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Water Resources Management and Rehabilitation in China

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Abstract : A water resources management plan should be implemented throughout China, which is based on a unified watershed-scale. Water prices should be increased as well as investments in agricultural and industrial water conservation. Save water methods should be applied in the whole regions of water shortage. Increased water use efficiency will ensure that China's water resources will be used in a reasonable, effective and sustainable manner. New technologies and management methods will be required which are underpinned by science. Greater attention must be given to prevention of pollution and other forms of water quality degradation in large river basins.

Key words: Water resources, Problems, Current usage, Countermeasures

Introduction

Current water resource concerns include: (i) severe shortages, (ii) frequent flooding, (iii) uneven distribution of water resources in time and space, resulting in acute conflicts between supply and demand, (iv) poor water conservation implementation leading to serious wastage, and (v) water pollution and environmental degradation. Sustainable changes must be based on the use, source, quantity and quality of current resources together with projections of future demands, taking account of different hydrological regions, as well as environmental conditions.

Hydrological and environmental changes in China have seriously impeded sustainable development, for four centuries. Hydrological conditions of China's watersheds have long been monitored and studied. Overuse of some water resources has led to soil salinization and desertification. Only in the last few decades has this land degradation become a strikingly apparent, leading to a recognition that hydrological factors and environmental sustainability are inextricably linked. Both government agencies and non-governmental organizations (NGOs) have taken or are taking steps to address these issues (Kenneth, 1997). Reasonable countermeasures to protect ecosystems, land and water quality during intense water resource development are proposed, which nonetheless promote social development.

Current Status: Provincial yearbooks have compiled hydrological data back to the 1950s. Some gauging stations have detailed measurements for over 40 years, while the remainder has at least 25 years data. Groundwater quantity and quality data were taken from China Water Research Bulletins published by Ministry of Water Resources (MWR). Agricultural, industrial, domestic and others water use data was obtained from the National Statistics Bureau (1998a,b, 1989). Data was not available for Macao, Hong Kong and Taiwan. China is divided into five regions, using hydrological, geological, geographical and climatological criteria. These are south east China (SEC), south west China (SWC), north east China (NEC), north west China (NWC) and north central China (NCC) (Fig. 1 and Feng *et al.* 1999a). Regions exhibit different water use, development issues and trends, necessitating different rehabilitation measures.

The SEC Region includes Shanghai, as well as Jiangsu, Anhui, Hunan, Jiangxi, Hubei, Zhejiang, Hainan, Guangdong and Fujian Provinces (Fig. 1), covering 1.23 million km^2 or 12.8% of China's total landmass (Table 1). Middle reaches of the Yangtze River house extensive plains, while lower reaches are more hilly, with littoral plains and an estuary into the East China Sea (G). Several other large rivers traverse the region, including the Huaihe (D) and Zhujiang (F), which serve as the major water sources for the region. Under the influences of SE monsoons and tropical storms, precipitation varies from 800 mm yr^{-1} in the north to over 1600 mm yr^{-1} in the south, resulting in a climate that ranges from semi-humid to extremely humid (Table 2). Resources include 905 km^3 in surface waters (97.4%) and 25 km^3 (2.6%) in net groundwater (Table 1).

The SWC region contains Sichuan, Yunan and Guizhou Provinces, Guangxi and Tibetan Autonomous Regions and Chongqing City (Fig. 1). Nine major rivers are located in or flow through the region. These are the Yangtze and Yellow (C), the Zhujiang, Honghe, Lanchangjiang, Nujian, Yiluowadi, and Yalunzangbu (H) as well as rivers close to the sea in Guangxi Autonomous Region. Numerous lakes dot the Tibetan and Yun-Gui plateaus, with a total area of 630,000 km^2. Precipitation varies from 200 to 4490 mm yr^{-1}, due to varied landforms and stratified climatic zones across a range of elevations (Table 2). The Tibetan glacial area accounts for 60% of China's glaciated area. Total net water resources in the region are 1280 km^3, of which net groundwater is only 2 km^3 (Table 1).

The NWC region is made up of Xinjiang and Ninxia Autonomous Regions, as well as the provinces of Qinhai, Gansu, and Shaanxi (Fig. 1). It is located at least 600 km from the ocean and is surrounded by tall mountains. It has up to 400 mm yr^{-1} of rain in mountainous areas, but is arid to semi-arid in the plains, where precipitation can be as low as 50 mm yr^{-1} (Table 2). Several inland rivers are distributed across the region being the Tarim, Heihe, Shiying, and Urumqi. Regional water resources amount to 220 km^3, with groundwater being less than 5% (Table 1).

