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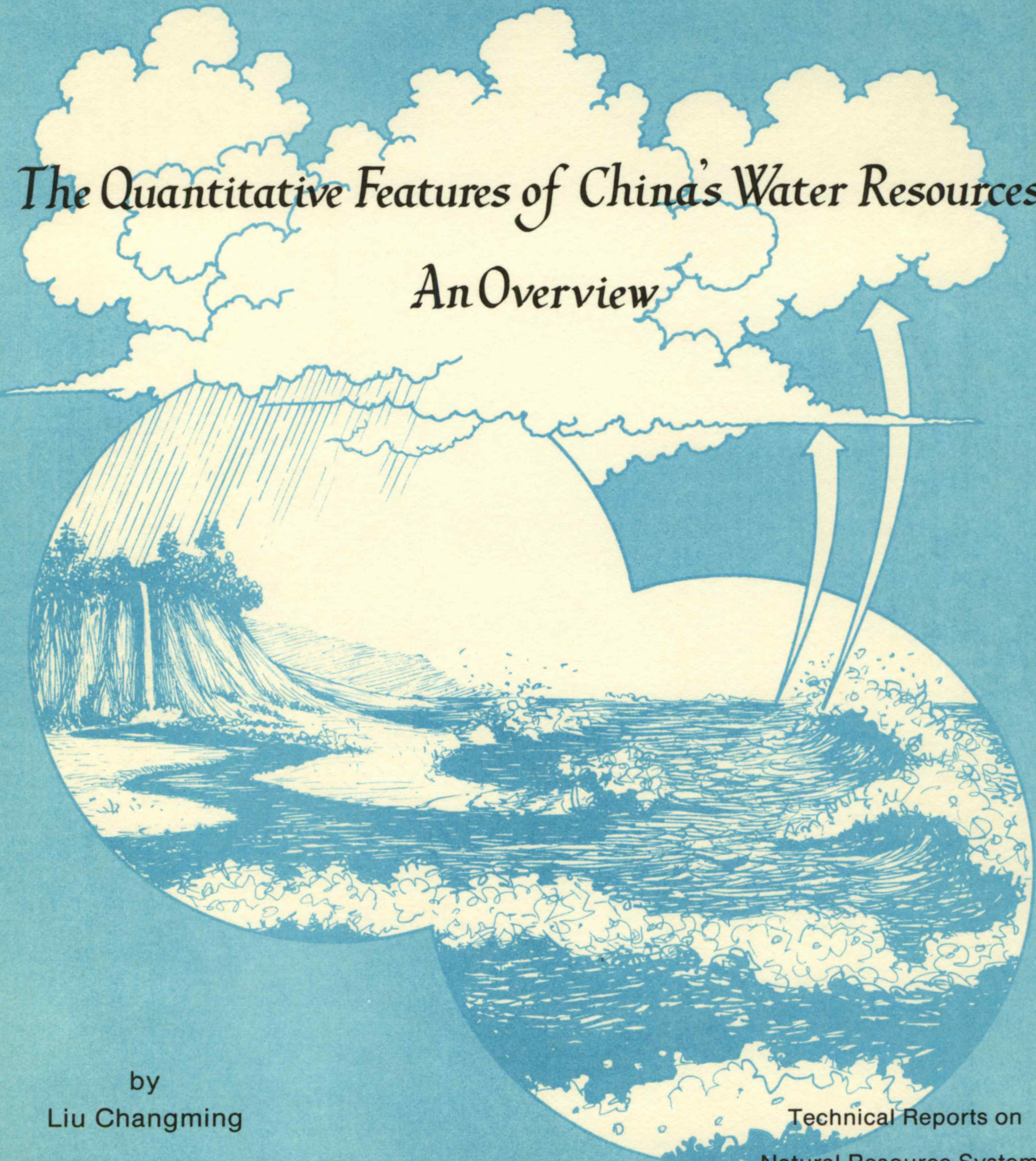

by
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The University of Arizona
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THE QUANTITATIVE FEATURES OF CHINA'S WATER RESOURCES: AN OVERVIEW

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INTRODUCTION

China has a long history of hydrological development. According to Chinese legends, famous projects of flood water diversion were developed by the Great Yu as early as the year two thousand B.C. The earliest hydrological record appeared in 256 B.C., when Mr. Lipin and his son constructed the Dujiangyan irrigation system in the upper reach of the Mingjiang River in Sichuan Province. At Baopingkao, the water intake point of the Dujiangyan irrigation system, a water staff gage was carved on a stone for the measurement of water levels. Although hydrological studies in China started early, hydrology and water resources as modern sciences have been developed only in the last several decades, particularly rapidly in the last 30 years. For instance, the number of hydrological stations has increased 45 times, from about 350 to more than 16,000. Of these, about 3300 stations also take flow velocity measurements. The average density of the hydrological stations is about one per 530 km^2 and that of discharge measurement stations about one in 3,000 km^2. These stations are highly concentrated in eastern China. The longest records of precipitation are maintained in the large cities in eastern China, including Beijing, Shanghai and Tianjing. Beijing has 140 years of precipitation records. The Hankao hydrological station on the Changjiang (Yangtze) River has the longest discharge record spanning 117 years (1865-1982).

In China there are about 50,000 rivers with basin areas greater than 100 km^2, of which 1,500 are greater than 1,000 km^2. Due to different climatic and geomorphological conditions, the distribution of the river systems in this country is very uneven. In the eastern external runoff regions, the river systems are well developed with extensive networks of tributaries and with higher discharge. In some areas the density of stream networks amounts to several kilometers per square kilometer. But in the western internal (closed basins) runoff regions, the rivers are sparse and short due to the dry climate, and in such regions their density is less than 0.1 kilometer per square kilometer. The external rivers in China flow into the Pacific, the Indian and the Arctic Oceans. The areas of external runoff regions are given in Table 1 [1]. China's internal runoff regions are found mainly in the arid and semi-arid regions of Gansu, Qinghai, Xinjiang, Inner Mongolia and Ningxia. About 36.2% of the country (3,478,712 km^2) is drained by internal river systems. In short, the areas of external runoff account for about two-thirds of the country while one-third of China is drained by internal river systems.

As a nation China is rich in water resources. The total annual runoff of the nation amounts to 2,600 km^3, making China the fifth ranking country in the world after Brazil, the Soviet Union, Canada, and the United States

Table 1. Areas of Stream Drainage Systems in China

Drainage Systems	Oceans	Drainage Area (km^2)	% of Nation's Area
External	Pacific Indian Arctic	5,445,932 624,494 50,862	56.7 6.5 0.6
	Total	6,121,288	63.8
Internal		3,478,712	36.2

[2]. In addition, China has groundwater resources of about 700 km^3. However, the per capita volume of water resources is very low, due to China's large population. For example, per capita volume of annual runoff amounts to only 2,600 m^3, which is about 18.4 percent of that of the United States (13,900 m^3), and 13.5 percent of that of the Soviet Union (18,500 m^3). It is even less than that of Asia as a whole (6,700 m^3). Not all of the 2,600 km^3 of total annual runoff is available for utilization because the flood flow portion of the annual runoff for the most part goes away without being used. Only the base flow, or the stable part of a river's runoff, is available for effective use. On the basis of preliminary estimation of the author, base flow in China makes up about 27 percent of total river runoff. This means that the per capita volume of water that would be available from stable river runoff is very small, about 700 m^3 per year only (less than 2,000 ℓ/capita/day).

In the last two decades China has been encountering water shortages in many places because of the rapid growth of industry, agriculture and population. In such a case the research in water resources, including water quantity and quality, and their distribution in time and space, as well as the rational utilization and management are of significance in further developing the nation's economy.

CHINA'S WATER BALANCE

In order to better estimate China's water resources, it is important to have a better understanding of water balance of the country. Water balance elements consist mainly of precipitation, runoff, evapotranspiration and storage. Precipitation (P) is generally the major source of water in a region, while runoff (R), evapotranspiration (ET), and water storage (ΔS) are directly or indirectly affected by precipitation. For a given time period the water balance of a region can be expressed as follows:

$$P = R + ET \pm \Delta S \qquad (1)$$

Over a long period of time the average change in storage approaches zero ($\Delta S \rightarrow 0$), thus equation (1) becomes:

$$P = R + ET \qquad (2)$$

In the internal runoff regions all runoff (R) is ultimately lost by evapotranspiration, and we obtain:

$$P = ET \qquad (3)$$

In the consideration of water balance changes caused by man's activities, the changing values corresponding to the δR, δET, $\delta \Delta S$ should be added to equation (2):

$$P = (R \pm \delta R) = (ET \pm \delta ET) \pm \delta \Delta S \qquad (4)$$

Equations (1), (2) and (4) can be used to study water balance under natural conditions and under man's activities respectively.

Natural Water Balance: China and World

In the external runoff regions of China, the amount of precipitation is comparable to that of the world average, but runoff in China is somewhat higher and evapotranspiration is slightly lower (Table 2). The internal runoff regions of China are adjacent to central Eurasia, and their mean

Table 2. Water Balance in External and Internal Runoff Regions of China (in cm)

Regions	External Runoff Regions					Internal Runoff Regions	
	P	R	ET	R/P	ET/P	P	ET
China	89.6	40.3	49.3	0.45	0.55	16.4	16.4
World*	87.3	32.0	55.3	0.37	0.63	23.1	23.1

*Source: Lvovitch, M.I., "World Water Balance", World Water Balance, v. 2, Proceedings of the Reading Symposium, July 1970, IASH-Unesco-WMO.

values of water balance elements are lower than those elsewhere in the world. China's internal runoff regions appear to be particularly dry. As a whole, China's precipitation and evapotranspiration are lower and runoff is higher than the averages of the world. The average runoff coefficient of China (R/P = 0.43) (Table 3) is 19% higher than that of the world (R/P = 0.36). This situation is related to the fact that there are numerous mountains in China which facilitate runoff and that, under the influence of the monsoon, precipitation is heavily concentrated in summer, which results in frequent floods and leads to an increase in runoff.

