons and there is a great temperature difference between the northern and southern parts of the country. In winter, the prevailing winds blow from Siberia, bringing the cold and dry climate. In the summer, warm and wet monsoons blow from the southeast Pacific Ocean and the southwest Indian Ocean bringing hot and rainy climate to the country. The rainfall is concentrated in July and August. There is also a big difference in annual average precipitation among different regions. The annual mean precipitation usually exceeds 1500 mm in the southeastern coastal areas but gradually decreases to less than 50 mm in the northwestern inland. It has been found that there is a center of thunderstorms located at the middle reaches of the Yangtze River, the second reason for frequent Yangtze River floods.

### 3.1.3. *Land types*

Of the country's total territory, about $135 \times 10^6$ ha are cultivated land, accounting for 14%; about $167 \times 10^6$ ha are forest land (16.5%); about 280 million ha are natural grasslands (29%); about $18 \times 10^6$ ha are fresh-water surface areas (2%) and about $27 \times 10^6$ ha are for industrial and human settlement (3%). Other lands such as deserts, glaciers, bare mountains and high, cold wastelands account for about 35% of the country's total, which is difficult to use for agricultural production.

The composition and distribution of China's land resources have three major characteristics: (1) variety in type – cultivated land, forests, grasslands, deserts and tideland; (2) many more mountains and plateaus than flatlands and basins; (3) unbalanced distribution of land resources: farmland is mainly concentrated in the east, grassland is largely in the west and north, and forests are mostly located in the far northeast and southwest.

In the Yangtze River basin, mountains and plateaus cover more than 85% of its area. It has been estimated that 80 to 90% of forests, which used to protect the topsoil, in the mountainous upstream of the Yangtze River have been destroyed (Ministry of Water Resources 1999). With more frequent torrential rains and floods, the water carries the topsoil down to the river thereby raising the river's bottom. As a result, the floodwater is now easier to flow over the river's banks when severe rainstorms occur in the basin.

### 3.1.4. *Rivers and lakes*

There are numerous rivers in China. More than 1,500 rivers a drainage area of over 1,000 km$^2$ each. Among these, the major ones are the Yangtze River, Yellow River, Heilongjiang River, Pearl River, and Huaihe River, each has a water catchment area in excess of one million square kilometers. More than 2,700 billion cubic meters of water flows in these rivers. Most of the large rivers originate in the Qinghai-Tibet Plateau. China has the richest hydro-power resources in the world, with a potential of $680 \times 10^6$ kw. China also has more than 2,800 fresh water and salt water lakes, of which 13 have an area of more than 1,000 square kilometers.

It is well known that the lakes and wetlands are good natural regulators of floods, especially for the Yangtze River basin. However, during the past several decades, encouraged by the government's policies, a large amount of wetlands and lakes were drained for farming purposes in response to the demands for land of growing populations. In the middle and downstream reaches of the Yangtze River, the water surface has been reduced from 35,000 km$^2$ in the 1940s to 22,000 square kilometers in 1990s (Ministry of Water Resources 1999). The number of lakes has also been reduced significantly. For example, in Hubei Province, which used to be called the 'Province of a Thousand Lakes', the number of lakes with a water surface area larger than 7 km$^2$ has been reduced from 1,322 to 843. The total available adjustment volume for flood protection has been reduced from $11.5 \times 10^9$ m$^{-3}$ to $3.1 \times 10^9$ m$^{-3}$! For the whole basin, there has been a total loss of $57 \times 10^9$

$m^{-3}$ of storage capacity for twenty-two large and mid-size lakes; and more than 15,000 × $10^9$ $m^{-3}$of lakes have disappeared (Zhou and Hu 1998).

## 3.2. Social and Economic Setting

### 3.2.1. *Political system*

The basic political structure of China is a multi-party system under the leadership of the Chinese Communist Party. The Communist Party together with other parties coexist and monitor each other and operate, under the framework of centralized democratic principles, and the people's representative congress system. The National People's Congress is the highest authority of the country. The Government is the executive branch, which is elected and supervised by the National People's Congress. The people exercise their authority through the National People's Congress. The people also participate in the political life of the nation through unions, communist youth and social organizations. Political consultative meetings are effective processes in the fight for democratic unity in the political life of the country. The laws and other regulations are passed by the National People's Congress or the Government and promulgated for implementation. The Chinese Government, as part of its political reforms and to make its structure more responsive to the needs of the socialist-market economic policy, has introduced a series of measures such as: the separation of party and executive functions, further downward delegation of power, reorganization of government institutions, refining socialist-democracy and the strengthening of the socialist legislative structure (http://www.china.org.cn/english/Political/25060.htm).