The NEC region contains the provinces of Heilongjiang, Jilin and Liaoning (Fig. 1). The region's watersheds include those of the Heilongjiang (J), Shuifen-Tumen and Liaohe-Yalujiang rivers (A). Under this semi-humid to humid climate, precipitation ranges from 500 to 1000 mm yr^{-1}, under the influence of monsoons and different landforms (Table 2). Total net water resources are 150 km^3, with 22 km^3 of net groundwater (Table 1).

The NCC region includes Beijing and Tianjin, the provinces of Hebei, Shandong, Shanxi, and Henan, and the Inner Mongolia Autonomous Region (Fig. 1). Main watersheds in the region include the Haihe and Lunahe rivers (B) and middle and lower reaches of the Yellow River (Fig. 2). Climate is semi-arid to semi-humid, with precipitation ranging from 500-600 mm yr^{-1} under the influence of eastern monsoons (Table 2). Total net water resources in the region are 170 km^3 with 43 km^3 (25%) of net groundwater (Table 1).

Precipitation and thawing of alpine glaciers are the primary sources of runoff in China, but such waters are only exploitable when they flow in surface channels or emerge from springs (Yang 1981). The Yangtze and Zhujiang rivers carry the bulk (48%) of total runoff estimated at 2,700 km^3. Based on measured seepage rates and volumes from farmland channel systems, particularly those in the piedmont plains, as well as a consideration of storm and flood event hydrographs, total net shallow groundwater in China represents about 100 km^3 (Liu *et al.* 1996). Groundwater resources, excluding those feeding streams, occur mainly in the shallow aquifers of plains regions and total some 100 km^3. While China ranks sixth amongst nations in total water resources, its per capita water resources (2344 m^3 $person^{-1}$) are roughly a quarter of the global mean (Table 3).

Use of water in agriculture is the largest sector in terms of water withdrawal, rising four-fold in the last 50 years (Zhao, 2000). Table 4 shows usage in relation to different regions. Different agricultural areas employ water in different ways. As agricultural water use includes irrigation, forestry and grassland use, fishery supplementation, so a wide range of problems has developed as a result of rapid agricultural development.

Water Issues

Unequal Distribution: China's water resources are unevenly distributed both in terms of area and population. China must feed 22% of the world's population with only 6.4% of the world's landmass, 7.2% of its farmlands and 5.8% of its runoff (Chen and Xia, 1999). With very high population densities in SE China per capita farmland area is low, roughly 500 m^2 $person^{-1}$. Catchment areas of the Yangtze River and its southern tributaries account for 80% of China's total runoff, but house only 36% of China's farmlands (Chen and Xia, 1999). Per capita water resources in northern China are one-quarter those in the south, while on an areal basis the north's water resources are a tenth of those in the south (Chen and Xia, 1999). The paucity of water resources in northern China results in more acute conflicts in supply and demand than in the south. Arid and semi-arid lands of the NWC region cover 47% of China, but only benefit from 7% of water resources (Table 1, 2). Humid and semi-humid regions of SE China account for the remainder and enjoy 93% of water resources (Table 2; Chen and Xia, 1999).

The Liaohe, Haihe, Yellow, and Huaihe rivers supply 41% of China's farmlands, but only carry 6% of China's total runoff (Chen and Xia, 1999). Per capita runoff volume in this region is only 431m^3 $person^{-1}$ yr^{-1}, significantly below the 1000 m^3 $person^{-1}$ yr^{-1} generally agreed threshold criteria for water shortage. Available farmland water volume is low at 40.5 m^3 km^{-2}, being only 14% of the national average. In contrast, the Yangtze and Zhujian rivers serve only 29% of China's farmland, but carry 48% of China's total runoff (National Statistics Bureau, 1998b). Water deficit predictions for the NW suggest deficits reaching 20% of available water by 2010, with significant impact on the region's agricultural production.