The average annual precipitation of China is about 14% less than the average of the world (Table 3), mainly because China has extensive arid and semi-arid areas. The average annual evapotranspiration of China is 23% lower than that of the world, and this is related to the actual evapotranspiration in the arid region of China's northwest, and to the fact that

Table 3. Water Balance in China and the Rest of the World

(in cm)

	P	R	ET	R/P	ET/P
China	63	27	36	0.43	0.57
Land area of the World*	73	26	47	0.36	0.64

*Source: Lvovitch, M.I., "World Water Balance", World Water Balance, v. 2, Proceedings of the Reading Symposium, July 1970, IASH-Unesco-WMO.

evapotranspiration in the extensive mountainous regions of China is much lower than that of other regions.

Elements of Water Balance in China

In the water balance equation (2), the values of runoff (R) and evapotranspiration (ET) depend on precipitation (P). In other words,

$$R = f\ (P) \tag{5}$$

$$ET = y\ (P) \tag{6}$$

The relationships of (5) and (6) are shown on Figure 1, which shows that

when $P \to 0$, $ET \to P$ and $R \to 0$;

when $P \to \infty$, $ET \to C$, and $dR/dP \to 1$;

where C, a parameter, depends on geographical conditions of a region, and

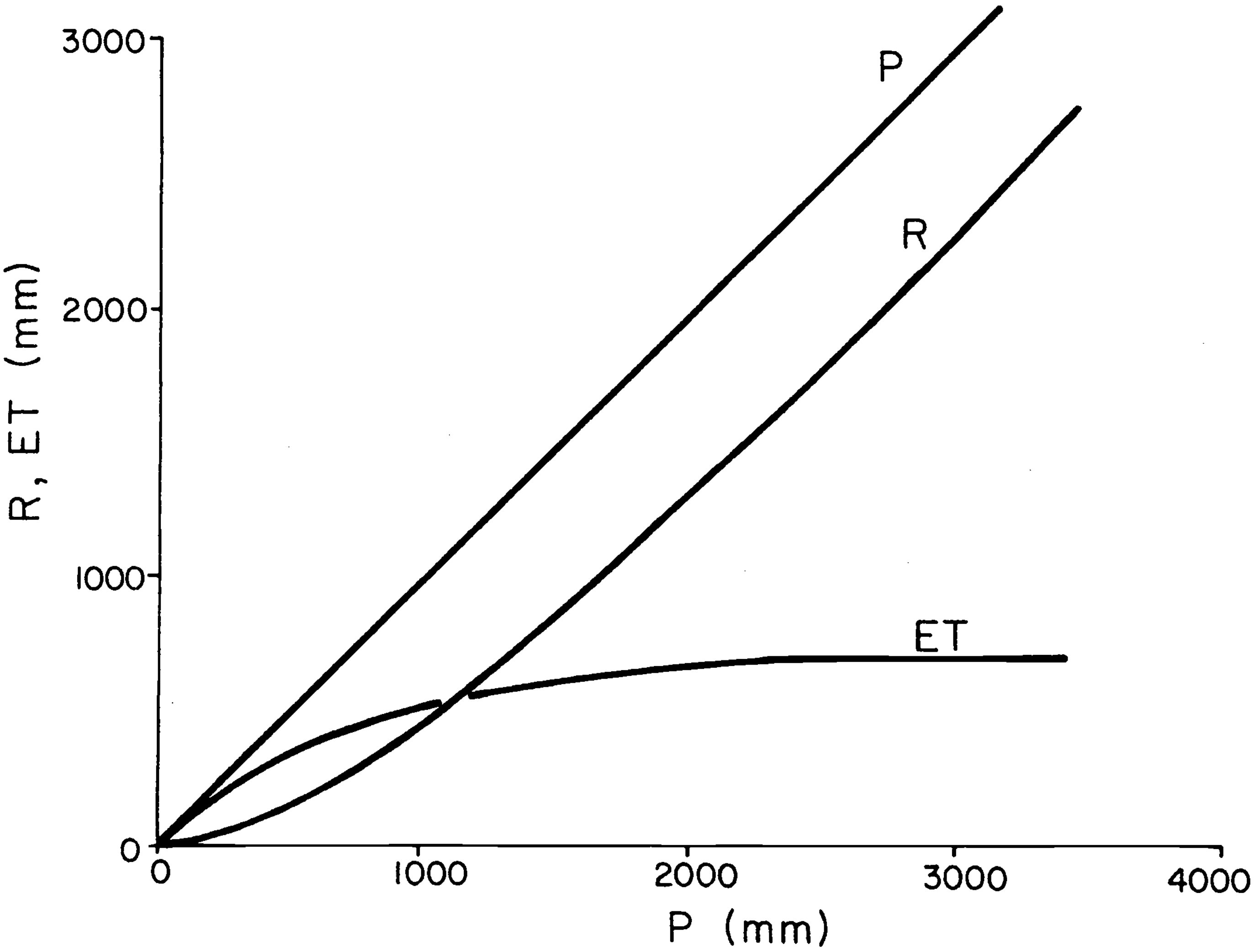

Figure 1. Relationship between Water Balance Elements of China's Mountainous Regions.

approaches the value of potential evapotranspiration. In these two cases, the former can be found in desert regions of China, such as the Tarim Basin of the Xinjiang Uygur Autonomous Region where the annual precipitation is below 50 mm and the annual runoff almost equals zero, $R \to 0$. The latter appears in the humid mountainous areas in southeastern China where the annual precipitation exceeds 1,100 to 1,200 mm and the annual evapotranspiration tends to approach a constant value. In such a case, $dR/dP \to 1$. By analyzing the relations of the water balance elements in river basins, an annual runoff model is obtained as follows:

$$R = P - P_0 - C\,[1 - \exp(-\frac{P-P_0}{C})] \qquad (7)$$

or

$$R = P\,(1 - \frac{P_0}{P}) - C\,[1 - \exp\,(-\frac{P(1 - \frac{P_0}{P})}{C})] \qquad (8)$$

where P_0 is annual precipitation which is insufficient to generate runoff, and C can be considered as a water loss coefficient. To simplify the calculation, we adopt P in lieu of the $P(1-P_0/P)$, and then equations (7) and (8) become:

$$R = P - C[1 - \exp(-P/C)] \qquad (9)$$

According to equation (2) we have

$$ET = C[1 - \exp(-P/C)] \qquad (10)$$

As seen from equation (10), the parameter (C) (the water loss coefficient), should be represented as a maximum value of the annual evapotranspiration from river basins, and it can be expressed as E_{max}. The nature of (ET) is as follows:

when $P \to \infty$ $ET = C = E_{max}$

when $P \to 0$ $ET = 0$

Apparently the above boundary conditions are in line with the general principles of evapotranspiration. If we have E_{max} instead of C, then the actual evapotranspiration can be estimated as follows:

$$ET = E_{max} [1 - \exp(- P/E_{max})] \qquad (11)$$

In this formula, E_{max} is a maximum potential, and it can be estimated by using data on radiation balance and on the latent heat regime for given river basins.

By analyzing the data of 86 medium-sized river basins selected from various mountainous regions of China, we obtained the relationship between the water balance components (see Figure 1) and found that the parameter (C) included in equations (9) and (10) equals 730 on the average. Therefore,

$$R = P - 730 [1 - \exp(- P/730)] \qquad (9a)$$

and

$$ET = 730 [1 - \exp(-P/730)] \qquad (10a)$$

These formulas, (9a) and (10a), basically express the relations between the P and R, and ET. From Figure 1 we find that these relations differ with different precipitation. The following features have been observed:

1. When the annual precipitation is quite small, the annual runoff curve approaches the abscissa and goes up very slowly with increased precipitation, but the annual evapotranspiration increases rapidly with precipitation. On the other hand, when the precipitation is very large, the

corresponding increase of annual evapotranspiration is small, and the annual evapotranspiration curve parallels the abscissa P. At the same time, the annual runoff curve approaches 45° (see Figure 1).

2. When the annual precipitation amounts to about 1,100 mm, the annual runoff probably equals the annual evapotranspiration, i.e., each accounts for about one half of the annual precipitation.

3. When the precipitation is less than 1,100 mm in a region, the annual runoff will be less than the annual evapotranspiration. But when the precipitation is greater than 1,100 mm, the annual runoff will exceed the annual evapotranspiration. According to the annual average isohyet of China, it will be easy to find that the areas in which $P > 1,100$ mm are relatively small, and most areas are under conditions of $P < 1,100$ mm, i.e., $R < ET$. Generally speaking, the former areas account for no more than one third and the latter areas make up at least two thirds.