### 3.2.2. *Population*

China's population has tripled from 450 × $10^6$ to about 1.3 × $10^9$ people since 1949. Its population is distributed unevenly with more in the east (more than 300 persons per square kilometer) and fewer in the west (about 40 persons per $km^2$). The national average population density is 119 per $km^2$ (1990 census). On the basis of adjusted data for the country as a whole, the percentage of China's urban population has risen steadily from the 1978 level of 18% to the 1993 level of 28%, and to the 2000 level of 36.1%. Historical data also showed a significant acceleration in the rate of increase for the urbanized population; with a 7% rise from 1949 to 1978, a 10% of rise from 1978 to 1993, and an expected 8% rise from 1993 to 2000 (Wang 1995).

### 3.2.3. *Economic development*

China has been in a complex transition from central planning to a civil society with a market economy since 1978. For over ten years, since the beginning of reforms and opening up, China has enjoyed a double-digit growth rate. In recent years, by recognizing that the per capita availability rates for most natural resources in China are well below those of the world's averages, the Chinese government has made changes in its development policy from a scale-oriented to an efficiency-oriented one and puts sustainable development and resource conservation as the first priorities in its economic development objectives. China's economy has slowed down its pace of growth at a rate less than 8 percent in the past few years.

The Yangtze River basin is very important for China's economy. For example, in 1995, the Gross Domestic Product (GDP) from the region was 39% of national GDP and it has been predicted that number will increase to 43–45% (Li and Yan 2001).

### 3.3. Natural hazards

Great economic losses in China result from natural hazards and range from 3.3% to 6.1% of Gross National Product (GNP) (Shi 1995; China National Report on Disaster Reduction 2000). The major natural hazards in China fall into four major categories: 1) drought, flood and waterlogging, tropical cyclones; 2) earthquakes, landslides, mud-rock flows; 3) disease and insect pests; 4) red tide, sea storms and storm surges.

## 4. Weather and Climate Forecasts in China

Seasonal to interannual climate forecasts have been made by the Chinese meteorological service since the early 1950s. During the 1960s, the forecasts were called 'long-term weather forecasts' and issued every month by the Central Meteorological Station. In 1995, with the establishment in China of the National Climate Center (NCC), the forecasting operation was transferred to the NCC and the products were then called 'short-term climate predictions'. The major focus of the predictions is the tendency toward summer precipitation and possible flood/drought episodes in the country. However, all the products are only for internal uses; none are available for the general public. However, this is starting to change with the successful forecasts of 1997 El Niño event and the 1998 abnormal rainfall in the Yangtze River basin.

### 4.1. Weather and climate forecasts at the national level

In China, the National Meteorological Center (NMC), within the China Meteorological Administration (CMA), is the only government agency legally issuing short-term, median-range and long-term weather and climate forecasts to the public. The NMC makes its weather and climate forecasts for the whole country, based on numerical modeling, statistical and empirical methods. Its products are then sent to the provincial meteorological centers. The NMC is also responsible for providing technical support and consultation in critical situations. Every year, before the summer rainy season would begin, the NMC prepares seasonal prediction reports to be delivered to the State Council and other government agencies.

However, in the case of El Niño events, the National Oceanic Bureau also makes its own predictions. It should be pointed out that, although making public announcements of any weather-related predictions is prohibited by law, forecasting El Niño has now become a 'hot competition' among several government agencies and universities. This is because El Niño is viewed not as a weather phenomena but as an oceanic one.

In the case of the 1997–98 El Niño event, by monitoring both the tropical atmospheric wind field and changes in sea surface temperatures in the equatorial Pacific, Chinese scientists warned, as early as the end of 1996, that there would be a possible El Niño event in 1997 (Li et al. 1998). But the official announcement of this possibility (which at first was kept internally) was made in April 1997, after the convening of the 'Consultative Workshop on the Observation and Prospect of an ENSO'. This workshop is hosted every spring by the China Meteorological Administration and is attended by experts from the Chinese Academy of Sciences, universities and various government agencies. The announcement of an El Niño appeared in the report 'A Briefing on ENSO Observations' and was based on the results of the 1997 workshop. The report was then sent to the State Council and all ministries. In late April, the CMA reported firmly that a new El Niño event would appear (National Climate Center 1997).