Serious Water Resource Shortages: Water shortages have restricted China's agricultural, industrial and urban development. About 300 of 600 medium sized cities, of 0.1-1.0 million inhabitants, have experienced water shortages, while 108 of these cities suffer from a serious lack of water (Feng *et al.*, 1999b). The area of drought-prone lands has risen by 50% since the 1950s, reaching 267,000 km^2 in 1990. Only 500 of a potential 640,000 km^2 of potential irrigated area has been developed, of which 100,000 km^2 has poor irrigation facilities. So agricultural production and grain supply is restricted. Additionally, about 7.0 million people and 60.0 million head of livestock must drink highly saline water as no fresh water is available (Feng, 1999).

Water shortages also adversely affect industrial production and living standards. In the late 1980s and 1990s, many electric power plants and factories in large, > 1.0 million inhabitants, and medium-sized cities of northern China had to suspend production due to water shortages. In Lanzhou mean power outages reached 600-1000 hr yr^{-1}. Similar power outages have occurred in some cities of southern China. Excessive pumping of groundwater has led to a drop in water table, surface subsidence, and destruction of water-bearing aquifers. At the Minqin oasis, Gansu Province, salinity of ground water has now reached 17 g l^{-1}, leaving roughly 76,000 people and 124,000 head of cattle with no potable freshwater and 37 million ha of farmland being abandoned (Feng, 1999). From the mid-1970s to early 1990s some 3.63 km^3 was pumped annually from underground aquifers in the arid inland Shiyang River watershed, leading to a 2-10 m drop in water table and formation of three water table depression cones. Across northern China, about 87% of water resources was drawn from groundwater stores, which was only replenished at a rate of 0.3 km^3 yr^{-1} (Feng and Cheng, 1998). The drop in water table extended over 23,000 km^2.

Deterioration of Aquatic Ecosystems: Regions susceptible to soil erosion have reached 38% of China's landmass. On the Loess plateau, 430 and 276,000 km^2, or 69% and 44% of total area, are subject to moderate and severe soil erosion, respectively (Feng *et al.*, 1999a). Across half the Loess plateau, soil erosion is greater than 5 Gg km^{-2} yr^{-1}, while in some areas it reaches 30.7 Gg km^{-2} yr^{-1}. Despite annual investments of $2.4 million (U.S.), reclamation rates are below rates of soil erosion, leading to loss of land productivity. In the Loess plateau alone, losses of nitrogen, phosphorus and potassium are estimated to amount to 40 Tg yr^{-1}, equivalent to the total annual chemical fertiliser output in China (Tang and Qu, 1992). Economic loss is roughly $50 billion.

Downstream sediment deposition not only decreases flood discharge capacity and shortens useful life of watercourses and storage facilities, but also encourages overflow under flood conditions, resulting in high evaporation of water as well as land salinization. Continued sediment deposition in river courses, reservoirs, and drainage networks will decrease their flood regulating capacity. Due to sediment deposition, lakes along the Yangtze have quickly shrunk dropping by 1500 km^2 in area and 12 km^3 in volume between 1949 and 1983 (Wang *et al.* 2000). Lake shrinkage has resulted in a 20% decrease in adjustment capacity, a rise in water level of 0.76 m, and a concomitant economic loss of $6.0 billion.

Water pollution is a very serious problem in China. In 1990, 56.0 km^3 of sewage drained into lakes and rivers, of which 68% originated from industrial sources and 32% from domestic sources (Feng *et al.*, 1999b). Discharge of largely (85%) untreated polluted water directly into rivers and lakes contributed 30-40 Tg yr^{-1} pollutants in the 1970's, and 45 Tg yr^{-1} by the 1980s, contaminating these water bodies of water and some farmlands. Use of polluted water to irrigation has resulted in contamination of 0.1 million km^2 of croplands, and contributed to economic losses of $5.2 billion (Shen and Su 1998). A survey showed that more than 400 of 500 rivers were contaminated to different degrees, and 12 of 15 large cities situated near big rivers had seriously contaminated water supplies. At present, urban sewage water disposal and reuse rates average are 18% and 15%, respectively.

Polluted water can affect people's standard of living and health indirectly or directly through local diseases outbreaks. Localized endemic illness has increased due to bad water quality: in Bailedou, Qinghai Province with diarrhoeal symptoms have been attributed to water with a high sulphate content. In Yan'an, Shaanxi Province and Qinyang, Gansuu Province (NWC), respectively, keshan and kaschin-beck diseases have been attributed to drinking water high in humic acid and low in selenium (Feng and Cheng, 1998).

