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# STUDY ON THE WATER DEMAND AND SUPPLY IN CHINA BASED ON BUSINESS AS USUAL SCENARIOS

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## Abstract

The demand for water in China is increasing remarkably in accordence with the country's rapid economic growth. A stable water supply is crucial to China's ability to achieve sustainable development in the coming century. Shortages in agricultural water, in particular, might affect not only food production in China but also the world grain market due to the huge demand needed to sustain the country's population. This paper proposes a framework for analyzing potential water demand from a long-term perspective, and examines the water supply-demand balance in China. Two case studies are performed. First, potential water demand in each province is estimated until the year 2030 assuming that the present supply-demand trends continue under a business-as-usual scenario. A comparison of the projections with the current regional water resource endowment indicates that provinces in eastern and north-eastern China are likely to face more significant water shortages by 2030. Then, the geographical distribution of water supply and demand is analyzed in the Yellow River basin in which cutoffs of water have taken place almost every year since the 1990's. Factors related to these cutoffs are discussed based on the supply-demand balance.

**KEYWORDS:** *water demand and supply, water resources, China, Yellow River basin, environmental forecasting*

## 1. Introduction

Since the introduction of a market economy at the end of 1978, China has experienced rapid economic growth. Driven by the introduction of foreign direct investment, the country continues to undergo rapid urbanization and industrialization (Ishihara, 1998). Moreover, in the farm-village, numerous village and township enterprises have been established. If this rapid industrialization and urbanization continues throughout the country, it will exert a great impact on both the regional and global environment.

Describing the long-term perspectives of economic development and the environmental situation from national and regional viewpoints is essential for any discussion related to China's sustainable development. In forecasting the future of China, it is necessary to face a number of difficult yet unavoidable questions: (i) Can the domestic food supply, as well as country's energy and the natural resources, be able to further support the entire population? (ii) Can current regional imbalances in

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development be corrected and can the transportation infrastructure between the coastal areas and inland regions be improved? (iii) Can the social institutions and legal system exert effective control over the country's development and environmental protection?

Ensuring a stable water supply is one of the most crucial and pressing issues that China is facing today (Zhang *et al.*, 1992). China's Agenda 21 states the need for stable water supply: "A long term plan for water supply must be directed at the reasonable development and protection of water resources, and relieving the bottleneck effect of water shortage to socioeconomic activities".

In order to estimate the future demand for water, detailed information is needed regarding its past situation. However, there is only a limited availability of such data. It is especially difficult to estimate the amount and the spatial distribution of water resources because of their dependency on the local climate. Moreover, two factors which are difficult to predict must be taken into account. One is the possibility of establishing appropriate hydraulic infrastructures, which will be determined by the country's political, technological and financial situation. The other is the inevitable deterioration of water quality that may result in increased costs for treating water for specific uses such as drinking water.

Due to these difficulties, few studies have examined the future supply-demand for water in China on a nationwide scale except for some short-term targets announced by the government. The Chinese Academy of Sciences (CAS) identified three major factors that can be expected to determine the water demand by 2050: irrigation, industry and urban life (CAS, 1996a). Within the context of this simplified frame, it forecasts the demand for each of these sectors: irrigation water will slightly decrease from 460.4 billion tons (1980) to 415.7 billion tons (2050); industrial water largely increase from 50.0 billion tons (1990) to 343.6 billion tons (2050); and water for urban life increase from 12.1 billion tons (1991) to 73.0 billion tons (2050). Another study was conducted by Brown (Brown *et al.*, 1998), projecting the impact of the sharply increasing demand for water and discussing its implications for the world food security. Unlike the CAS, Brown's projection is pessimistic, especially with regard to agriculture and urban residential use. He concludes that, under present circumstances, some of the water for agriculture will have to be diverted for industry and urban life, and that this will lead to serious water shortages in the agricultural sector. The resulting shortage can be expected to reduce crop production since 70% of the crops in China are currently harvested from irrigated farmland. On the other hand, Yu *et al.* carried out long-term forecasts on the water supply by paying attention to the amount of investment allocated for water resource development (Yu *et al.*, 1996). The predicted value of the total supply in 2030 under four different investment scenarios ranged from 837.8 billion tons to 962.1 billion tons.

The difference in the above three projections is significant. The method of forecasting and the structure of the models they used should be compared and reexamined in order to establish a more reliable model while taking various factors into account. Variations in factors such as lifestyle, income distribution and the industrial structure should be taken into consideration from the microscopic viewpoint. The present study attempts to provide a basis for an assessment of water shortages by performing two case studies. First, water demand for each province is forecasted in the three sectors, *i.e.*, agriculture, industry and urban life, using a bottom-up approach with a business-as-usual (BaU) scenario. The demand for industrial water is analyzed with respect to 17 industrial sectors. Then, the geographical distributions of supply and demand for water are analyzed, focusing on the Yellow River basin which has recently experienced increasing duration of "cutoffs" (drying up before reaching the sea), and possible factors causing the cutoffs are discussed.

## 2. Modeling Framework

A framework for modeling the water demand-supply balance is shown in Fig. 1. This frame consists of a supply-module and a demand-module. The supply-module includes sub-modules for water resource endowment and supply. The former is greatly influenced by natural factors such as atmospheric temperature, precipitation, evapo-transpiration, percolation, and runoff. River flow is largely affected by policy-related factors such as economic investment and technology, which govern the improvement of water supply facilities. The demand-module consists of human activities including economic growth, population, the industrial structure as well as living standards and lifestyles. Ideally, various local and regional factors should be taken into account and assessed from town to town throughout the entire country since the demand for water in a particular location is adapted to the local water supply conditions. For example, the demand will be reduced if that location continuously faces water shortages. However, this factor is neglected in the module because of data shortage. Therefore, in the present study, "demand" is understood to mean the "potential demand" that could be realized when constraints to the supply do not influence the demand.