After the workshop in April, the CMA held two additional mid-course-correction consultation meetings (in June and July 1997) focused on the summer climate with El Niño as the major concern. These results were then reported to the State Council along with discussion about its possible impacts. The report was referred to by most government agencies, during their planning processes in preparation for the summer rainy season.

### 4.2. Weather and Climate Forecasts at the Provincial Level

In China, every province has its own meteorological bureau, which is under the dual leadership of both the local (i.e., provincial, city, and county) government and the CMA. The provincial meteorological bureaus have a more direct responsibility for making local forecasts. Their forecast products are usually distributed only within the provincial boundary. In general, provincial meteorological bureaus lag behind the NMC in terms of available technology such as computers, models and communication. The situation has changed in some provinces, especially along the east coast, where the local governments in these provinces (such as Guangdong, Zhejiang and Shanghai) have invested significantly in local weather services to improve monitoring and early warning.

Another recent change relates to the cooperation among the neighboring provincial meteorological bureaus. In the past, only in emergency situations, as for example, in the summer of 1998, would forecasters in one bureau consult with neighboring bureaus and the NMC. Now, after the 1998's Great Flood, instead of making forecasts based on jurisdictional boundaries, the meteorological services in the Yangtze River Basin are starting to issue forecasts for the whole basin.

### 4.3. Changes in meteorological services after the 1997–98 El Niño event

#### 4.3.1. *Factors considered in summer precipitation forecasts*

Climate in China is dominated by the Asian monsoon. For most of the country, precipitation is usually concentrated in June, July and August, which causes frequent catastrophic floods along the Yangtze and Yellow rivers. So, accurate and timely predictions of summer rainfall are always the first priority for all levels of meteorological services in China.

After more than fifty years of operational forecasting, the forecasters in the NMC and provincial meteorological bureaus have accumulated a great amount of knowledge and experience in making predictions for different time scales. For summer rainfall, the five major physical factors to be considered are summarized by Chen and Zhao (2000):

- In the east, sea surface temperature in the warm pool and convective activities in the tropics;
- In the west, the thermodynamic status of the Qinghai-Xizhang (Tibet) Plateau;
- In the south, the Asian monsoon activity;
- In the north, the blocking highs which reflect cold air movement in the middle latitudes;
- In the middle, the subtropical high, the activities of which have been found to have a very good relationship with China's summer rainfalls.

After the successful forecasts for the 1997–98 El Niño and the 1998 Great Flood, more Chinese forecasters are now paying great attention to the extent of snow cover in the Tibet Plateau and to ENSO activities in the tropical Pacific (Tao and Zhang 1998). They found that when there was more snowfall in the Tibet Plateau during the winter, the major rain belt in China in the following summer would be located southward in the Yangtze River basin (Yao, Song and Chen 2001). ENSO's impacts on China's summer precipitation are quite complicated. The relationship is not dependent only on whether it is an El Niño or a La Niña year but as well as the timing of the onset of El Niño or La Niña (Gong and Wang 1998; Zhao 1998).

#### 4.3.2. *Other changes*

Climate is becoming a 'hot' issue in China. Recently, China has mapped out a national program for intensifying climate observations, research and predictions to help facilitate the country's sustainable economic and social development plans over the next 10 years.

Long-term climate-monitoring and data-collection networks are under development in order to improve the accuracy of climate predictions. Precipitation forecasting products are river basin-based.

## 5. Water Resources Management in China

In this section, we first briefly summarize China's water resources. Then, we provide an overview on the development of water resources management in China based on a review of reports from different government agencies, Chinese research (written in Chinese), and technical files. Changes in water resource policies that were made after the 1998 Great Flood are also discussed. It should be pointed out that information presented in this chapter on how climate and weather information was used in water resource management was mainly collected from research papers and technical reports from the water resources community.

Historically, the management of water services in China was put under the control of several agencies of government whose differentiated tasks were to deliver specific services to the people: domestic water supply, irrigation, power generation, navigation, and so forth. As economic activities increase along with increases in urban population growth, there is an urgent and timely need to integrate these water services functionally if not structurally. Like most countries in the world, China is now facing problems of too little water, which is mainly because of two key causes: insufficient quantity of water in relation to population increases, and the ways that people use water in terms of extreme climate variations; and reduced quality of water, due most often to pollution from industrial, agricultural and urban usage. However, the problem of too much water (floods) is always listed as the top concern in China's list of water issues. A change has been called for from the top level in the Ministry of Water Resources: efficiently managing water resources is to become the high priority task along with floods prevention (Wang 2002).