In China, 334,000 km^2 of desertified land accounts for roughly 15.5% of total land area (Zhu and Cheng, 1995). From the late 1950s to mid-1970s, land desertification in north China expanded at a rate of 1,570 km^2 yr^{-1}. By the end of the 1980s, desertified land area had reached 176,000 km^2 in north China, with a further 122,000 km^2 of desert-prone farmlands and pastures (Wei and Tang, 1987). Similarly, during the past forty years, mismanagement of water resources has led to salinized land in north China increasing at a rate of 12.8 km^2 yr^{-1}.

Flood and Water Logging Damage: Seasonal and annual variations in precipitation and stream flow in China are comparatively large. Precipitation within the four months of the flood season may account for 60-80% of annual totals. Ratio of annual streamflow in a wet year to that in a dry year may approach five in southern regions, but may exceed ten in the north. As floods, water-logging and drought occur frequently, a keen awareness of hydrological extremes guides development and use of water resources in China. Despite building many conservation structures in the past forty years, their ability to prevent floods remains poor. In addition to inadequate control of soil erosion and serious silting of waterways, criteria for water conservation projects have been rather lax. Statistical analysis has shown that about 100 of 370 large reservoirs (? 0.1 km^3) have potential dangers, 670 of 2,500 common reservoirs (0.01-0.10 km^3) have potential dangers, and 32,000 of the 80,000 small reservoirs (0.001-0.010 km^3) also have serious problems. Frequent flooding in recent years throughout China has clearly demonstrated the limited communication and forecasting systems. Poor condition of flood safety structures has seriously compromised flood control. In 1998 he most extensive flood of the 20th century on the Yangtze River damaged a quarter of the cities in southern China, affected 12 cities of 0.1-1.0 million inhabitants, and resulted in losses of $36 billion (Zhao, 2000). In 1995, a large flood in Liaoning Province hit 9 cities, 39 counties and 500 villages, flooded large tracts of farmland, surrounded numerous homes, and resulted in significant economic losses. Some 146,000 km^2 of farmland as well as homes over an area of 330 km^2 were destroyed, resulting in economic losses of $0.96 billion. In 1994, flooded areas totalled 193,000 km^2, affecting 223 million people, and resulting in direct economic losses of $2.17 billion (NIHWR, 1997).

Acute Gap Between Water Demand and Supply: Conflicts between water supply and demand are mainly the result of poor regulation of water resources, competition between users along rivers and uncoordinated structure and distribution of industrial development (Qu, 1998). Conflicts between water users along rivers has become more apparent in recent years due to inadequate management legislation, uncoordinated water distribution, uncontrolled development and water resource wastage in river basin. Such conflicts have the potential to cause land desertification and environmental degradation in the lower reaches of rivers (Feng *et al.*, 2001). In the landlocked watersheds of the NWC region, use of most of the streamflow in middle reaches has resulted in the area of terminal lakes being significantly reduced. The surface area of West Juyan Lake on lower reaches of the Heihe River in Inner Mongolia was 3,000 km^2 in the 1960s, but by 1995 only 17 km^2 remained. In recent years the lake has dried up in the summer. Some 4,565 km^2 of the 38,000 km^2 of desertified lands in the Tarim basin are directly attributable to unreasonable water resource exploitation (Zhu and Cheng, 1995).

Natural poplar (*Populus euphratica*) and shrub forest (*Tamarix* spp.) are generally distributed along riverbanks in a corridor-like manner (Wu 1992). This has been seriously degraded due to increasing use of water and land resources, *P. euphratica* and *Elæagnus angustifolia* L. are the main tree species of NW China's arid plains and forest areas in lower reaches of the Tarim river declined by 3820 km^2, from 1958 to 1990. At the same time shrub and meadow areas declined by 200 km^2, at a rate of 6.25 $km^2\ yr^{-1}$ (Feng *et al.*, 2000).

Haphazard construction of industrial infrastructure is common in China, which has prevented location of industries being geared to more effective use of water resources. Different governmental departments have set up factories, each developing water resources for their own economic benefit in an excessive manner. In agricultural production, water consumption is closely related to crop species. Similarly, water requirements for growing cotton (*Gossypium hirsutum* L.) are 110-112% of precipitation, still 6-17% short of available precipitation in normal precipitation year, but much better than those for wheat (Qu and Ma, 1995). An irrational distribution of crops adversely affects sound allocation of water resources.