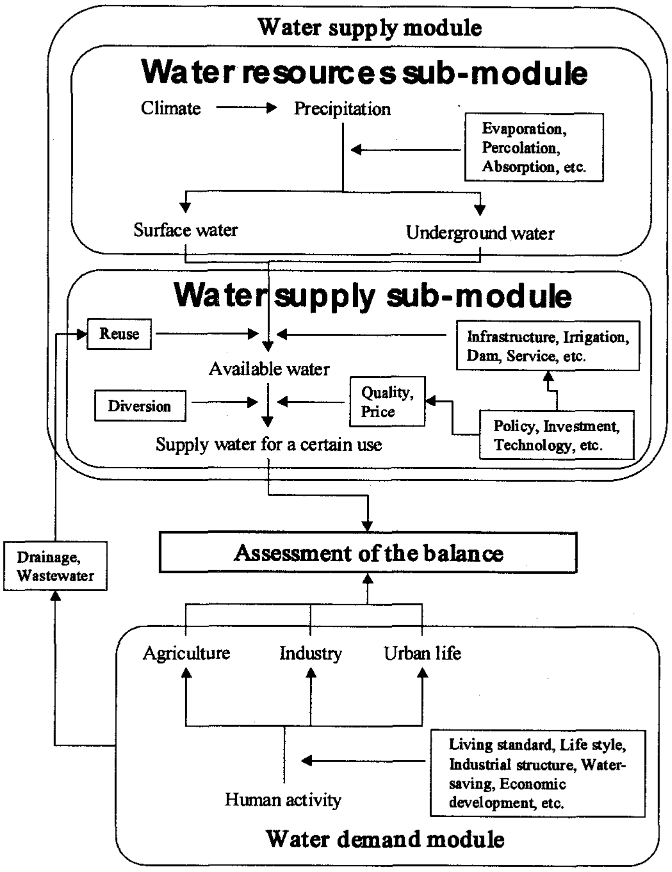


Figure 1. Modeling framework for the assessment of water shortage

## 3. Forecasting of National Water Demand by Provincial Data

### 3.1 Estimating the potential water demand toward 2030

This section presents a model to estimate the national total demand of water in agriculture, industry, and urban life by using provincial data. The long-term forecast for water demand is carried out under the BaU scenario where no change is expected to occur in current national policies, economic development and environmental trends. Total water demand is obtained by aggregating the demand for the three end-use sectors of agriculture, industry, and urban life. The forecasting term is until 2030, and the calculation is performed for every province. Innovational measures for water saving beyond the current trends as well as negative influences such as stagnation of economic growth due to water shortages is ignored.

Table 1. Irrigation water volume by river basin in China
Data Source: Utilization of Water Resources in China
(The state ministry of water resources and power, 1989)

| Basin | Irrigation water per hectare (tons/ha) |
|---|---|
| Songhua River and Rivers in Northeast China | 10,200 |
| Hai River | 8,175 |
| Huai Rivers and Rivers in Shandong Peninsula | 7,125 |
| Yellow River | 5,625 |
| Yangtze River | 13,950 |
| Pearl River and Rivers in South China | 10,200 |
| Rivers in Southeast China | 10,200 |
| Rivers in Southwest China | 8,625 |
| Rivers in inland regions | 14,475 |

Table 2. Empirical formula of the temporal change of irrigation rate by pirovinces
Data Source: China Statistical Yearbook (1986, 1992-1997) and Compilation of Historical Statistics of Provinces, Self-governing Districts and Direct-control Cities in China 1949-1989 (1991)

| $p$ | Province | $\beta_p(t) = a \ln(t) + b$ | | $R^2$ | Note |
|---|---|---|---|---|---|
| | | $a$ | $b$ | | |
| 1 | Beijing | 12,586 | -95,275 | 0.738 | (1) |
| 2 | Tianjin | 11,416 | -86,362 | 0.826 | (1) |
| 3 | Hebei | 138,234 | -1,046,175 | 0.936 | (1) |
| 4 | Shanxi | 37,222 | -281,585 | 0.911 | (1) |
| 5 | Inner Mongolia | 120,728 | -915,607 | 0.753 | (2) |
| 6 | Liaoning | 47,041 | -356,311 | 0.884 | (1) |
| 7 | Jilin | 36,719 | -278,073 | 0.934 | (1) |
| 8 | Heilongjiang | 46,328 | -350,917 | 0.886 | (1) |
| 9 | Shanghai | - | - | - | (5) |
| 10 | Jiangsu | - | - | - | (4) |
| 11 | Zhejiang | 12,296 | -91,928 | 0.535 | (1) |
| 12 | Anhui | 81,400 | -615,675 | 0.912 | (1) |
| 13 | Fujian | 7,844 | -58,662 | 0.324 | (1) |
| 14 | Jiangxi | 27,954 | -210,500 | 0.592 | (1) |
| 15 | Shandong | - | - | - | (4) |
| 16 | Henan | 148,260 | -1,122,459 | 0.901 | (1) |
| 17 | Hubei | 47,778 | -360,622 | 0.629 | (1) |
| 18 | Hunan | 47,623 | -359,061 | 0.815 | (1) |
| 19 | Guangdong | 18,269 | -137,110 | 0.137 | (1) |
| 20 | Guangxi | 37,403 | -282,661 | 0.859 | (1) |
| 21 | Hainan | 5,266 | -39,833 | 0.338 | (2) |
| 22 | Sichuan | - | - | - | (4) |
| 23 | Guizhou | 24,867 | -188,324 | 0.801 | (3) |
| 24 | Yunnan | 37,383 | -282,856 | 0.918 | (1) |
| 25 | Tibet | - | - | - | (5) |
| 26 | Shaanxi | 45,343 | -343,146 | 0.850 | (3) |
| 27 | Gansu | 25,637 | -193,860 | 0.928 | (1) |
| 28 | Qinghai | 3,981 | -30,066 | 0.855 | (1) |
| 29 | Ningxia | 4,697 | -35,413 | 0.903 | (1) |
| 30 | Xinjiang | 28,124 | -210,868 | 0.606 | (3) |

Note: Regression curves are obtained using data during the period shown below:
(1) 1952-1996, (2) 1978-1996, (3) 1978-1996,
(4) 1991-1996, (5) constant (decreasing trend in the past)