As to China's plains, the water balance features are different from the above-mentioned mountainous regions. In eastern China there are three major plains: Northeast Plain (350,000 km^2), North China Plain (310,000 km^2), and the Changjiang Plain in the lower-middle reaches of the river (about 310,000 km^2). The total area of the three plains approaches a million square kilometers. For these three plains the parameter (C) in equation (9) rises much higher than that of mountainous areas; it amounts to 1,300-1,900 and it averages about 1,600 because evapotranspiration in these flat areas is very intensive regardless whether in the north or in the south (Figure 2). Particularly in the North China Plain, north of the Huanghe (Yellow) River, evapotranspiration accounts for 90% of the precipitation and the runoff accounts for only 10%. Obviously on China's plains, water exchange takes

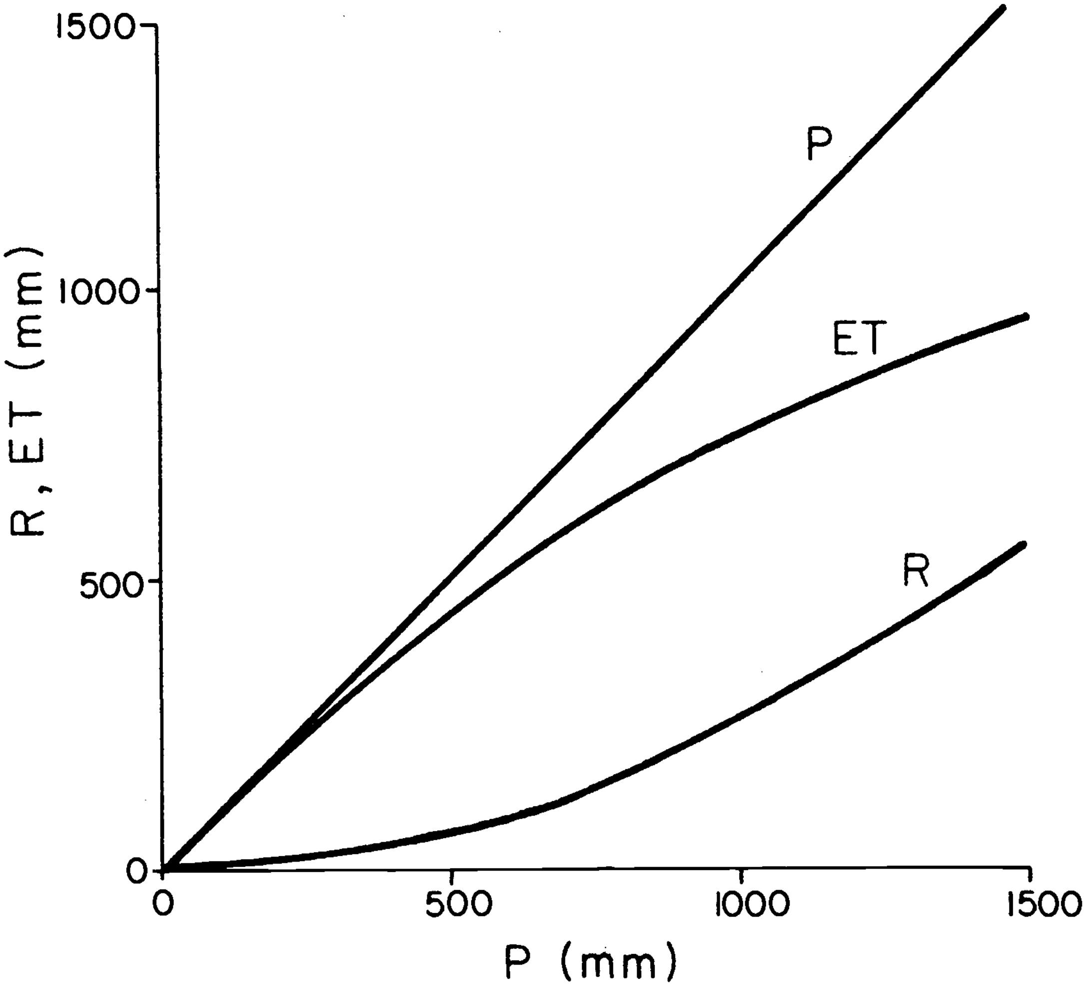

Figure 2. Relationship between Water Balance Elements of China's Plains.

place mainly vertically. In other words, most of the precipitation reaching the surface is returned to the atmosphere by evapotranspiration.

China's major river basins have different characteristics of water balance (Table 4). For the rivers of north China (the Songhuajiang, Haihe, Huanghe (Yellow) River), and northern branches of the Huaihe River, ET is greater than R, while in the south and the southwest, in the basins of the Changjiang (Yangtze River), the Zhujiang (Pearl River), and the Yarlung-Zangbojiang, etc., ET is less than R. The Yarlung-Zangbojiang is located in the southeastern part of the Qing-Zang Plateau in Tibet where the high mountains with many glaciers facilitate runoff generation and thus the runoff is more than three times as large as the evopotranspiration.

AN ESTIMATION OF CHINA'S WATER RESOURCES

It is well known that different forms of water in the hydrologic cycle have different renewal periods. This period can be called the period of

Table 4. Water Balance in China's Major River Basins*

River Basin	Area ($\times 10^3$ km^2)	P (cm)	R (cm)	ET (cm)	R/P (%)	ET/P (%)
Songhuajiang	549.7	52.5	14.5	38.0	28	72
Haihe*	264.6	55.7	8.6	47.1	15	85
Huanghe (Yellow)	754.6	49.2	7.6	41.6	15	85
Huaihe	261.5	92.9	19.1	73.8	21	79
Changjiang (Yangtze)	1,807.2	105.5	54.2	51.3	51	49
Chujiang (Pearl)	452.6	143.8	77.2	66.6	54	46
YarlungZangbojiang	246.0	69.9	47.4	22.5	68	32

*Source: From reference [1] except Haihe which was added by the author.

water exchange activity [3], or the duration of discharge and recharge period [4]; some American hydrologists, such as Todd [5], call it detention period. The detention period can be simply expressed as follows:

$$DP = W/q \tag{11}$$

where W = water reservoir capacity (L^3), q = the rate of water discharge or recharge (L^3T^{-1})(assumed equal), and DP = detention period. From (11) we get

$$DP = \frac{W}{q} = \frac{L^3}{L^3T^{-1}} = T.$$

Consequently, the unit of DP is a time period (T) related to the unit of q, generally in terms of years, thus the unit of detention period is also in years. The detention period of water is of great significance in the use and development of water resources. The shorter the DP, the more readily the water becomes available for use. Conversely, the longer the DP, the slower the renewal of the water resources and the less available is the water for human use. In addition, the DP of water resources is also a very important base on which the quantity of water of a region can be estimated. If the DP can be accurately determined, the water reservoir capacity (W) can be obtained through q:

$$W = q \quad DP \tag{12}$$

or the q can be estimated through the W

$$q = \frac{W}{DP} \tag{13}$$

It must be pointed out that in solving equations (11), (12), and (13) the influence of man's activities upon the q and W obtained from observations or investigations was taken into consideration in the estimation. Along the large river basins in eastern China there is a very high density of population so that the influence of man's activities on water resources, which have been taking place in many river basins, is quite severe. According to preliminary analysis, we have learned that this influence is greater in arid regions than in humid regions, more serious in plains than in mountains, and more evident in small watersheds than in large river basins. Using equation (4) to analyze observed data of the Malang Hydrological Station (area of 3,900 km^2) on the Qinliangjian River, the tributary of the Haihe River in the North China Plain, we found that with the same amount of annual precipitation, the annual runoff has been very different before and after 1958. Because of rapidly increasing water uses for irrigation since 1958, the annual runoff of the Qinliangjiang River has decreased by about 50 percent (Figure 3).

The average annual runoff of the Huanghe (Yellow) River (watershed area 754,600 km^2) during the period between 1969-1978 was 10 billion m^3 less than that of the 1950's, suggesting that the average annual runoff of the river decreased by 18% due to increase in water uses. In the 1970's, the lower reaches of the Huanghe near the estuary dried up seven times temporarily in spring and early summer as a result of droughts and heavy water uses upstream.

In the humid regions of the Changjiang (Yangtze) River, the annual precipitation in the hilly areas exceeds 1,100 mm. The observed data of the Changjiang's discharge, measured by the Planning Office of the Changjiang's