Wastage of Water Resources: While China suffers from shortages, a large proportion of water resources in China are wasted. Much of the water in reservoirs built between 1960s and 1970s on the plains evaporates. Large irrigation quotas and heavy irrigation are common. Annual irrigation norms across China range from 150 to 530 mm (Table 5). Areas where water conservation techniques applied are few, as some farmers still use traditional but inefficient multi-channel water-diverting methods for irrigation, thus wasting a great deal of water. Poorly constructed channels for water conveyance suffer from severe seepage, mean conveyance efficiency in the NEC and SWC regions ranges from 0.03 to 0.45 (Table 5).

Under flood irrigation conditions with excessive amounts of water, water tables can rise and soils become salinised. Consequently fields must be irrigated in the spring in order to leach salts from the topsoil, thus significantly reducing water use efficiency. In Shandong Province, Hainan, Shiyang River area and over the entire Shiyang River basin water use efficiencies are 24 kg m^{-3}, 25 kg m^{-3}, 75 kg m^{-3}, and 41 kg m^{-3}, respectively. The latter case represents wastage of over half the water (Xia and Takeuchi, 1999). In China water use efficiency is very low, and the output water demand index of 0.4-0.7 kg m^{-3} much lower than the worldwide mean of 2.0 kg m^{-3}.

Legislation on urban water use is seldom enforced. Furthermore, low water prices result in a great waste of urban water resources. The range of rural domestic water quotas is 65 – 110 l $person^{-1}\ yr^{-1}$ (Table 5). In some locations where well water is used, water consumption may rise as high as 200 l $person^{-1}\ yr^{-1}$, resulting in a sizeable waste of water (Qu and Ma, 1995).

Water wastage by industries is widespread. The comprehensive industrial index of water use per $1000 product output averaged 86, 158, 118, 95, 46 m^3 in the SEC, SWC, NWC, NEC and NCC regions (Table 5), showing the high and extremely variable water consumption of China's industries. Industrial water reuse ratios are as low as 10-20%.

Rehabilitation Measures: To ensure sustainable development and use of water resources, some new policies will have to be implemented. Detailed rehabilitation measures are proposed for the five geographical regions (Table 6). Efforts must be made to promote urban, industrial and agricultural water conservation. Sprinkler and drip irrigation are only used on 1.5% of irrigated areas, though water savings relative to traditional irrigation methods could be as high as

50% and 70%, respectively (Qu and Ma 1995). The water wasted under flood irrigation occurs mainly through channel seepage and saturated water evaporation, and results from the lack of coordinated canal systems and poor seepage control techniques. If increasing expenditures on channel upgrading could raise their water conveyance efficiency, 10-15% of the total water used in field irrigation could be saved. An enhancement of field water conservancy projects, including the levelling of fields and a change from flooding to sprinkler or drip irrigation could save 10-20%, even up to 40%, of total irrigation water use in arid regions and up to 30% of total irrigation water use in humid regions (Cheng, 1996). A rise of water use efficiency from 0.4 to 0.7 would result in water savings of 120-160 km^3 yr^{-1}.

As the highest water consumption per $1000 of output for the SWC region is over six-times greater than the lowest value for the NCC region, it is clear that a great potential exists for water conservation in the industrial sector (Table 5). The water-reuse ratio is low in the SWC and NWC regions, being 40 and 60% in most cities, but somewhat higher in the NCC and SEC regions. Were all industries to operate at NCC industrial water use and reuse levels, 160 km^3 yr^{-1} of water resources could be saved.

A great potential also exists for urban water conservation; however, given low water prices, pressure for water conservation and efficient use of existing water resources are low in most Chinese cities. Water consumption in these cities ranges from 130-260 L $person^{-1}$ yr^{-1} (Table 5). Poor management and maintenance of water conveyance infrastructure can result in serious wastage of water resources. Water leaking from pipes, excessive water usage in some large hotels and gardens, and public fountains can waste large quantities of water. By reducing waste and with wastewater reuse, cities could save 33-50% compared to their current water usage.