## 3.2 Method

### 3.2.1 Agriculture

In this model, the water for agriculture in the $p$-th province in the year $t$, $W_p^{(Agr)}(t)$, is expressed as:

$$W_p^{(Agr)}(t) = \alpha_p \times L_p^{(Irr)}(t),$$

$$L_p^{(Irr)}(t) = \beta_p(t) \times L_p^{(Arb)},$$

where $\alpha_p$ is irrigation water per hectare which depends on the respective basin as shown in Table 1, $L_p^{(Irr)}$ is irrigated land area, $\beta_p$ referred to hereafter as the "irrigation rate" is the percentage of irrigated area in arable land, and $L_p^{(Arb)}$ is arable land area. Calculation is performed under the following assumptions: (i) when two or more basins exist in the $p$-th province, $\alpha_p$ of the largest basin is taken for the province, (ii) $\beta_p$ follows the curve obtained by a diachronic regression analysis by provinces shown in Table 2, (iii) when $\beta_p$ shows a decreasing trend in the past or when data are not available for the regression analysis, this variable is taken as a constant, and (iv) $L_p^{(Arb)}$ is regarded as a constant because of the difficulty and uncertainty associated with forecasting in changes in land use. It is noted that since the irrigation rate is largely depending on the non-economical factors such as weather and types of agricultural product, economic growth such as per capita GDP can not fully describe its future change.

## 3.2.2 Industry

The water for industry in the $p$-th province in the year $t$, $W_p^{(\mathrm{Ind})}(t)$, is expressed as:

$$W_p^{(\mathrm{Ind})}(t)=\sum_{q=1}^{N} w_{p,q}^{(\mathrm{Ind})}(t),$$

$$w_{p,q}^{(\mathrm{Ind})}(t)=\gamma_q^{*}(y_p)\times Y_{p,q}^{(\mathrm{Ind})}(t),$$

$$Y_{p,q}^{(\mathrm{Ind})}(t)=\delta_{p,q}\times Y_p^{(\mathrm{Ind})}(t) \qquad (\sum_{q=1}^{N}\delta_{p,q}=1).$$

Here, $N$ is the total number of industrial sectors ($N$=17) and $w_{p,q}^{(\mathrm{Ind})}$ represents water demand for the $q$-th industrial sector in the $p$-th province for the year $t$. $Y_p^{(\mathrm{Ind})}$ denotes the total industrial production of the $p$-th province, $Y_{p,q}^{(\mathrm{Ind})}$ is production of the $q$-th industry in the $p$-th province, $\gamma_q^{*}$ is the water demand per unit of the production of the $q$-th industrial sector (Table 3), and it is assumed to depend on the level of industrial development represented by the per capita GDP of the province $y_p$; the parameters with asterisk denote that the national data are used for all provinces. $\delta_{p,q}$ is the share of the $q$-th industry in the total production of the $p$-th province.

Table 3. Water demand per unit of production for manufacturing sectors
Data Source: China Environment Yearbook (1992-1995) and China Industrial Ecnomic Yearbook (1992-1995)

| $q$ | Industrial Sector | $\gamma_q^{*}= a\exp(by^{*})$ | | $R^2$ | Note |
|---|---|---|---|---|---|
| | | $a$ | $b$ | | |
| 1 | Mining Industry | 0.0372 | -0.00040 | 0.87 | |
| 2 | Food, Beverage & Tabacco Processing | 0.0195 | -0.00030 | 0.93 | |
| 3 | Textile Industry | 0.0113 | -0.00020 | 0.41 | |
| 4 | Leather, Furs & Related Products | 0.0160 | -0.00068 | 0.94 | |
| 5 | Papermaking & Paper Products | 0.0752 | 0.00003 | 0.11 | # |
| 6 | Printing Industry | 0.0029 | 0.00001 | 0.01 | # |
| 7 | Petroleum Processing and Coking, Gas & Coal Products | 0.0094 | 0.00008 | 0.28 | # |
| 8 | Chemical Industry | 0.0590 | -0.00027 | 0.59 | |
| 9 | Medical and Pharmaceutical Industry | 0.0259 | -0.00049 | 0.81 | |
| 10 | Chemical Fiber Industry | 0.0248 | -0.00016 | 0.69 | |
| 11 | Rubber Products | 0.0087 | -0.00025 | 0.50 | |
| 12 | Plastic Products | 0.0031 | -0.00007 | 0.02 | # |
| 13 | Building Materials & Other Nonmetal Minerals | 0.0076 | -0.00005 | 0.03 | # |
| 14 | Smelting & Pressing of Metals | 0.0209 | 0.00002 | 0.01 | # |
| 15 | Metal Products | 0.0089 | -0.00048 | 0.94 | |
| 16 | Machine Building, Electric Machinery & Electronic Equipment Manufacturing | 0.0104 | -0.00064 | 0.89 | |
| 17 | Other Industries | 0.0292 | -0.00023 | 0.84 | |

Note: A regression fromula $\gamma_q{}^{*}= a\exp(by^{*})$ is applied to each industry, while the values for the industries with sharp (#) are set constant at the most recent level.

Relevant data are not available for industrial water use in China, but wastewater discharged from each industry is reported in the statistical yearbook of China. Here, estimation is made under the assumption that the water used is equal to the water discharged.

## 3.2.3 Urban life

The water demand for urban life in the $p$-th province, $W_p^{(\mathrm{Urb})}(t)$, is forecasted by the following formulas:

$$W_p^{(\mathrm{Urb})}(t) = \varepsilon_p(t) \times P_p^{(\mathrm{Urb})}(t),$$
$$P_p^{(\mathrm{Urb})}(t) = \zeta_p(y_p) \times P_p(t),$$
$$\varepsilon_p(t) = \eta_p \times \varepsilon^*(y^*),$$

where $P_p^{(\mathrm{Urb})}$ is the urban population of the $p$-th province, $\varepsilon_p$ is per capita water use for urban life (urban water use unit), $\zeta_p$ is the rate of urbanization, $P_p$ is the total population in the $p$-th provice, $\varepsilon^*$ is an urban water use unit used as a national standard, $\eta_p$ is the coefficient used to adjust for regional differences and $y^*$ is the per capita GDP of the country. The relation between $\zeta_p$ and per capita GDP is shown in Table 4 as a result of regressional analysis by province. The relation between an urban water unit of national standard $\varepsilon^*$ and the per capita GDP is illustrated in Fig. 2.