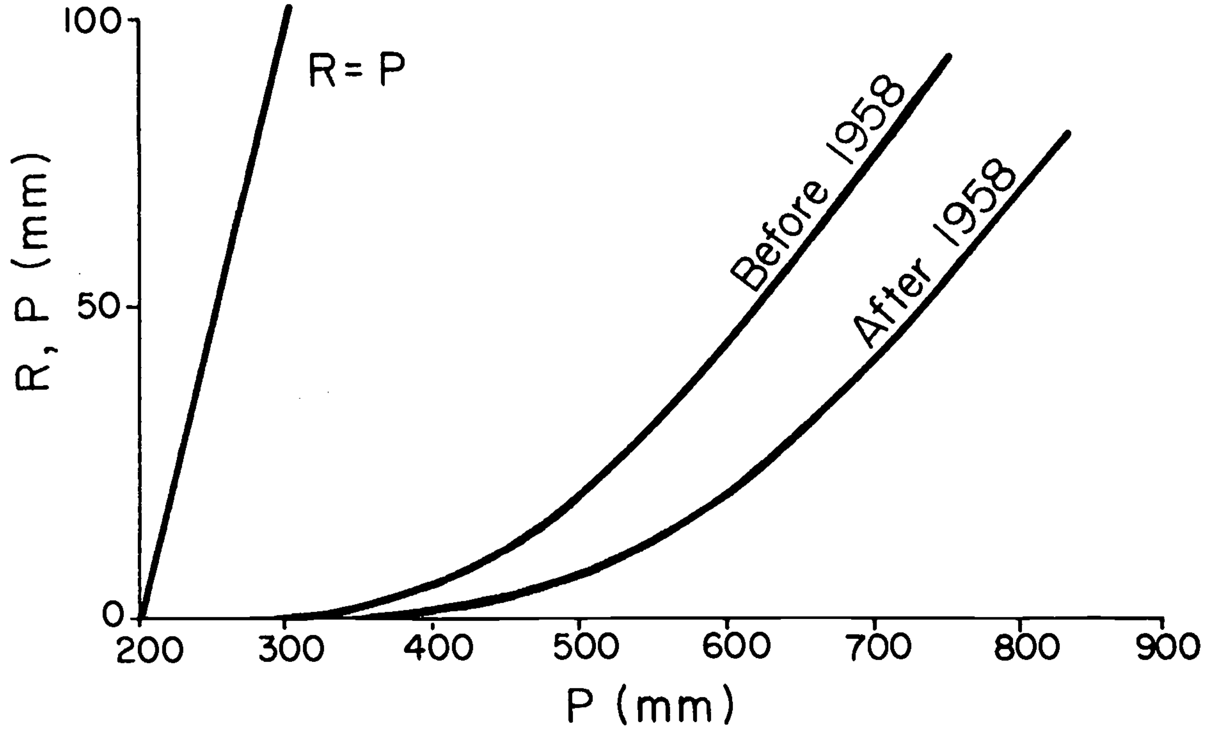

Figure 3. Influence of Man's Activities on River Runoff in the Qinliangjiang Watershed.

Water Conservancy, indicates that the river's average annual runoff in the last 30 years has decreased about 5% because of increasing water uses, despite the fact that the average annual precipitation in this period increased about 4%. It is likely that the amount of decrease of river discharge caused by man's activities in the Changjiang River basin reached 70 billion m^3 a year. It is equivalent to 122% of the total natural annual runoff of the Huanghe River (57.45 billion m^3), and to 7.1% of the total natural annual runoff of the Changjiang River. Therefore, it is clear that the influence of man's activities on water resources quantity is apparent both in the south and in the north, and in small watersheds, as well as in large river basins.

As to water quantity in China, by using various sources of information, as well as hydrometeorological data, the volumes of China's water in different physical states were estimated as shown in Table 5. In Table 5, the area of 9,543,000 km^2 estimated for the groundwater excludes the area of mountain glaciers (57,000 km^2). The actual depth considered in this estimation is 497 m, excluding a soil zone of 3 m, assuming that the average effective porosity is 12% [4], and the specific yield adopted by author for this depth is about 0.1. In such a case, it should be easy to get a volume of 56,915 km^3 of groundwater in storage.

Soil moisture refers to the amount of water stored and renewed annually in the 3-m soil zone. The amount was estimated by separating total river runoff (R) into surface runoff (Rs) and groundwater runoff (Rg). That is,

$$R = Rs + Rg \qquad (14)$$

Based on equation (2), we get

Table 5. Estimated Volumes of Water Stored in China

Conditions of Water	Area (km^2)	Volume of Water		Annual Circulation (km^3/year)	Detention Period (years)
		Water in Liquid (km^3)	Percentage of China(%)		
Liquid Water					
Groundwater in 500 m zone	9,543,000	56,915	88.47	700	81
Soil moisture	8,260,000	3,355	5.21	3,355	1
Lakes	80,645	821	1.28	51	16
(Reservoirs)		(400)			
Marshes	110,000	50	0.08	10	5
Rivers	8,510,000	86	0.13	2,600*	0.033**
Water Vapor	9,600,000	163	0.25	6,048	0,027**
Glaciers, Ice and Snow	57,000	2,946*	4.58	51	58
Total of Water Volume		64,336	100.00		

Notes: * source from reference [1]
**source from reference [3]

$$P = Rs + Rg + ET \tag{15}$$

and the soil moisture as annual renewal of soil moisture storage (SM) can be estimated as follows:

$$SM = P - Rs \tag{16}$$

The area estimated for the soil moisture amounts to 8,260,000 km^2, which excludes the areas covered by glaciers, lakes, marshes, and deserts. Using equation (16) we obtained the soil moisture of 3,355 km^3.

Since data are lacking on all lakes in China, the total water storage in the lakes was very roughly estimated by inference from some lakes which were investigated. Total water storage in China's lakes is likely to be a volume of 821 km^3 (total area of the lakes is 80,645 km^2). According to the research conducted by the Changchun Institute of Geography, Academia Sinica, the water content in the marsh zone averages 90%. The amount of water reserved in China's marshes was estimated from their total area of 110,000 km^2. Total water storage in the marshes amounts to about 50 km^3.

Water stored in river channels is the average annual storage, which is generalized by the following equation [4]:

$$W_r = K \frac{\overline{Q}u + \overline{Q}e}{2} L \tag{17}$$

where W_r = volume of the average annual storage in a river channel; K = conversion coefficient; L = river length; $\overline{Q}_u$ and $\overline{Q}_e$ are the average annual discharges at the river source and estuary (river mouth). To simplify the calculation, equation (12) was used instead of equation (17) for the estimation of W_r. Assuming DP = 0.033 [3], we get

$$W_r = DP \quad q = 0.033 \times 2600 = 85.8 \text{ km}^3$$

Therefore, China's water storage in river channels is about 86 km^3. In the same way, the amount of water vapors existing in the atmosphere in annual average was estimated by the annual precipitation of the country (6,048 km^3) multiplied by the detention period (DP = 0.027 years) [3]:

$$W_a = 6{,}048 \times 0.027 = 163 \text{ km}^3$$

Water stored in China's glaciers has been measured by the Institute of Glaciology and Cryopedology, Academia Sinica. The total water storage of mountain glaciers in China amounts to 2,946 km^3, from which an annual meltwater runoff of about 50.5 km^3 is obtained. Correspondingly, the DP of the glacier's water storage can be estimated by equation (11):

$$\text{DP (glaciers)} = \frac{2946}{50.5} = 58.3 \text{ years}$$

This DP is somewhat longer than than of the United States (DP = 40 years) [5]. To sum up, the total amount of water storage in China, excluding the groundwater below 500 m, is 64,336 km^3. Groundwater within the 500 m zone accounts for about 88% of the total water storage. The other components of water storage are, in descending order: soil water, glaciers, lakes, atmospheric water, rivers, and swamps. Percentages of various water storage elements are shown in Table 5.

The amount of water that may be available for effective use is far less than the amount of water in storage as estimated above. Based on the active circulation (replenishment) of water, only an estimated amount of 2,661 km^3 in China is available for use. This amount accounts for just about 4.1% of the nation's water storage and consists mainly of surface water and groundwater. As Table 6 shows, in China's water resources surface water makes up about three-fourths and groundwater accounts for about one-fourth. Water resources originating from glaciers, lakes and marshes are each small in quantity, accounting only for 4.2% (Table 6). This being the case, the river runoff, 2,600 km^3 (= surface runoff and underground runoff (base flow) + glacier's meltwater runoff = 1,894 + 700 + 51), is of great significance to China's water utilization and development.

It must be pointed out that the total absolute amount of water resources, in terms of river runoff, is not sufficient to represent the entire availability of water for human use. One of the reasons is that the distribution of China's river runoff in space and time is very uneven, and in fact, we cannot enable this absolute amount to be fully utilized, so in developing water resources the factor of water distribution must be considered.

TEMPORAL AND SPATIAL DISTRIBUTION OF CHINA'S WATER RESOURCES

China's water resources are characterized by uneven distribution in space and time mainly because of China's large territory and the concentration of precipitation in summer caused by the monsoons.

In most regions of China water vapors come mainly from the Pacific Ocean. Part of southwestern China receives water vapors from the Indian Ocean, and to a limited degree moisture from the Arctic and the Atlantic Oceans can reach inland to the Xinjiang Uygur Autonomous Region through a long path. In general, the amount of precipitation in a region is inversely related to its distance from the oceans. Thus, southeastern China has more

Table 6. Available Water Resources in China

Water Resources	Surface Water					Ground Water		Total
	Surface runoff	Glacier melt water	Lake water	Swamp water	Total	Annual replenishment*	Total	
Volume (km^3)	1,849	51	51	10	1,961	700	700	2,661
Percentage (%)	69.5	1.91	1.91	0.38	73.7	26.3	26.3	100.0

*Annual replenishment of ground water was estimated by base flow.

precipitation, while northwestern China is very dry. China's annual precipitation distribution is shown in Figure 4.

The spatial distribution of water resources basically coincides with precipitation. For instance, in the rainy southeastern coastal areas, surface runoff has the highest values and it decreases to the northwest. The nation's highest annual runoff of 6,390 mm is found on the Hualianxi River in northeastern Taiwan [6], while some places in the desert regions of northwestern China have almost no surface runoff. Based on distribution of annual runoff depths, four major zones have been identified for China's surface water. They are water abundant zone, water sufficient zone, water deficient zone, and water very deficient zone (Figure 5).

Figure 5 shows that the water deficient zone and the water very deficient zone are widely distributed in the western and northern parts of China. The area of these two zones is over half of the country's territory. Apparently, such a distribution of water resources results in a big problem of water supply in northwestern China.