The capacity to allocate water resources would be enhanced if new water sources could be tapped, and in turn could remedy China's economically inefficient use of water resources (Table 6). As precipitation is an important water resource for development in northern regions, development of new techniques for collection and storage should be a priority (Kang *et al.* 2000). Collection of rain in mountainous regions could provide inhabitants with drinking water requiring little treatment (Tang and Qu, 1992). Retention of rain could also improve soil moisture conditions in forested alpine lands. Studies have shown that for a rain harvesting efficiency of 70%, rain-harvest irrigation can increase crop yield by 30%, and production rate to 1.5 kg m^{-3} or more. In rural areas, surface runoff water sources can be developed, and more efficiently used through construction of terraced fields supported by local government. In the future, for certain regions, de-salinization of seawater may provide a solution to water shortages (Agnew and Anderson, 1992). The local environment can be improved by use of floodwaters to recharge wetlands or groundwater, prevention of changes in river courses, attempts to control sediment deposition, and regulation of some international rivers. Water shortages in specific regions can continue to be alleviated by water diversion projects.

Water resource management at the societal and environmental levels must be improved. Ecosystem variability is inevitable, but ecosystems can be modified to some extent to improve their ecological efficiency (Frederick 1994). Natural ecosystems inevitably vary with time; however, if one only considers economic benefits, ecosystems can be damaged (Jones 1999). Water pollution in China is serious and linked with economic development. According to interdepartmental investigations and analyses, 5.2 and 20% of the 95,000 km^2 of river networks are either seriously polluted or polluted to a lesser degree, respectively. In recent years, the area affected by water pollution has been expanding, resulting in economic losses of roughly $400 billion. Consequently, China must strengthen its water resource management policies, establish water conservation regions, reduce water pollution and continue to raise water use efficiency.

Holistic resource management plans are needed. Inland rivers flowing through different regions require watershed-wide co-ordination. River management draws on expertise in conservation, forestry, industry, agriculture, water quality protection, and urban construction. Each department manages some aspects of the water supply-demand problem, but there is a lack of watershed-wide coordination. Water pollution, wastage and misuse occur when the right hand does not know what the left hand is doing. Co-ordinating water resource usage, requiring users to observe the water laws and unifying allocation of water resources at the watershed scale should be completed as soon as possible (Liu, 1996).

Such improvements will require an investment in water conservation and water resources development based on state-of-the-art science and technology (Table 6). Between 1950 and 1990, government policy supported construction of water conservancy infrastructure, but in spite of social development and population growth such investments and such construction is now decreasing. However, in recent years, the government has increased investment in large-scale water development and conservation facilities, such as the Three Gorge and Three-Route Water Diversion projects. The Fifth Plenary Session of the Fourteenth Central Committee in 1998 adopted a proposal to put water conservation at the forefront in terms of infrastructure construction. This indicates that administrators' awareness of water conservation has been raised to a new level.

Table 1: Water resources distribution in China in 1990 (MWR, 1997, 1998)

Region of China	Extent of water resources [%relative to all China]				
	Surface water (10" m^{1})	Ground water (10" m^{1})	Total		
			Volume (10" m^{1})	Percapita (10^{1} m^{1} person^{1})	Per area (10^{1}m^{1} km^{3})
Southeast (SEC)	905[34.2]	25[24.5]	930[33.8]	2.0[88.5]	756[264]
Southwest (SWC)	1278[48.3]	2[1.9]	1280[46.5]	5.3[236.7]	492[172]
Northwest (NWC)	210[7.9]	10[9.8]	220[8.0]	2.5[111.3]	71[25]
Northcentral (NCC)	127[4.8]	43[42.2]	170[6.2]	0.5[23.5]	89[31]
Northeast(NEC)	128[4.8]	22[21.6]	150[5.5]	1.4[63.4]	188[66]
All	2648	102	2750	2.2	286

Table 2: Water resources in different climatic zones of China

Zones %	Precipitation (mm yr^{-1})	Runoff (mm yr^{-1})	Area of China (%)	Proportion of Chinese Water Resources
Arid	<200	<10	26.6	2
Semiarid	200-400	10-50	20.9	5
Total			47.5	7
Semihumid	400-800	50-200	18.6	12
Humid	800-1600	200-800	26.0	58
Extremely humid	>1600	>800	7.9	23
Total			52.5	93

Table 3: Total area, population, farmland, rain and water resources in China and the world

Region	Landmass area (10^6 km^2)	Population (10^9)	Farmland (10^6 km^2)	Rainfall 10^3 km^3)	Water Resources		
					Volume (10^3 km^3)	Percapita (m^3 person^{-1})	Perarea of farmland (m^3 km^3)
World	149.5	5.4	13.26	120	46.8	8690	353
China	9.60*	1.2	0.96	6.19	2.81	2344	293
Ratio%	(6.42)	2.22	1.0	5.2	6.0	27.0	832

Table 4: Current situation of water usage (km^3) by different sectors in China in 1997 (MWR, 1997, 1998).