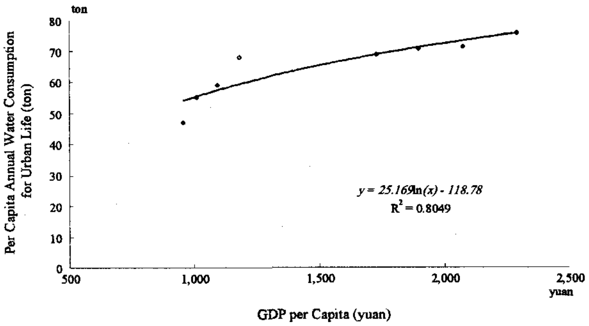


Figure 2. National average per capita yearly water consumption for urban life
Data Source: China Statistical Yearbook (1987-1997), State Statistical Bureau, China Statistical Publishing House

Table 4. Urbanization rate by province
Data Source: China Statistical Yearbook (1992-1997)

| $p$ | Province | $\zeta_p = a \ln(y_p) + b$ | | $R^2$ |
|---|---|---|---|---|
| | | $a$ | $b$ | |
| 1 | Beijing | 2.78 | 44.25 | 0.61 |
| 2 | Tianjin | 0.70 | 60.40 | 0.15 |
| 3 | Hebei | 17.13 | -96.22 | 0.92 |
| 4 | Shanxi | 27.56 | -165.82 | 0.87 |
| 5 | Inner Mongolia | 6.99 | -18.72 | 0.78 |
| 6 | Liaoning | 35.86 | -219.49 | 0.97 |
| 7 | Jilin | 27.31 | -142.49 | 0.86 |
| 8 | Heilongjiang | 19.79 | -96.99 | 0.95 |
| 9 | Shanghai | 28.32 | -179.35 | 0.87 |
| 10 | Jiangsu | 32.34 | -202.77 | 0.94 |
| 11 | Zhejiang | 23.77 | -133.25 | 0.99 |
| 12 | Anhui | 18.88 | -107.39 | 0.84 |
| 13 | Fujian | 24.41 | -152.17 | 0.98 |
| 14 | Jiangxi | 21.25 | -120.19 | 0.99 |
| 15 | Shandong | 22.19 | -117.74 | 0.98 |
| 16 | Henan | 20.22 | -118.90 | 0.88 |
| 17 | Hubei | 21.66 | -106.91 | 0.89 |
| 18 | Hunan | 14.84 | -77.17 | 0.92 |
| 19 | Guangdong | 72.40 | -525.94 | 0.92 |
| 20 | Guangxi | 14.51 | -79.76 | 0.82 |
| 21 | Hainan | 38.71 | -261.86 | 0.75 |
| 22 | Sichuan | 34.36 | -213.09 | 1.00 |
| 23 | Guizhou | 35.60 | -210.98 | 0.98 |
| 24 | Yunnan | 10.76 | -57.30 | 0.68 |
| 25 | Tibet | -0.22 | 10.76 | 0.04 |
| 26 | Shaanxi | 10.05 | -44.30 | 0.90 |
| 27 | Gansu | 3.84 | 0.34 | 0.61 |
| 28 | Qinghai | 1.39 | 7.65 | 0.68 |
| 29 | Ningxia | 2.57 | 8.20 | 0.72 |
| 30 | Xinjiang | 5.31 | -10.13 | 0.96 |

### 3.2.4 GDP and the population

The total industrial production of the $p$-th province is calculated by:

$$Y_p^{(\mathrm{Ind})}(t) = \theta(y_p) \times Y_p(t),$$
$$Y_p(t) = \iota_p(t) \times Y^*(t) \qquad (\sum_{p=1}^{M} \iota_p = 1),$$
$$\iota_p(t) = \frac{r_p^{(\mathrm{GDP})}(t-1) \times Y_p(t-1)}{\sum_{p=1}^{M} (r_p^{(\mathrm{GDP})}(t-1) \times Y_p(t-1))},$$
$$r_p^{(\mathrm{GDP})}(t) = \frac{Y_p(t)}{Y_p(t-1)},$$

where $\iota_p$ is the provincial share of GDP, $Y^*$ is the GDP for China, $M$ is the total number of provinces ($M$=30) and $r_p^{(GDP)}$ is the GDP growth rate in the $p$-th province. The empirical relation $\theta(y_p)$ between the per capita GDP and the industrial structure is formulated by using a method similar to that of Nakayama *et al.* (1997). The total population in the $p$-th province, $P_p$, can be expressed:

$$P_p(t) = \kappa_p(t) \times P^*(t) \qquad (\sum_{p=1}^{M} \kappa_p = 1),$$

$$\kappa_p(t) = \frac{r_p^{(Pop)}(t-1) \times P_p(t-1)}{\sum_{p=1}^{M} (r_p^{(Pop)}(t-1) \times P_p(t-1))},$$

$$r_p^{(Pop)}(t) = \frac{P_p(t)}{P_p(t-1)}$$

$$y^*(t) = \frac{Y^*(t)}{P^*(t)},$$

$$y_p(t) = \frac{Y_p(t)}{P_p(t)},$$

where $P^*$ is the total population of China, $\kappa_p$ is the provincial distribution ratio of population and $r_p^{(Pop)}$ is the population growth rate. Here, both the annual growth rates of the GDP and the population of China are given as variables shown in Table 5, based on the results of a questionnaire survey (Kaneko *et al.*, 1997) and the UN projection of population growth, respectively (UN, 1995). Two GDP growth scenarios are set by assuming higher and lower growth rates. All parameters used for this model are listed in Table 6.

Table 5. Growth rate scenarios of GDP and population in China (%)

Data Source: World Population Prospects (1993)

| Year | | 1995-2000 | 2001-2010 | 2011-2020 | 2021-2030 |
|---|---|---|---|---|---|
| GDP | High | 8.0 | 7.0 | 5.0 | 4.0 |
| | Low | 8.0 | 5.0 | 3.0 | 2.5 |
| Population | | 1.3 | 0.8 | 0.7 | 0.4 |

Note: The economic growth scenarios are set based on the existing study reports (Environment Agency of Japan and Science and Technology Agency).