Another of the important features of China's surface water is its large annual and seasonal variations as a result of the summer monsoon's influence. For most regions in China, precipitation is mainly concentrated in summer and autumn. For instance, in the four months from June to September, precipitation amounts to 50 to 60% of the annual total in the southeast, and this unevenness increases toward the northwest, providing 70% of the annual total in the Hexi Corridor of Gansu Province. Corresponding to the distribution of precipitation, runoff during the same period accounts for about 55-60% of the annual total in the southeast and 70-90% in the Kunlun

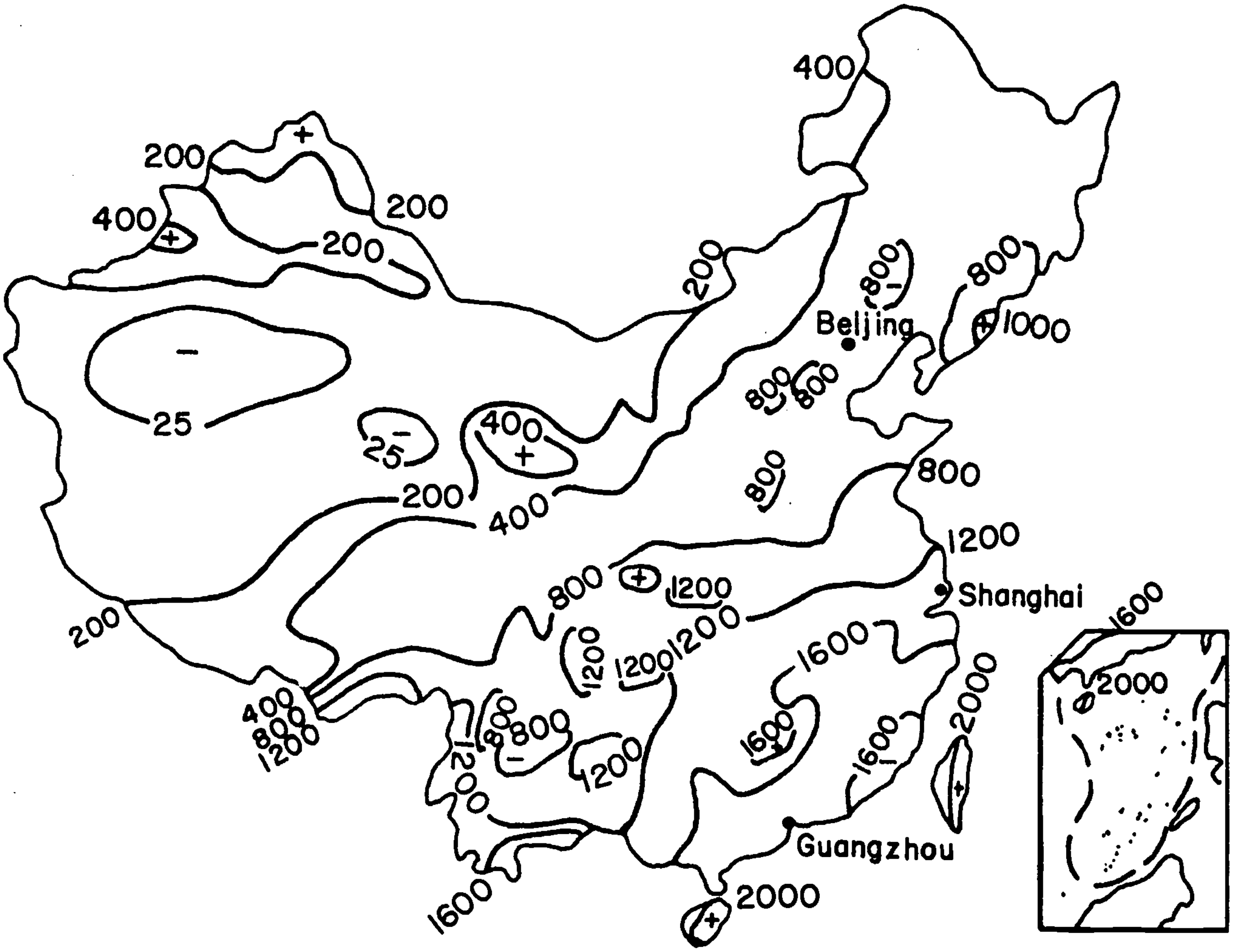

Figure 4. Annual Isohyetal Map of China.

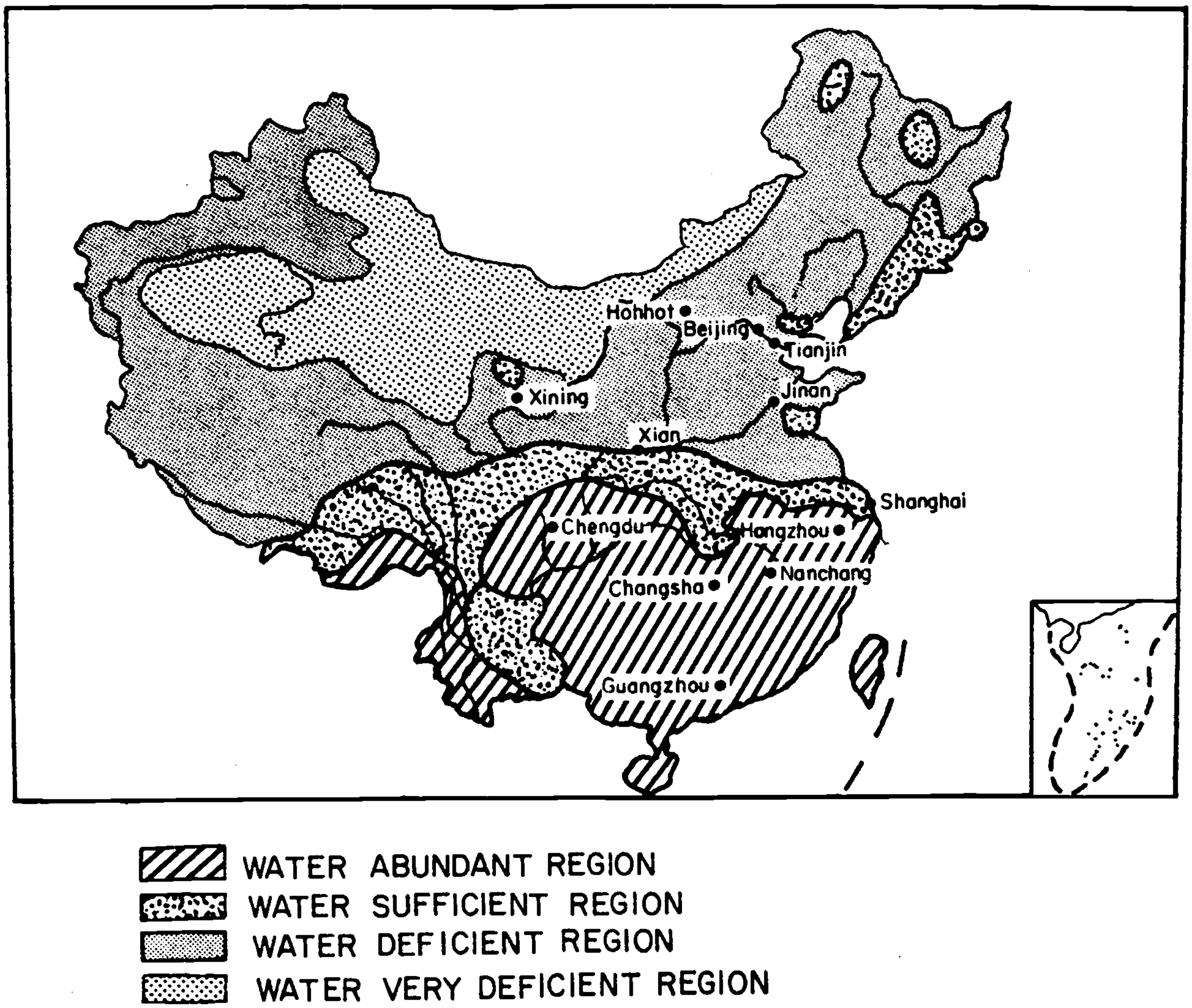

Figure 5. Regionalization of China's Surface Water Distribution.

mountains to the northwest. So, seasonal distribution of surface water in the arid northwest is particularly uneven.

As for the long-term fluctuation of surface water, the coefficient of variability can be used for its expression, which is a ratio of the standard deviation (S) to the arithmetic mean $(\bar{x})$ for a variable. The formula can be written as:

$$C_V = \frac{S}{\bar{x}}$$

where C_V = coefficient of variability for variable x. The areal distribution of the C_V values of China's annual precipitation can be simply described as follows:

$C_{VP} = 0.15 - 0.30$ in the southeast and $C_{VP} > 0.3$ in the north and northwest. The C_V values of the annual runoff (C_{VR}) is related to C_{VP} and it can be calculated by the following equation:

$$C_{VR} = \alpha \; C_{VP}\sqrt{\left(\frac{1}{C_R}\right)^2 + \left(\frac{1}{C_R} - 1\right)^2\left(\frac{C_{VE}}{C_{VP}}\right)^2 - 2\left(\frac{1}{C_R}\right)\left(\frac{1}{C_R} - 1\right)\left(\frac{C_{VE}}{C_{VP}}\right)r_{E/P}} \qquad (18)$$

where α = coefficient, $r_{E/P}$ = coefficient of correlation between the variables of evapotranspiration and precipitation; C_R = runoff coefficient; C_{VE} = coefficient of variation of evapotranspiration. Clearly, C_{VR} is a function of the C_{VP}, C_R, C_{VE} and $r_{E/P}$, and it basically depends on the C_{VP}. The C_{VR} can be estimated empirically, and the following formula for C_{VR} was developed by the author [7]:

$$C_{VR} = \frac{\alpha_1}{\delta C_R^n} \; C_{VP} \qquad (19)$$

where α_1 is a geographical parameter and δ is a ratio of base flow. The α_1, C_R and δ will be constant under the given conditions of a region, so the C_{VR} mainly depends on C_{VP}. Because the C_{VP} is related to the size of the estimated area (A), the estimation of C_{VR} can be also simplified as:

$$C_{VR} = f(A) \tag{20}$$

Figure 6, as an example, shows this relationship, which was obtained by using data observed in some rivers of eastern China.