Region	Irrigation	Forestry, Pastures fisheries	Agriculture	Rural	Urban	Domestic	Industrial	Total
Southeast	150	7	158	14	11	25	63	245
Southwest	51	8	59	5	6	10	12	81
Northwest	46	20	66	1	2	3	5	73
Northcentral	71	5	77	6	5	10	15	102
Northeast	36	3	40	2	3	4	12	55
Total	354	43	400	28	27	52	107	557

Table 5: Current water consumption of different usres in China

Region	Irrigation quota (m^3 m^{-2})	Irregation rate %	Domestic water quota		Indus trial water consumption (m^3/1000 USD)
			Urban (L)	Rural(L)	
Southeast	0.20	76.5	260	110	86
Southwest	0.53	47.0	245	85	158
Northwest	0.25	50.4	130	65	118
Northcentral	0.50	57.0	185	71	46
Northeast	0.15	24.3	145	90	95

Table 6: Water resources problem and countermeasures in China

Region	Groundwater storage capacity	Problem	Countermeasures
Southeast	Poor	Seasonal drought; serious water pollution; frequent flood damage	Intensify construction of hydrological structures; intensify water pollution law enforcement
Southwest	Poor	Low water use efficiency; uneven land; poor water quality	Raise water use efficiency; intensify water management; control water pollution
Northwest	Abundant	Quite uneven lands; aquatic ecosystems seriously deteriorated; water wastage; increasing water deficits	Applying advance technique to save water; prevent environmental degradation and control water and soil loss; enhance management system on inland rivers
Northcentral	Abundant in plains	Scarcity; uneven water distribution; low water use efficiency; deterioration of aquatic ecosystems; frequent droughts and water-logging	Transport water from other drainage basin; increase the water use efficiency; support experimentation with new water conservation techniques; increase investment
Northeast	Poor	Uneven water distribution; serious flood damage	Improve water sharing agreements between upper and lower reaches; improve the ability of watersheds to adjust to floods by increasing their storage capacity

Table 7: Predicted shortage of water resources in the year of 2010 (10^8 m^3)

Regions	Items	Total	Industry	Irrigation	Forestry, pasture and fisheries	Urban	Rural
Southeast	Requirement	3264	832	2003	92	146	191
	Supply	2942					
	Shortage	-322					
Southwest	Requirement	996	211	582	77	66	60
	Supply	911					
	Shortage	-85					
Northwest	Requirement	980	68	674	206	8	24
	Supply	811					
	Shortage	-168					
Northcentral	Requirement	1421	234	957	72	70	88
	Supply	1148					
	Shortage	-273					
Northeast	Requirement	745	150	460	30	65	40
	Supply	646					
	Shortage	-99					
The whole China	Requirement	7406	1495	4676	477	355	403
	Supply Shortage	-947					