## 3.3 Results

The projection results for the water demand in agriculture, industry, and urban life are summarized in Table 7. The future demand obtained by the CAS in 1996 and that projected by WWI (the World Watch Institute) in 1998 are also shown for comparison. According to the present study, total demand in 2030 is estimated to be approx. from 1.7 to 1.9 times to that of 1995. Compared to the current demand, the demand in 2030 for the end-use sectors of agriculture, industry and urban life is expected to increase to 1.5 times, 2.6~3.7 times and 3.0~4.1 times, respectively. The increase in water demand for industry and urban life is forecast to be particularly large. This study predicts that the total demand in 2030 will be larger than that predicted by the CAS by about 38 to 50 %. This difference indicates that the situation surrounding Chinese water resources is even more serious than the current CAS predictions suggest. The total water demand predicted by the present model is similar to that by WWI, although a considerable difference is seen in the forecast for agriculture. Major factor for this difference in agricultural sector is the assumption in this study that the arable

Table6.List of parameters in the model

$t$: time, $p$: $p$-th province, $q$: $q$-th industrial sector
$W_p^{(\mathrm{Agr})}$ : water for agriculture in the $p$-th province
$W_p^{(\mathrm{Ind})}$ : water for industry in the $p$-th province
$W_p^{(\mathrm{Urb})}$ : water for urban life in the $p$-th province
$\alpha_p$ : irrigation water unit in the $p$-th province
$\beta_p$ : irrigation rate in the $p$-th province
$\gamma_p^*$ : water demand per unit of production for the $q$-th industrial sector
$\delta_{p,q}$ : share of the $q$-th industrial sector in the $p$-th province
$\varepsilon_p$ : urban water use unit in the $p$-th province
$\varepsilon^*$ : national standard urban water use unit
$\zeta_p$ : the rate of urbanization in the $p$-th province
$\eta_p$ : the adjusting coefficient for regional differences of urban water use unit in the $p$-th province
$\theta_p$ : the industrial share in total provincial GDP of the $p$-th province
$\iota_p$ : the provincial share in GDP in the $p$-th province
$\kappa_p$ : the provincial distribution ratio of population in the $p$-th province
$L_p^{(\mathrm{Irr})}$ : irrigated land are in the $p$-th province
$L_p^{(\mathrm{Arb})}$ : arable lan d are in the $p$-th province
$W_{p,q}^{(\mathrm{Ind})}$ : water demand for the $q$-th industrial sector in the $p$-th province
$Y_{p,q}^{(\mathrm{Ind})}$ : production of the $q$-th industrial sector in the $p$-th province
$Y_p^{(\mathrm{Ind})}$ : total industrial production in the $p$-th province
$Y_p$ : total GDP in the $p$-th province
$Y^*$ : the total GDP of China
$P_p^{(\mathrm{Urb})}$ : urban population in the $p$-th province
$P_p$ : total population in the $p$-th province
$P^*$ : total population of China
$r_p^{(\mathrm{GDP})}$ : the GDP growth rate in the $p$-th province
$r_p^{(\mathrm{Pop})}$ : population growth rate in the $p$-th province
$y_p$ : the per capita GDP in the $p$-th province
$y^*$ : the per capita GDP of China
(Note: asterisk (*) denotes be national level or national average)

land area will be maintained. The forecast for every province is shown in Table 8. Guangdong province shows the highest rate of increase with regard to total demand. A sharp increase is also forecast in Inner Mongolia and Liaoning. In the agricultural sector, Inner Mongolia and Henan show a rapid growth in demand. In Jiangsu, Shandong, and Guangdong, the demand for industrial water is expected to significantly increase. The largest increase in water for urban life is expected in Guangdong.

The next question is the gaps between the estimated potential water demand and capacity of water supply. Here, we define the risk index of water scarcity by dividing the amount of total demand by the water resources endowed in each province. The values given by the CAS for the year 1980 are used for the total amount of water endowed throughout the forecast period since the change in natural

Table 7. Comparison with the existing researches of future water demand of China (100 million tons)

billion tons

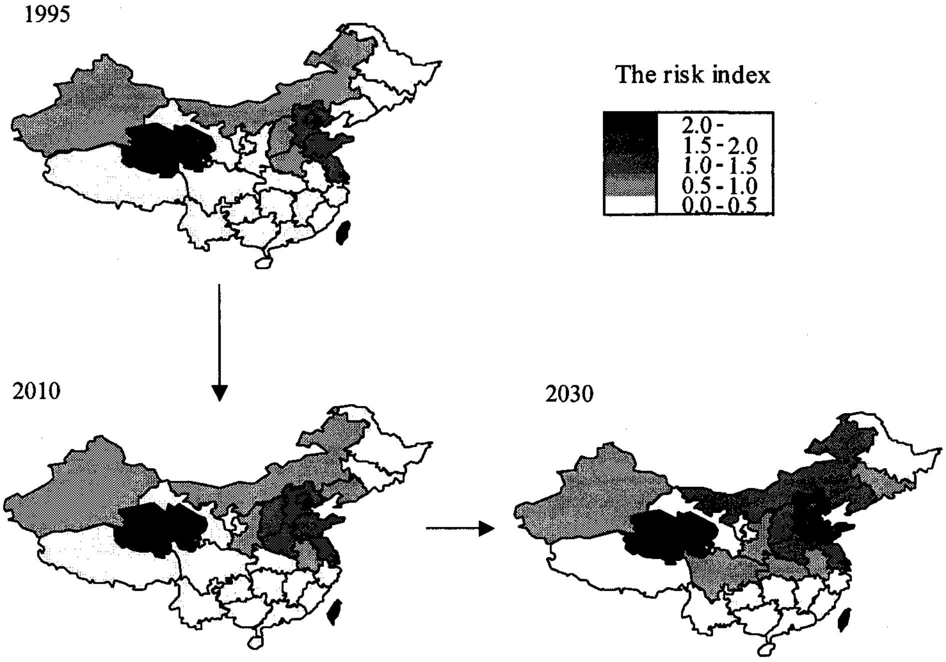
| Year | Agriculture | | | Industry | | | | Urban life | | | | Total | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | This study | WWI | CAS | This study | | WWI | CAS | This study | | WWI | CAS | This study | | WWI | CAS |
| | | | | High | Low | | | High | Low | | | High | Low | | |
| 1995 | 465 | 400 | | 69 | | 52 | | 36 | | 31 | | 569 | | 483 | |
| 2010 | 558 | - | 465 | 137 | 127 | - | 93 | 96 | 73 | - | 27 | 791 | 759 | - | 585 |
| 2030 | 672 | 483 | 453 | 212 | 167 | 269 | 190 | 147 | 106 | 134 | 46 | 1,032 | 945 | 1,068 | 686 |