By analyzing the values of C_{VR} of most medium-sized rivers in China, we learn that the high values of C_{VR} occur in level areas such as the North China Plain, the Northeast Plain, as well as some inland basins in the northwest. The low values of C_{VR} appear only in the southeastern coastal areas.

An additional important feature of the long-term fluctuation of China's surface water is the appearance of successive sets of wet and dry years [8]. For instance, the number of successive dry years and wet years, observed at the Shanxian Hydrological Station in the middle reaches of the Huanghe (Yellow) River, was 11 and 9 respectively. In comparison with this, the volume of water in the Changjiang (Yangtze) River is rather stable, even though the number of succesive dry and wet years amounts to 6 and 4 years respectively. In both areas of northern and southern China, the number of successive dry years for most rivers is greater than the successive wet years, and this is also an important feature of China's water resources.

To express the general trend of the long-term fluctuation of the annual runoff, the use of differential mass curves has to be adopted. The curves are calculated by the following formula:

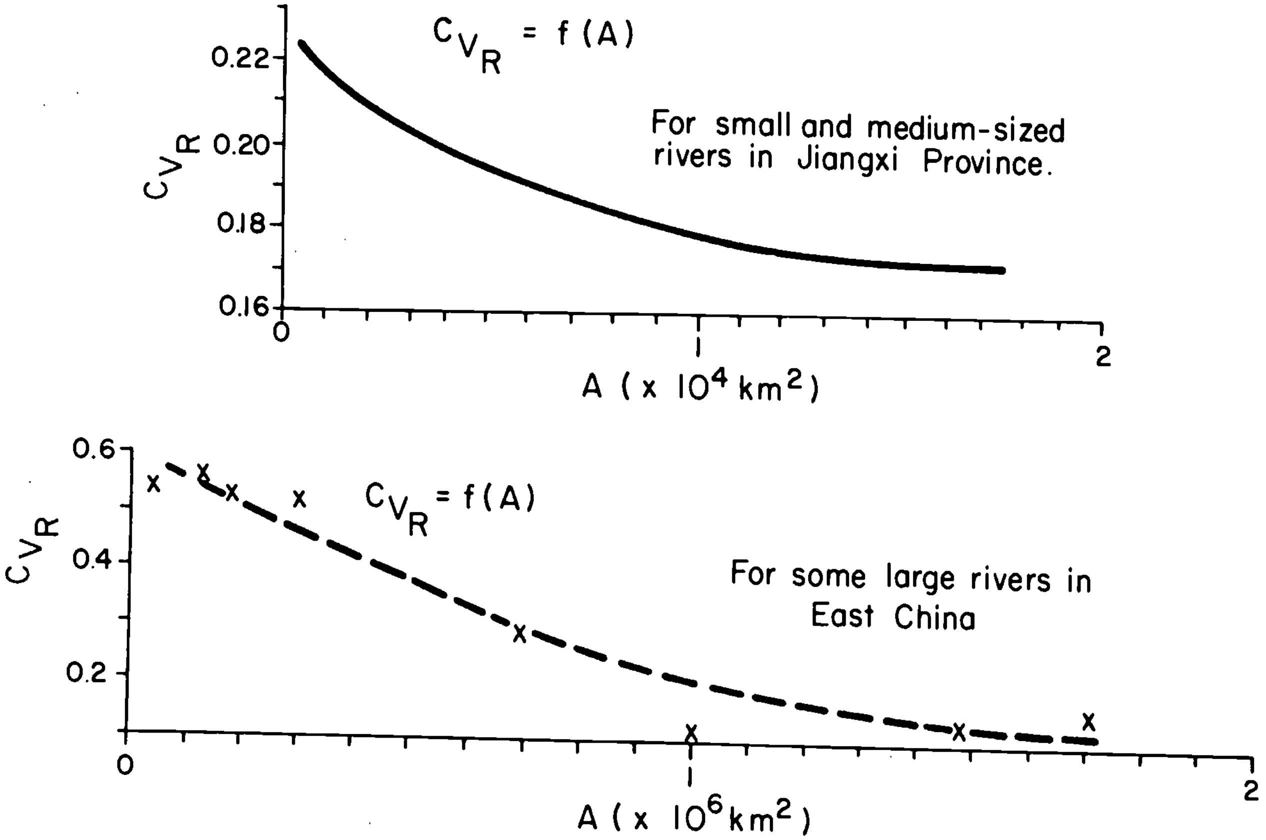

Figure 6. Relationship between C_V and Watershed Area (A).

$$\frac{\sum(K-1)}{C_V} = f(t) \tag{21}$$

where K is the modulus coefficient of the runoff. But these curves can be also expressed as follows:

$$\sum(K-1) - a = f(t) \tag{22}$$

where

$$a = \frac{\sum_{j=1}^{n} \sum_{i=1}^{n} (K-1)}{n}$$

and where n is number of years adopted for calculation. Figure 7 shows the results calculated by equation (22) for four major rivers in eastern China. These curves demonstrate that the variation of the rivers' runoff is very large north of the Changjiang (Yangtze) River, especially in the Huaihe River, and it is quite small in the Changjiang (Yangtze) River.

GROUNDWATER AND ITS DISTRIBUTION

It is very difficult to estimate the exact volume of groundwater resources of China because of the nation's vast territory and its varied geological/geographical conditions. As Table 5 has shown, China's groundwater resources, in terms of replenishment in the active water-exchange zones, totals about 700 km^3, which can be available for water use. It may be mentioned in passing that the volume of shallow groundwater resources in China, estimated by the Ministries of Geology and Water Conservancy in 1981, was 782 km^3, a figure slightly higher than the volume adopted by the author. Obviously, there is no big difference (less than 12%) between these two

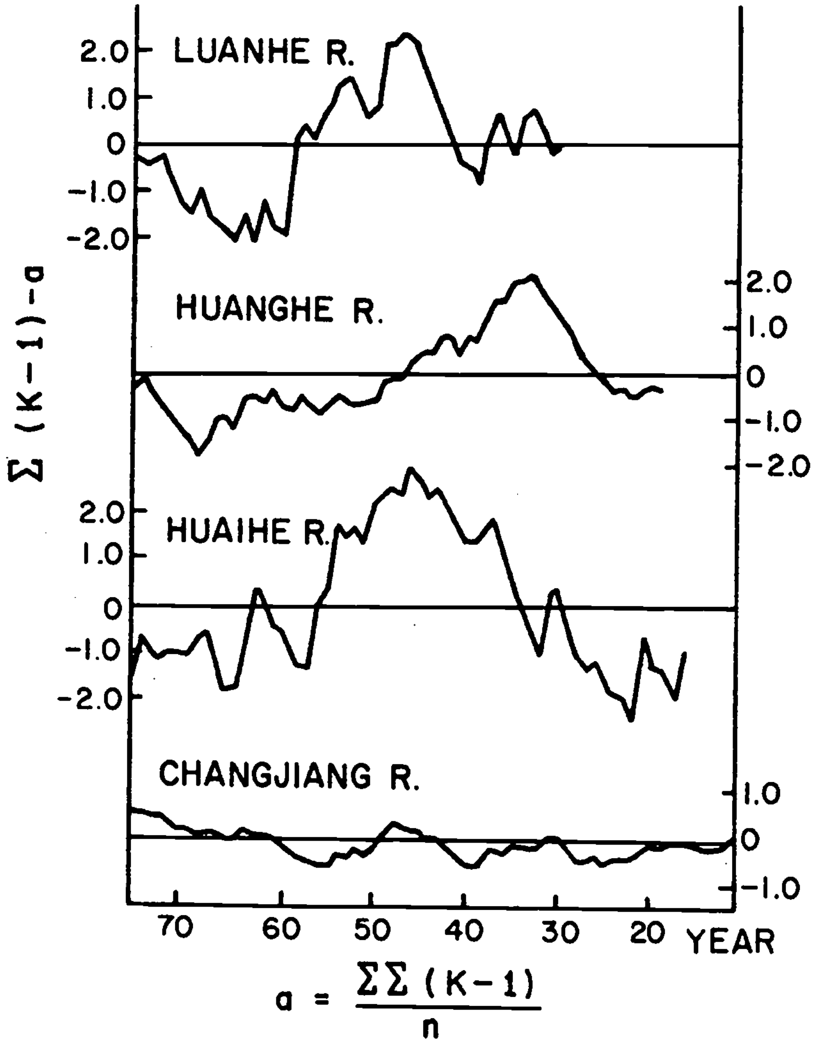

Figure 7. Differential Mass Curves of Four Major Rivers in Eastern China.

figures, which shows that the amount of China's available groundwater resources is far less than the total estimated groundwater reserves of 56,915 km^3. On the basis of these figures and of the results from the above-mentioned water balance analysis, the average precipitation percolation coefficient of groundwater in China is between 0.115 and 0.129, which is determined by dividing 700 to 780 km^3 by the precipitation of 6,048 km^3. Generally speaking, about 12% of annual precipitation in China becomes effective groundwater resources.