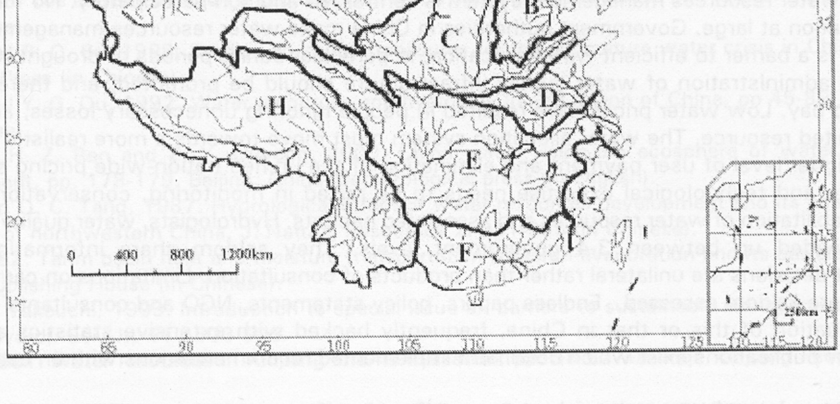

Fig. 1: Sketch of water resources subdivision by provinces in China

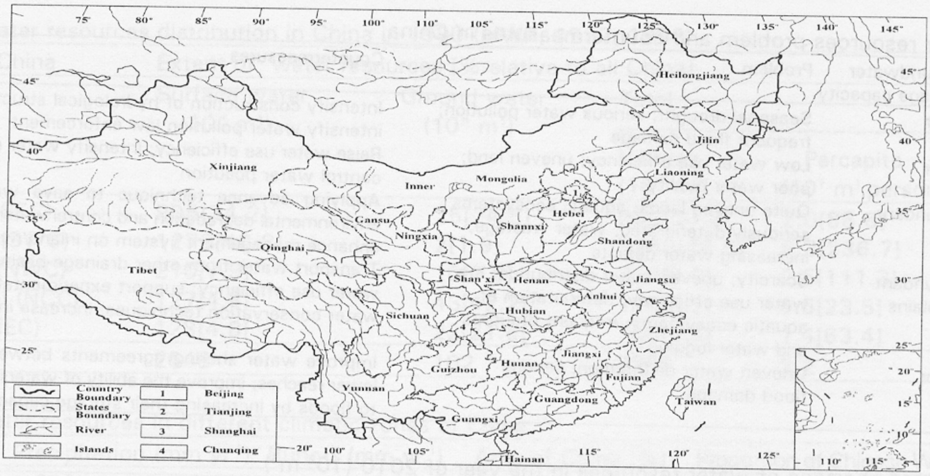

Fig. 2: Water resources regions by watershed or river basin in China
A: Liaohe; B: Haihe and Lunahe; C: Huanghe; D: Huaihe; E: Yangtze; F: Zhujiang river basins; G: rivers basins along the east China Sea in Guangxi Autonomous Region; H: Honghe, Lanchangjiang, Nujian, Yiluowadi, and Yalunzangbu rivers, excluding the rivers in G; I: Inland river basins including the Tarim and Heihe river basins, etc. J: Heilongjiang, Shuifen-Tumen and Liaohe-Yalujiang river systems.

Susceptibility to flood damage, extent of floodwaters and their impact during and after the floods should feature in plans (Table 6). Areas where certain land uses are to be restricted or prohibited according to flooding risk must be delineated. Development of flood hazard control areas and appropriate building codes should assure that only low-value infrastructure such as flood-proofed homes with elevated foundations are built on flood plains. In dealing with actual flood conditions, it is necessary to address disaster contingency planning, community self-protection teams, flood forecasting and warning systems, improved information and education on floods and on actions to take in a flood emergency (Kundzewicz and Takeuchi 1999 and Kundzewicz, 1997). Once such legislation and networking are put in place, then dams and flood control reservoirs can be constructed. Diversions, flood ways, channels with improved capacities to convey a flood wave, embankment reinforcement, enhanced source control, must be implemented in a manner which considers the extent and location of the flood plain and wetlands. After and during flood damage, likelihood of recurrence, and the forecasting of river stage should be investigated. During post-flood environmental and economic recovery its is important to consider revision of existing flood management activities to improve the process and planning for future events (Kundzewicz, 1999).

Conclusion

Water scarcity seems to result from a region experiencing a series of droughts due to global climate changes and an outdated water resource management system.
Sustainable use of available water resources requires the present system must be radically upgraded, then users might get a fair share of whatever is available. The two primary barriers to this are the water rights system and the pricing of water. The water resources management system is centralized and non-participatory. No forum exists for inputs from the population at large. Government authorities in China make water resources management decisions. Present infrastructure is a barrier to efficient water allocation, in particular during periods of drought. Consequently a more decentralized administration of water supply infrastructure should be promoted, and thereby enhanced willingness of users to pay. Low water prices have resulted in people ignoring unnecessary losses, and perceiving that water is an unlimited resource. The water allocation system must move towards a more realistic and localized pricing structure, a higher level of user payment and elimination of the unified nation-wide pricing system.
The level of scientific and technological expertise needs to be raised in monitoring, conservation, protection, management, and rehabilitation of water resources and associated habitats. Hydrologists, water quality and irrigation experts are often divided up between 3-4 government levels. They seldom share information and work independently, so that decisions are unilateral rather than products of consultation. Limitations on carrying capacity of a given watershed are seldom assessed. Endless papers, policy statements, NGO and consultants' reports exist about the terrible situation of this or that in China, frequently backed with extensive statistics and verbiage. Unfortunately very few publications exist which document implemented recommendations with an estimate of their effectiveness.

* Ministry of Water Research (MWR). Yearbook of China Water Resources (1997 and 1998).

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