### 5.1. Water resources and uses in China

China has immense water resources, with a total annual precipitation on the order of some 6,200 billion cubic meters and a total surface runoff of 2,700 billion cubic meters. There are many rivers, streams and lakes, and more than 1,500 river basins that exceed 1,000 kilometers. On a per capita basis, however, annual runoff averages about 2,300 m$^3$, which is only a quarter of the world average. In the northern provinces, it is even lower with only 500 m$^3$ per capita.

The water resources are also very unevenly distributed geographically. There are severe droughts periodically in the north and west of the country. There is a growing macro-scale water shortage in the Yellow River basin, which is the primary source of water in the northern region. Although the potential water supply is abundant in the south, many areas are subject to frequent droughts as well as floods.

Currently, industries use 7% and domestic use accounts for 6%. About 87% of water in the national average is used for agricultural production. However, in terms of water supply and cropland area, there is a significant imbalance between the north and the south of the country. In the south of the Yangtze River basin (including the vast Yangtze River itself), there is a population of $700 \times 10^6$ with four-fifths of the total water resources in the country but only one-thirds of the cropland. The arid and semiarid north, however, includes the Yellow, Liao, Hai, and Huai rivers, and has a population of $550 \times 10^6$. While four-fifths of the water is in the south, two-thirds of the cropland is in the north! As a result, the water per hectare of cropland in the north is only one-eighth of that in the south.

## 5.2. Goals in water resources management

After the 1998 Great Flood in China, many scientific studies and policy analyses were conducted on the causes, mechanisms, and policies of mitigation and prevention. Based on the findings and all recommendations, the Ministry of Water Resources decided to pay greater attention on how to efficiently manage water resources in the context of the transition from a planned economy to a market economy in China. The Ministry of Water Resources (Ministry of Water Resources 2002) implemented the 'Tenth Five-Year Plan of Water Resources' in which the following issues were chosen as the major foci for the next decade:

### 5.2.1. *Flood prevention*

China rainfall and runoff vary widely throughout the country, and also vary greatly from year to year. Flood and drought prevention, mitigation and response are always listed as the top task not only for the water resources agencies but also for the government in order to maintain the stability of the society. Since 1949, vast investments in water resources works and development have been undertaken. Approximately 260,000 km of dikes, levees and coastal embankments have been constructed for flood protection and river control. More than 85,000 reservoirs of different sizes have been built. Despite all of these investments, the flood protection standard on the major rivers is still low. It is estimated that most dikes and levees along the major rivers do not meet the current national standard for flood protection and 40% of reservoirs are operated in poor condition (Ministry of Water Resources 2002). With increasing economic development along these rivers and in their river basins, greater economic losses would be occurring, with risks of more frequent floods, if no new major flood control and protection works are undertaken. Therefore, more investment is needed to enhance the physical condition of the existing dikes and levees as well as to build more protection facilities along these major rivers.

### 5.2.2. *Water conservation and development*

By promoting new technology for water conservation and increasing the usage efficiency in industry, agriculture and people's daily life, the goal is to increase the recycle rate of industrial water from current level of 50% to 60% and water usage for per 10,000 RMB (about 1,200USD) reduced from 340 $m^3$ to 170 $m^3$. The goal also includes developing several model cities for water conservation by establishing new policies and regulations for water use and pricing, increasing ground water storage capacity, and developing new hydropower stations in the countryside (Ministry of Water Resources 2002).

5.2.3. *Improving irrigation efficiency in agriculture*

Currently, 87% of the water used in China is used within the agricultural sector. Water resources development is critical to continued improvement in China's agricultural performance. Irrigation currently accounts for about 70 percent of total grain output and about 80 percent of fruits and vegetables. In the past decade, irrigated land in China has expanded from about $20 \times 10^6$ ha to nearly $50 \times 10^6$ ha. However, irrigation efficiency ranges between 30 and 60%, because of such reasons as the lack of accumulated water in the reservoirs, decreased water flow in the rivers, badly maintained irrigation schemes, etc. Some experts estimate that by increasing irrigation efficiency by 10%, more than $40 \times 10^9$ $m^{-3}$ of water could be saved (Ma and Zhang 2000). This is the amount that the 'South to North Water Transfer Project' aims to draw from the Yangtze River (Chen and Ma 2000). Clearly, improving the irrigation efficiency in agriculture is very important and should be one of the government's highest priorities.