Distribution of China's groundwater resources is very uneven. Because the groundwater is mainly recharged by precipitation, so its distribution is generally related to climate. But in any given region, the hydrogeological/geomorphological conditions play a very important role in the actual distribution of groundwater resources. On the plains, having very thick sedimentary rocks with multiple aquifers, such as the Northeast Plain, the North China Plain, and the plains in the lower-middle reaches of the Changjiang (Yangtze) River, groundwater is plentiful in reserve and in replenishment. For example, in the North China Plain, water yield of a single well amounts to about 2,000-20,000 m^3/day at the foot of the mountains, about 1,000-4,000 m^3/day in the alluvial plains, and about 500-1,500 m^3/day in the coastal plains. Conversely, in mountainous regions groundwater is rather less abundant. In south China, the karst region covers a large area of over a million square kilometers, and it is also rich in groundwater resources. Based on China's geological structure the artesian basins are located in many places. There are about 12 large artesian basins, such as the Sichuan Basin in the southwest humid region, the Jungger, Tarim, and Qaidam Basins in the northwest arid region. In artesian basins, groundwater can be exploited much more easily than in mountainous regions. China is a mountainous country, the mountain area accounting for about one-third of the whole country. In mountainous regions the springs, including mineral and hot water sources, can be found everywhere.

It must be pointed out that the hydrogeological conditions of groundwater storage in northern China, where sedimentary deposits forming groundwater aquifers are distributed widely and thickly, are relatively better than those in southern China, where rock mountain ranges are spread over a vast area. This is also an important feature of the distribution of China's groundwater resources. Because of surface water shortages in north China, the exploitation of groundwater for various kinds of use in this area has been well-developed.

As for variation of groundwater resources, climatic and physical geographical factors of an area greatly affect the regime of shallow groundwater. In China, the seasonal and annual variations of shallow groundwater levels generally increase from the southeast to the northwest. For example, the amplitude of seasonal variations of shallow groundwater levels varies from about one meter in Guangzhou (Canton) in the south to several meters in the North China Plain. In most regions of China high levels of shallow groundwater usually occur once a year in late summer or by the end of the year. The long-term fluctuation of shallow groundwater levels in the southeast is also smaller than those in the northwest. In many places the seasonal variations and annual fluctuation of groundwater all have apparent periodicity. In order to illustrate this periodicity, Figure 8, which shows the fluctuation of groundwater levels in Handan City, Hebei Province (in the North China Plain), can be taken here as an example [9]. From Figure 8 we

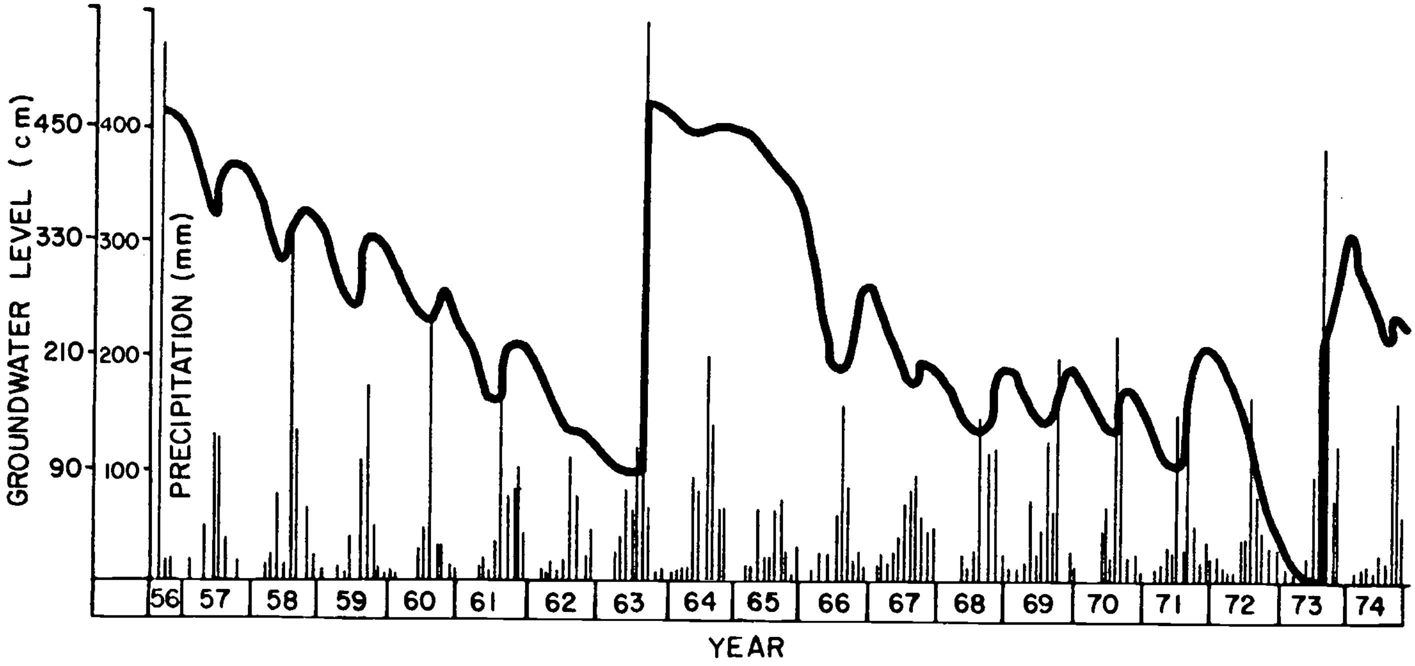

Figure 8. Long-Term Fluctuation of Groundwater Levels in Handan City, Hebei Province. [Source: <u>China's Physical Geography</u> (in press)].

can see that precipitation has a great effect on the regime of shallow groundwater, and the periodicity of long-term fluctuation of water levels following precipitation is about 10-11 years. Figure 8 also indicates that overdraft of shallow groundwater can be recharged naturally by intensive precipitation in a rainy year with a return period of about 10-11 years.

UTILIZATION OF WATER RESOURCES IN CHINA

From 1949 to 1979, China built about 80,000 reservoirs of different sizes, of which the large-sized reservoirs were designed on the basis of multiple-purpose utilization and most small and medium-sized reservoirs were developed mainly for agricultural irrigation. The storage capacity of these 80,000 reservoirs totaled about 400 km^3. There were about 300 large reservoirs, each having a storage capacity of over 100 million m^3, and these 300 reservoirs had a total storage capacity of 300 km^3 which accounted for three-fourths of the country's total storage capacity. This amount was equal to one-third of the storage capacity of the large reservoirs in the United States. Since water consumption in China is very great, but the total amount of available water is less than that of the United States, more reservoirs should be built in China to increase the water storage.

Agriculture is still a major user of water in China. The cultivated land of China amounts to about 100 million hectares, and it is concentrated in the eastern regions. Up to now about half of the cultivated land has been irrigated (irrigated area equals to 48 million hectares). The volume of water used for irrigation is about 440 km^3 per year, including 400 km^3 of surface water and 40 km^3 of groundwater. Domestic water supply for farmers amounts to 8 km^3 or so. Thus, the total amount of water used by the agricultural sector is 448 km^3, which accounts for about 16% of China's total effective water resources (2661 km^3). Detailed data on China's industrial water use are lacking. It is roughly 40 km^3 per year. Urban domestic water use amounts to about 7 km^3 a year. Thus, the total volume of water used by agriculture, industry and the urban population at present is 495 km^3, of which agriculture makes up almost 90%.

China uses more or less the same quantity of water as the United States, but the proportions of water uses are different. Agricultural water use in the United States is relatively low, about 50% of the total water supply, but the quantity of urban-industrial water used in the United States is about 5 times larger than that in China [5, 10]. Looking to the future, China will need much more water by the year 2000. The nation's irrigated areas are expected to increase to 66 million hectares, and agricultural water supply will have to be enlarged by about 100 km^3. Water for industrial and domestic needs will have to be increased even more. According to the estimation conducted by the Office of Water Resources Planning of the Changjiang (Yangtze) River, water supply in the Changjiang Basin is expected to increase from the present level of 10 km^3 to 210 km^3 in the year 2000. This estimation appears to be too high, because it was inferred on the basis of the annual rates of increase of industrial water supply from 1948 to 1978 for the cities of Shanghai and Nanjing where the levels of industrial development are among the highest in China. Industrial water supply in Beijing amounted to 1.35 km^3 in 1979, and it is expected to increase to 3.0 km^3 in the year 2000, i.e., an increase of only 2.2 times [11]. This estimation seems to be reasonable because Beijing is the capital of the country and recent policies are calling for limited industrial development in the city

[12]. For the nation as a whole, programs of modernization and industrial production in the next two decades will certainly require a large quantity of water. It is estimated that the industrial sector may use at least 140 km^3 of water in the year 2000. Assuming that China's population will be 1,200 million in the year 2000, and assuming 200 liters of water will be needed per capita per day, which is relatively low by world standards, the total volume of water supply for domestic use in the year 2000 will be about 88 km^3. Thus, the total water supply needed for all uses will be about 768 km^3. Figure 9 shows the present situation of water used in 1978 and future growth of water uses predicted for the year 2000 in China.

POLICY PROBLEMS OF WATER RESOURCE MANAGEMENT IN CHINA

The rational management of water resources is so complex that a wide field of various problems should be considered either in natural aspects or within a social context. Among the problems involved, the following key or vital subjects in water resources management in China must be pointed out.