Table 8. Future water demand by province

billion tons

| *p* | Province | Agriculture | | | Industry | | | | | Urban Life | | | | | Total | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 2010 | | 2030 | | | 2010 | | 2030 | | | 2010 | | 2030 | |
| | | 1995 | 2010 | 2030 | 1995 | High | Low | High | Low | 1995 | High | Low | High | Low | 1995 | High | Low | High | Low |
| 1 | Beijing | 1.8 | 2.2 | 2.2 | 1.6 | 2.5 | 2.3 | 3.7 | 2.8 | 0.7 | 1.2 | 1.0 | 1.5 | 1.2 | 4.1 | 5.9 | 5.5 | 7.5 | 6.2 |
| 2 | Tianjin | 2.0 | 2.4 | 2.4 | 1.6 | 2.6 | 2.4 | 3.7 | 2.9 | 0.3 | 0.4 | 0.4 | 0.6 | 0.4 | 3.8 | 5.5 | 5.2 | 6.7 | 5.7 |
| 3 | Hebei | 22.7 | 29.4 | 36.6 | 3.8 | 8.8 | 8.0 | 14.9 | 11.1 | 1.2 | 3.2 | 2.4 | 5.2 | 3.6 | 27.7 | 41.3 | 39.8 | 56.7 | 51.3 |
| 4 | Shanxi | 9.8 | 12.4 | 15.5 | 1.5 | 2.7 | 2.6 | 4.0 | 3.3 | 0.5 | 1.5 | 1.1 | 2.7 | 1.8 | 11.8 | 16.7 | 16.2 | 22.1 | 20.5 |
| 5 | Inner Mongolia | 25.7 | 38.2 | 55.5 | 0.9 | 1.8 | 1.7 | 2.8 | 2.1 | 0.4 | 0.8 | 0.6 | 1.1 | 0.8 | 27.0 | 40.8 | 40.5 | 59.4 | 58.5 |
| 6 | Liaoning | 12.3 | 15.1 | 19.9 | 3.9 | 7.6 | 6.8 | 12.3 | 8.8 | 1.7 | 4.1 | 3.1 | 5.0 | 4.0 | 17.8 | 26.7 | 25.0 | 37.1 | 32.6 |
| 7 | Jilin | 9.2 | 12.3 | 16.0 | 1.2 | 1.7 | 1.6 | 2.2 | 1.9 | 0.8 | 1.9 | 1.4 | 2.7 | 2.0 | 11.2 | 15.9 | 15.4 | 20.9 | 19.9 |
| 8 | Heilongjiang | 11.2 | 14.8 | 19.5 | 2.4 | 3.5 | 3.4 | 4.5 | 3.8 | 0.9 | 2.0 | 1.6 | 2.9 | 2.1 | 14.5 | 20.4 | 19.8 | 26.9 | 25.4 |
| 9 | Shanghai | 2.9 | 2.9 | 2.9 | 3.4 | 5.9 | 5.3 | 9.1 | 6.6 | 0.9 | 2.0 | 1.6 | 2.4 | 2.0 | 7.3 | 10.8 | 9.8 | 14.4 | 11.5 |
| 10 | Jiangsu | 27.3 | 29.1 | 31.6 | 7.4 | 13.6 | 12.9 | 18.3 | 15.7 | 4.1 | 10.2 | 7.7 | 13.8 | 11.0 | 38.8 | 52.9 | 49.7 | 63.7 | 58.3 |
| 11 | Zhejiang | 14.5 | 16.2 | 16.5 | 4.3 | 8.5 | 7.9 | 12.3 | 10.1 | 1.6 | 3.9 | 3.0 | 5.6 | 4.1 | 20.4 | 28.6 | 27.1 | 34.3 | 30.7 |
| 12 | Anhui | 29.9 | 35.1 | 43.3 | 2.2 | 4.5 | 4.2 | 7.4 | 5.8 | 1.2 | 3.7 | 2.8 | 6.4 | 4.3 | 33.4 | 43.3 | 42.0 | 57.2 | 53.4 |
| 13 | Fujian | 9.6 | 10.2 | 11.0 | 2.6 | 6.0 | 5.5 | 10.2 | 7.8 | 1.0 | 3.1 | 2.4 | 5.2 | 3.6 | 13.1 | 19.4 | 18.1 | 26.5 | 22.5 |
| 14 | Jiangxi | 19.2 | 21.6 | 23.5 | 1.2 | 2.7 | 2.5 | 4.5 | 3.4 | 1.0 | 2.7 | 2.0 | 4.5 | 3.0 | 21.4 | 27.0 | 26.1 | 32.6 | 29.9 |
| 15 | Shandong | 33.2 | 38.8 | 47.6 | 6.8 | 14.0 | 13.1 | 21.5 | 16.9 | 2.3 | 5.5 | 4.3 | 8.4 | 6.0 | 42.3 | 58.4 | 56.1 | 77.5 | 70.4 |
| 16 | Henan | 28.8 | 37.0 | 47.5 | 3.4 | 7.0 | 6.6 | 11.0 | 8.9 | 1.6 | 5.1 | 3.8 | 8.9 | 5.9 | 33.8 | 49.1 | 47.4 | 67.3 | 62.3 |
| 17 | Hubei | 22.2 | 28.3 | 33.1 | 2.6 | 5.9 | 5.4 | 10.2 | 7.6 | 2.9 | 7.2 | 5.5 | 11.6 | 8.2 | 27.7 | 41.4 | 39.2 | 55.0 | 48.9 |
| 18 | Hunan | 27.3 | 32.2 | 33.0 | 2.3 | 4.9 | 4.4 | 8.0 | 6.0 | 2.0 | 5.1 | 3.9 | 8.0 | 5.5 | 31.7 | 42.2 | 40.5 | 49.0 | 44.5 |
| 19 | Guangdong | 20.8 | 25.7 | 28.2 | 5.8 | 13.7 | 12.8 | 22.8 | 18.3 | 4.6 | 14.3 | 11.6 | 20.0 | 16.1 | 31.1 | 53.7 | 50.0 | 71.0 | 62.6 |
| 20 | Guangxi | 20.5 | 25.4 | 30.5 | 1.4 | 2.9 | 2.8 | 4.7 | 3.8 | 1.4 | 3.7 | 2.8 | 6.3 | 4.3 | 23.3 | 32.0 | 30.9 | 41.5 | 38.6 |
| 21 | Hainan | 2.5 | 3.0 | 3.8 | 0.3 | 0.6 | 0.5 | 0.7 | 0.7 | 0.3 | 1.0 | 0.8 | 1.8 | 1.3 | 3.1 | 4.6 | 4.3 | 6.3 | 5.7 |
| 22 | Sichuan | 29.6 | 30.2 | 42.8 | 3.9 | 7.9 | 7.3 | 12.7 | 9.6 | 2.3 | 7.4 | 5.4 | 12.7 | 8.2 | 35.7 | 45.5 | 42.9 | 68.1 | 60.6 |
| 23 | Guizhou | 6.2 | 8.3 | 10.8 | 0.4 | 0.7 | 0.7 | 0.9 | 0.8 | 0.5 | 1.7 | 1.2 | 3.1 | 1.9 | 7.1 | 10.6 | 10.1 | 14.8 | 13.4 |
| 24 | Yunnan | 10.8 | 12.7 | 15.9 | 1.0 | 2.2 | 2.1 | 2.9 | 2.6 | 0.4 | 1.2 | 0.9 | 1.9 | 1.3 | 12.2 | 16.0 | 15.7 | 20.7 | 19.8 |
| 25 | Tibet | 1.4 | 1.3 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.4 | 1.3 | 1.3 | 1.3 | 1.3 |
| 26 | Shaanxi | 11.0 | 14.1 | 17.8 | 0.8 | 1.5 | 1.4 | 2.0 | 1.7 | 0.7 | 1.6 | 1.2 | 2.4 | 1.7 | 12.4 | 17.1 | 16.7 | 22.2 | 21.2 |
| 27 | Gansu | 7.3 | 9.3 | 11.3 | 0.6 | 1.2 | 1.1 | 1.7 | 1.4 | 0.3 | 0.7 | 0.5 | 1.0 | 0.7 | 8.2 | 11.1 | 10.9 | 14.0 | 13.5 |
| 28 | Qinghai | 2.6 | 3.1 | 3.6 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 2.8 | 3.3 | 3.3 | 4.0 | 3.9 |
| 29 | Ningxia | 2.3 | 2.6 | 2.9 | 0.2 | 0.4 | 0.4 | 0.6 | 0.5 | 0.1 | 0.2 | 0.2 | 0.3 | 0.3 | 2.6 | 3.2 | 3.1 | 3.9 | 3.7 |
| 30 | Xinjiang | 40.2 | 44.0 | 46.0 | 0.9 | 1.6 | 1.5 | 2.1 | 1.9 | 0.3 | 0.6 | 0.5 | 1.0 | 0.7 | 41.4 | 46.2 | 46.0 | 49.1 | 48.7 |
| | National Total | 464.8 | 557.8 | 672.4 | 68.5 | 137.1 | 127.4 | 211.9 | 166.8 | 35.9 | 96.2 | 73.4 | 147.2 | 106.2 | 569.2 | 791.1 | 758.6 | 1,031.5 | 945.4 |