5.2.4. *Ecological environmental protection*

At present, the Chinese natural ecological environment is degraded and threatened by human activities. The total degraded land caused by water erosion and desertification is about $3.67 \times 10^6$ $km^{-2}$ or 38% of the total land territory. The total waste-water generated from industrial and agricultural production and municipal sources amounts to more than $60 \times 10^9$ mg per year of which only 20% was processed to meet national water standards. Currently, over 47% of the rivers and 63.8% of the city-rivers are severely polluted. 75% of the lakes and 53% of the coastal oceans are significantly polluted (National Environmental Protection Bureau 2001). Therefore, the ability to control water pollution should be strongly supported.

### 5.3. Lessons learned for water resources management after the 1998 great flood

In the summer of 1998, abnormally high rainfall, which was in large measure due to the 1997–98 El Niño (National Climate Center 1999), fell over the Yangtze River Basin. During these rainfall events, more than 3,600 people died and the areas affected reached over 21 million hectares with over US$36 billion in total economic losses (Gao 1998). Many investigations of the Great Yangtze Flood of 1998 were conducted afterwards by different government agencies in their attempts to understand the causes and to re-examine existing water management policies (National Environmental Protection Bureau 2001; National Climate Center 1998; National Meteorological Center and National Satellite Meteorology Center 1999; National Disaster Prevention Association 1999; Ministry of Water Resources 1999, 2000; National Planning Committee 1998.). The following is a summary, based on many government agency reports, technical reports and scientific research papers.

### 5.3.1. *Causes for damage increases*

To identify the causes of the 1998 Great Flood in the Yangtze River Basin, many studies were undertaken by comparing this flood with the disastrous flood in 1954. The '54 flood had caused more than 100,000 deaths and a loss of property in the billions of US dollars (at 1998 value), and is ranked as the most severe Yangtze River flood in the past 100 years (Ministry of Water Resources 1999). The identified problems for flood control management can be summarized as follows:

- massive floodwater quantity and the unfavorable encounter with peak floods.
- decrease in the number and size of natural flood storage capacity and floodwater detention areas.
- reduction in the discharge capability within the river reaches between the outlet of Dongting Lake and the Wuhan municipal area, because of sand sediment deposition (Xu 2000).
- discharge-capacity decline of the three diversion rivers and the discharge increases within the Jingjiang reach.
- the Jingjiang floodwater detention area and other man-made detention areas had not been used for floodwater storage, as had been done during the 1954 flood.

In terms of natural causes for the 1998 Great Flood in the Yangtze River Basin, anomalous weather was singled out with excessive rainfall being associated with the El Niño episode of 1997–98. In normal years, the Yangtze River Basin rain belt moves from east to west. Rainfall occurs mainly in the areas of the Poyang and Dongting lakes, during April to June. The rain belt then moves westward in June with rain mainly falling in Sichuan Province in July and August. In September and October the rain belt is centered at the Hanjiang River Basin. As described in the previous section, due to the 1997–98 El Niño, there was a great extent of snow cover in the Tibet Plateau in the winter of 1997, which led to the major rain belt in China in the following summer was located southward in the Yangtze River basin (Chen and Zhao 2000). In the summer of 1998, the main flood period took place from June to August with the rain belt in the central and northern Jiangxi, northwestern Hunan, the areas along the mainstream of the middle and lower Yangtze, the Three Gorges reach of the Yangtze and the tributaries to the Yangtze in Sichuan Province, where the rainfall was 50% to 150% more than that in a normal year. The areas affected by heavy rainstorms with high intensities and long periods of precipitation were on both sides of the Yangtze. This resulted in bigger floods than those in 1954 (Zhou and Hu 1998).

In terms of hydrological characteristics, compared to the 1954 flood the 1998 flood had in fact a lower maximum discharge of flood peaks at Yichang, Luoshan and Wuhan stations at the upper reach, but the highest water level of flood peaks in the reach from Shashi to Jiujiang (except Wuhan station) in the middle reaches.

The water level corresponding to the same magnitude of discharge was also higher in the reach from Shashi to Wuhan, and the duration of the rainfall season was also longer in 1998 than that in 1954. More discharge to the river occurred due to changes of the river-lake relationship and the reclaiming of land from lake marshes. These resulted in the highest water level of the 1998 flood peaks being higher and the channel deposition caused the water level during the flood of 1998 to be even higher than that in the 1954 flood with the same discharge.