Flood Control and Drought Prevention

According to China's historical literature of 2,155 years from 206 B.C. to 1949, more than 1,000 floods and droughts have taken place in certain areas of China, where these hazards have affected residents to a significant degree. This record implies that either a flood or a drought occurs every other year in China's territory, on the average. Up to now, preventing floods and mitigating drought consequences is still a big problem of water conservancy planning in this country, although a huge amount of work on flood control and alleviation of drought effects has been done successfully in the last 30 years. The threat of flood in wide areas of China has

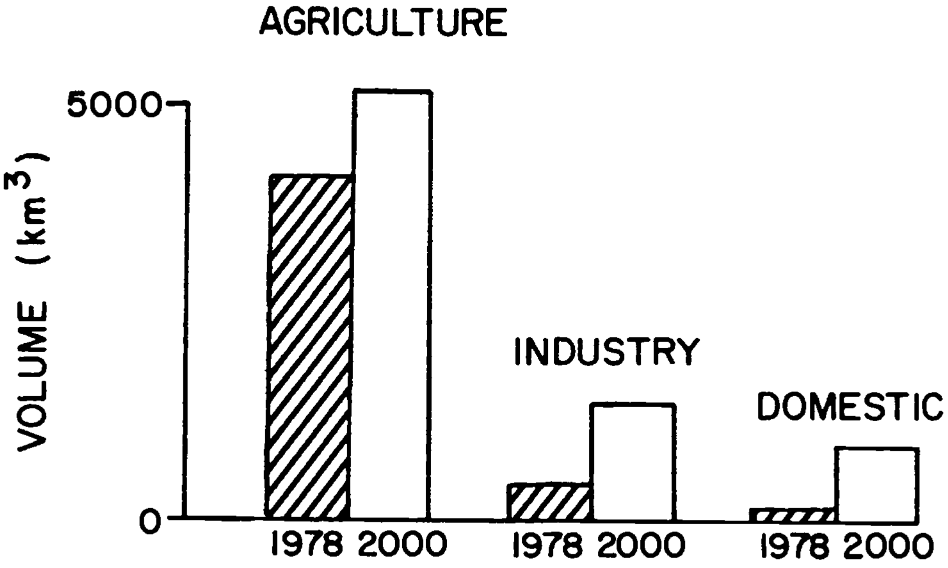

Figure 9. Water Consumption in China, 1978 and 2000.

remained serious. For instance, in the middle-lower reaches of the Yellow River, the flood prevention capacity is still low, particularly since the river bed rises in the lower reaches over 3 inches on the average each year by the deposit of large quantities of sediments from the Loess Plateau. Besides, many other places are also in danger of floods, particularly in the flat regions along the major rivers' courses, such as the lower reaches of the Huaihe River, Haihe River, Chujiang River (Pearl River), the Songhuanjiang River and the Liaohe River, as well as the middle-lower reaches of the Yangtze River. The basic reason for frequent occurrence of flooding in China are the intensive rainstorms caused by the summer monsoons. For example, the 24-hour and 72-hour maximum rainstorm, observed in August, 1975, in Linzhuang, Henan Province, was 1,005 mm (39.6 inches) and 1,605 mm (63.2 inches), respectively. In order to reduce flood damages, large amounts of summer flood water have to be released from storage to accommodate the next peak discharge. Thus, significant amounts of water are wasted to the sea, due primarily to insufficient storage capacity, despite the fact that this water could be used to alleviate serious water shortages occurring perennially in northern China (the probability of spring drought in north China can reach 97%). Therefore, preventing flood and drought is always a key problem of water conservancy in China.

Water Supply

In the last two decades, the water consumption in China has increased year by year. As previously noted, the water supply in the future (in the year 2000) is expected to be increased by 55%; moreover, in recent years most regions in China have suffered water shortages to a certain degree. In the future, water supply will be even more deficient, particularly the water shortage in northern China, where the semi-arid and arid regions are located, will be severe. So there is a big problem in water supply. To solve this problem, the following countermeasures should be adopted:

(1) Water Conservation. This countermeasure is always related to the water management policy. In most cases, the rational cost of water can be priced to control water requirements. In China, the price of water charged to most farmers is still calculated by their irrigated acreage, not by water volume actually used (this situation more or less exists in some areas of industry). Thus a lot of water may be wasted by users. Because water price in many places in China is very low, it is not conducive to save water, so that to raise the water price will be very important for water management.

(2) Water Storage. In consideration of the uneven distribution of China's surface water, which serves as a major source of water supply, the emphasis on water storage (regulation) should be suggested in order to use local water resources to the utmost efficiency. This countermeasure is of significance for northern China, where the distribution of river runoff is particularly uneven. Apparently more new reservoirs should be constructed in the future, even though a number of reservoirs of different capacities have been built in these areas in the past. It must be pointed out that the countermeasure of water storage is not only effective for water supply, but also feasible for flood water control, so that water storage can be seen as a measure of "killing two birds with one stone."

(3) Water Transfer. There are many small and medium-sized water diversion projects which have been developed in many areas of China for the purpose of surmounting uneven areal availability of water. In recent years, a

large scale and long distance water transfer from the Yangtse River to the North China Plain, where water is deficient, was proposed. In connection with this proposal, first of all, the overall water planning on a national scale should be worked out, because this project would affect water management of several major river basins in the country. For ultimately solving the water shortage problem in north China, the water transfer project is likely to be necessary, but its feasibility must be evaluated very carefully. The assessment of the project is so complex that the following aspects should be dealt with:

(a) assessment of techniques,
(b) assessment of social economy,
(c) assessment of the environment.

The above three aspects of assessment, plus policies and laws, are connected to each other and composed as an entire system. Therefore, the systems approach must be involved in the analysis.

Some Problems in Present Water Management in China

(1) Although a lot of work on water resources development has been done in the country, the efficiency of the many projects is not high because of the lack of effective management. For instance, the coefficient of water utilization for many irrigated systems is still low: it is less than 0.5. In a number of irrigated areas of northern China, where the salt content in the soil is quite high, drainage systems associated with the irrigation systems have not been completed simultaneously. To increase the efficiency of the irrigation systems, the improvement of management in these areas is required to be strengthened.

(2) In the past, China did not care for water legislation very much, and conflicts of interest in water uses occurred in many places quite often. Thus, a complete water legislation should be worked out as soon as possible. The water law always plays an important role in effective water management.

(3) Groundwater Exploitation. In China there are more than 2 million pumping wells used for water supply. Intensive overdraft of groundwater has taken place in plains or flat areas in north China, where surface water is particularly deficient. Because the amount of groundwater replenishment is limited as mentioned above (only 700 km^3), the policy of groundwater mining should be worked out on the basis of natural and artificial recharge. The conjunctive use of groundwater with surface water must be considered in water resources management and planning. In China, groundwater and surface water are managed by different administrative bodies, i.e., the Ministry of Geology and the Ministry of Water Conservancy. Obviously, such a situation is not satisfactory for effective management. Therefore, an institution for commonly administering groundwater and surface water should be established.

(4) According to China's modernization program, industry and urbanization will be developed rapidly, so the avoidance of water pollution by industry and urban expansion is a very significant problem.

(5) At present, China is starting to establish watershed management systems, and many new institutions set up for large river basins have been formed in the last two years. Therefore, more rivers are managed on the basis of watersheds instead of by local administrative bodies. This measure will be more efficient for water resources management than that by administrative regions.

From the above analysis we can learn that:

1. The total amount of water supply of China at present is about 495 km^3, of which the agricultural sector makes up about 90% and domestic water use only accounts for 3%.

2. The assumed total water uses throughout the country in the year 2000 will be increased by 273 km^3, or to a total of 768 km^3, of which the agricultural sector will still make up 70% (540 km^3).

3. In the future, the proportion of domestic and industrial water uses to total water supply in China will increase rapidly. The domestic water use will be increased by almost 6 times from 15 km^3 to 88 km^3.

CONCLUSION

In China the total volume of water resources amounts to a large quantity, however, the available water per capita per year is limited due to the large population size. In addition, the distribution of China's water resources is characterized by considerable unevenness in comparison with many other countries. The uneven allocation of China's water resources shows that more water is concentrated in the southeast. For instance, the Changjiang (Yangtze) River yields about 1,000 km^3 (811 maf) of water each year, which makes up almost 40% of the nation's total. In contradistinction to this, water shortages are widely encountered in the north and northwest, where the temporal distribution of water resources also is very uneven. Thus, there is a big problem in water supply for northern and northwestern China. Because of lack of surface water in these regions, people have to overdraw groundwater. As a result of overdraft, the levels of groundwater have been dropping every year. For example, in central Hebei Province located in the North China Plain, a deep cone of groundwater depression of about a hundred feet has been formed in the last 20 years. At present, such deep cones in the North China Plain can be found in many places. Therefore, to solve this problem has become an important subject for Chinese geohydrologists and hydrologists. From previous descriptions, we realize that water resources in most regions were not available for use. However, by programs of China's modernization agriculture and industry will continue to develop; consequently, water requirements will be enlarged too. What can we do with this situation of water shortage in the north and northwest? It seems that there are many ways that can lead to solving this problem, but the most important one is a reallocation of China's water resources by means of increasing local water storage and developing interregional water transfer systems. Of course, in solving the water shortage problem, rational use of local water and scientific planning of the nation's water resources should be considered simultaneously.

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