water endowment is considered to be relatively smaller than that of the change in demand (CAS, 1991). The calculated result of the index is shown in Fig. 3; the risks under high economic growth scenario in 2010, and 2030 are shown here. The calculated values for the index exceed 1.0 for some provinces since supply-demand dependency upon other provinces is not taken into account. It can be seen that provinces in eastern and northeastern China are likely to face serious water shortages by 2030. Here, this risk is based on an assumption that the amount of water resources endowment is constant over time. In the longer term, however, the factors affecting water resources endowment such as the global warming need to be taken into consideration.



Note: The risk index is defined as the ratio of total demand to water resources endowment

Figure 3. Risks for water scarcity during 1995-2030 in the case of high economic growth scenario

# 4. A Regional Case Study: The Yellow River Basin

## 4.1 The region for analysis

In the above, we presented an analysis based on provincial data. Actual water demand and supply, however, depends upon local conditions. This section, therefore, takes up the Yellow River basin as an example, and makes an analysis of the water resource endowment based on geographical data. The demand for water use in agriculture is also estimated by using the method similar to that adopted in the above for counties and cities. The data for water use in industry and urban life for counties and cities are attained from statistical yearbook (China Urban Statistic Yearbook, 1993).

The Yellow River is about 5,500km long and it drains an area of about 2,752,000 $km^2$. As of 1996, almost 150 million people were estimated to be living in this basin. In the downstream region of the Yellow River, most of the large cities with a population over 500,000 are located in a relatively narrow area (Fig.4 and 5). In recent decades, a number of cutoffs have occurred throughout the basin.

The basin used in calculating the water resource endowment and amount of consumption is shown in Fig. 5. The boundary of the basin is usually obtained as digital data based on the ridgeline calculated from altitude data such as a DEM (Digital Elevation Map). Some data have been also

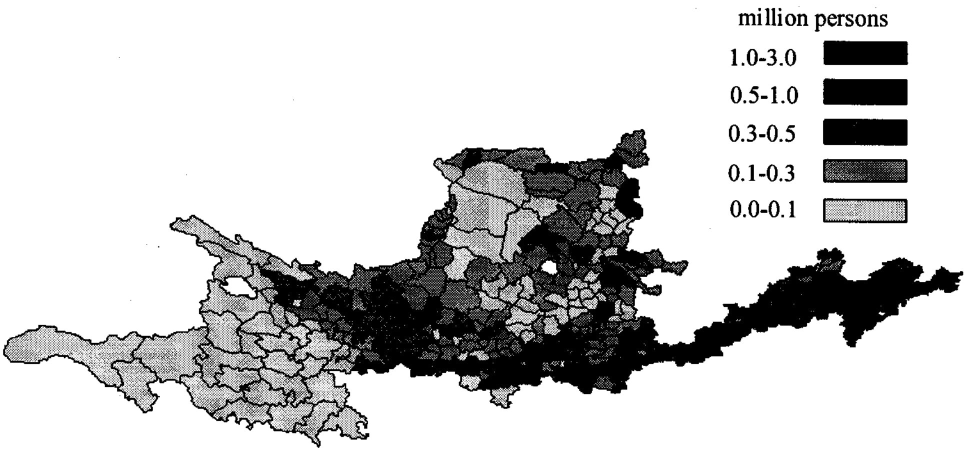


Figure 4. Population distribution by county in the Yellow River Basin
Data Source: Statistic Handbook of Agriculturral economy in county of China (1992)