Based on the long-term hydrometric records from the Minjiang River, Jialingjiang River and the upper reaches of the Yangtze River, the effects of deforestation on the hydrological regimes were exposed (Han 1998, 1999). In these areas, about 30% of the total forest cover was lost since 1980 with an annual rate of 87,000 ha as logging was carried out without a policy of sustainable forest management (Wang 1993). Excessive cutting for timber and clearing for agriculture, including commercial plantation crops, have been the two major direct causes of deforestation (FAO 1997). Once deforestation takes place, land suffers soil erosion and sediment is washed down stream from mountainous areas. It arrives in the central and lower regions of the river where it builds up on the river bed, raising the level of the water far higher than normal. Moreover, as a result of the reclamation of the flood plain and floodwater detention lakes, the retention area for the lower Yangtze had been reduced to about a half of that in 1954 (Zhou 1999). The cut-off of some meandering reaches of the river has resulted in negative impacts because of increasing flow speed. In the upper part of the river basin and areas along the Yangtze heavy rainfall fell in a short span of time contributing to huge flows (Hong 1999; Li and Guo 1999).

It is also believed that the underlying causes of the recent floods in the Yangtze River Basin are becoming much more severe, mainly due to the long duration of rainfall seasons, the large amount of silt in the rivers and lakes, and the very large population increases in the flooded areas (National Environmental Protection Bureau 2001). Moreover, although much has been done with regard to the construction of reservoirs and the strengthening of dikes in China since 1949, the following problems still exist:

- the level of flood prevention planning is still too low;
- the loss of top soil and the consequent increase in sedimentation;
- the lakes has been reduced greatly to be transferred into farmland;
- many man-made obstacles such as housing, farming and fish-farming along the rivers, banks and many hidden weaknesses in the dikes in need of repairs.

5.3.2. *Recommendations on changes in water resource management practices*

The experience from the catastrophic floods in 1998 reveals that it is very important to improve upon original flood control planning, to strengthen reservoir construction, to reinforce the embankments as well as to construct flood-diversion and flood-detention basins and to enhance water and soil conservation (Yuan et al. 2001). More attention must also be paid to flood control including river sedimentation control. Attention should also focus on strengthening the awareness of disaster impact vulnerability and disaster preparedness and increasing investment in hydraulic engineering in order to change from a passive response to the active control of floods. Future plans for flood management should consider not only how to control flood, but also how to safely and reasonably utilize the floodwaters as a resource (Zheng and Liu 2000). It is suggested that: raising the flood control water level in reservoirs to store more floodwater on the basis of comprehensive analysis, at the time of flooding, using the front end of the flooding to flush out pollutants in the river, diverting flood water to farmlands and flood plains in order to recharge groundwater, ameliorate lake shrinkage by flood detention by improving the water supplies to, environment and aquatic production of, the lakes (Xiang and Jiang 2000). Greater effort should be devoted to soil and water conservation for the Upper Yangtze basin as well as for the watersheds of the Dongting and Poyang lakes (National Environmental Protection Bureau 2001). More support should be given to river gauging and scientific research. In comparing the 1998 flood to that of 1954, stages in 1998 were generally higher than those in 1954, although the discharges did not differ much. A number of qualitative explanations have been advanced (National Environmental Protection Bureau 2001). Existing mathematical models should be used to conduct a comprehensive hindcast of the rainfall flooding and river processes in order to arrive at a reliable quantitative explanation.

### 5.4. Use of climate and weather information in water resource management

Based on a review of the 'gray' (unpublished) literature after 1998 (e.g., the government reports, research papers and technical information written in Chinese), we reviewed how climate information for different time scales (from daily to seasonal) has been used during and after the 1998 Great Flood by policy makers in water management with the realization that El Niño events will continue to occur in every 3–7 years. The general findings are as follows:

#### 5.4.1. *Decision-makers in water resource management have apparently become more reluctant to use climate and weather forecasts in their decision-making processes*

In China, although decision-makers in water resource management always publicly praise the great efforts made by the country's meteorological services to provide weather and climate forecasts, there are still many obstacles in using climate information in their decision-making processes. Nevertheless, forecast accuracy is the most worrisome issue for the water resources people, when they try to use climate and weather information to make their key decisions. In case of the 1998 Great Flood, the China Meteorological Administration was well prepared for the event and made an excellent prediction of the onset of El Niño and the possibility of big floods in the Yangtze River. The occurrence of the 1998 Great Flood proved that the forecasts in different time scales from seasonal to daily were all quite accurate.

The damage caused by the flood event helped the water resource agencies to identify the weakness both in flood prevention measures and in water management. Unfortunately, from the central government to local water managers, they all seemed to rely fully on the weather forecasts for making flood prevention plans in the following year, 1999. The erroneous long-term predictions in 1999 then brought them (forecasters and policy makers) back to reality. As a result, almost all recommendations from engineers, scientists and policy makers in hydrological fields asked for more investments to improve flood prevention facilities, such as building more reservoirs and higher dams, enhancing dikes and other hydrological engineering projects.

How to incorporate climate information into their decision-making processes has been once again left untouched. Although people from the weather service and water resource management both ask for more investment from the government to improve forecast accuracy, the water resources people appear to have given up on using climate information at least for a while. Sometimes, however, they will use what the weather service predicts as a way to get more funding from the government.

### 5.4.2. *Changes are needed in weather services to provide better and more reliable products*

Many water resources people have complained about the information provided by the meteorological services as hardly matching what they need for decision-making. Although changes have been made recently such as the weather services are now providing forecasts based not just on political or bureaucratic jurisdictions regions but based on river basins as well, improvement is still needed for explaining the forecasts and climate phenomena such as ENSO's extremes and their impacts.

We have observed that most climate and weather forecasts are used for flood prevention and mitigation. However, considerably less effort has been made to improve how best to use this information for water management and the planning of future water projects. Weather services at all levels must work with policy makers in water management to study how to use climate information more efficiently. To meet this goal, meteorological services should develop training programs for the forecasters by considering the users' concerns, requirements, decision processes, and needs.

## 6. Summary

China has always faced a great challenge in managing its water resources and the future will likely be no different. Climate and weather play dominant roles in the hydrological cycle. With the rapid population growth and economic development in China, the need for water has been increasing dramatically. This in turn leads to an increase in dependence on climate and weather information. As described in the previous section, the 1998 Great Flood in the Yangtze River Basin revealed many weaknesses in China's water resources management tactics and strategy. Most of the weaknesses are more or less related with climate variations and extreme weather events. There is clearly a need to change the current use of climate and weather information in water resources management after the 1998 Great Flood. Instead, we observed many efforts by meteorological services as well as water management agencies to receive additional funding in order to enhance their own capability. Although there are many experiences and lessons about the benefit of using climate information in water management decision-making processes both in China and in other developed and developing countries, we see hardly any solid evidence that climate and weather information was used efficiently or actively in decision-making processes in China.

In general, climate and weather information was found to be useful for water management purposes, especially during the flooding seasons. However, there are no official documents on how climate information could be used in the water resource management agencies. It is mainly dependent on how knowledgeable the water managers are about the usefulness of climate information and the various ways to apply it in their decision-making processes. One exception appears to be when flood peaks come and local authorities need to make quick and hard decisions such as whether, when and where to break dikes in order to save more relatively important targets (e.g., big cities in many situations). Weather forecast information then plays a decisive role in the decision-making process.

Although there have been some changes in making forecasts to meet users' needs such as, for example, basin-wide precipitation forecasts, the gap between the meteorological services and potential users (in this case, the policy makers and decision-makers for water resources management) appears to have grown even after the 1998 Great Yangtze Flood. An extreme example is that after the 1998 Great Flood, the National Environment Protection Bureau asked the United Nation Environmental Program (UNEP) and United Nations Center for Human Settlements (UNCHS) to help identify the weaknesses and to provide solutions and suggestions for future policies. From September to December 1999, there were three consecutive workshops held in China with many government agencies involved, EXCEPT for the Chinese Meteorological Administration! It was ironic that the final report of these workshops was published by the Meteorological Publishing House.

Since there is still no comprehensive impact study and application group in the China Meteorological Administration to conduct 'marketing' tasks for the CMA, considerable effort will be needed for meteorological services to develop user-specified products under the current meteorological service bureaucracy. A strong meteorological impacts research, education and application program is needed to educate not only the users about what levels of accuracy and reliability they might realistically expect from the forecast community but also forecasters on how to modify the forecast products by an improved understanding users' needs.

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