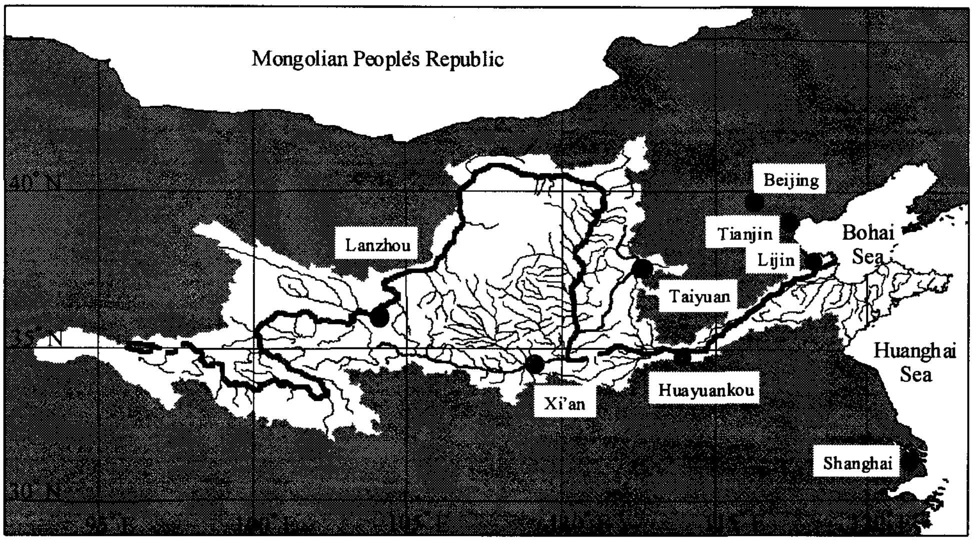


Figure5.Area for analysis: Location of the Yellow River Basin and major cities included

collected and presented by each province. Therefore, the following method is used to combine the two kinds of data contained in the GIS data set named LREIS Data (1:4,000,000) (CAS, 1996b). First, the main stream of the Yellow River and all of its branches (line data) are overlaid on the map of county's administrative boundaries (polygon data). The boundary of the basin is then specified under the assumption that each of the counties is located within the same basin and that no county crosses any boundary of the basin. Therefore, the total basin is taken to be the region that is linked up by the neighboring counties that meet these conditions.

## 4.2 Natural water resources endowment

In order to assess the water supply, the potential limit of water supply in a particular region must be known. For this analysis, a map of water endowment was constructed to identify the spatial distribution and total amount. The distribution is calculated using temperature and precipitation data with the accuracy of a 0.5-degree mesh provided by IIASA (Leemans & Cramer, IIASA Database for Mean Monthly Values of Temperature, Precipitation, and Cloudiness on a Global Grid, 1991) (NOAA, 1994). The amount of potential evaporation can be estimated using the Thornthwaite method, which has been developed primarily for macroscopic analyses as a function of temperature and latitude (Kayane, 1989). The actual amount of evaporation is affected by numerous factors including soil moisture and land use, *etc.* The actual average water resources endowment of the basin for the years 1956-1979 was reported to be 74.4 billion tons (The state ministry of water resources and power, 1989). Here, we assumed that the ratio of actual and potential evaporations takes the same value throughout the basin. Then, the ratio is estimated to be 0.85 based on the actual data of precipitation, water resources endowment and potential evaporation. We use this constant ratio for all meshes. The results of this calculation are shown in Fig. 6.

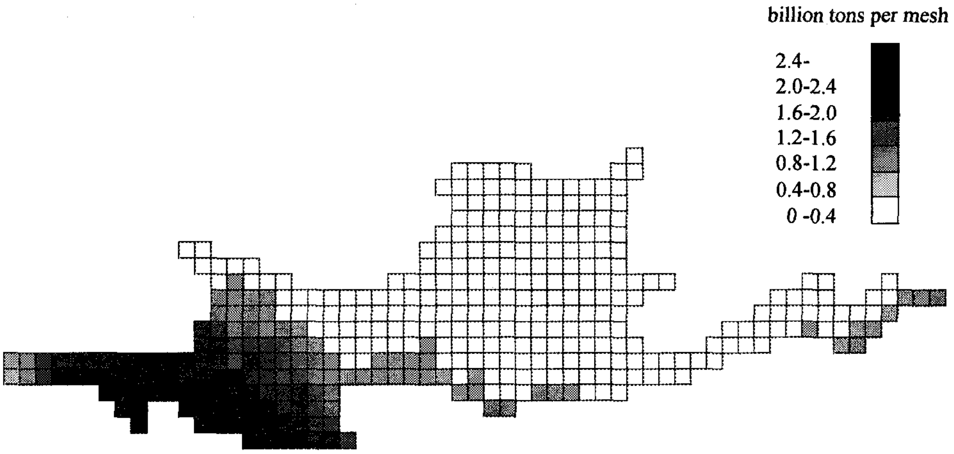


Figure 6. Water resources endowment in the Yellow River Basin

## 4.3 Water use

The present situation of water consumption by cities/counties is estimated for the three sectors of agriculture, industry and urban life. Water consumed for agriculture is estimated based on the amount of land area under cultivation in 1990 (State Statistical Bureau, China, 1991) and the irrigation water unit (see 3.1.1 (a)) determined for the Yellow River basin. The water consumption for each industry of cities is assumed to be equivalent to the amount of industrial wastewater discharged in 1992 (State Statistical Bureau, China, 1993). The water for urban life is also obtained by the assumption that water consumption for urban life is equal to the amount of domestic wastewatre by housefolds in 1992 (State Statistical Bureau, China, 1993).

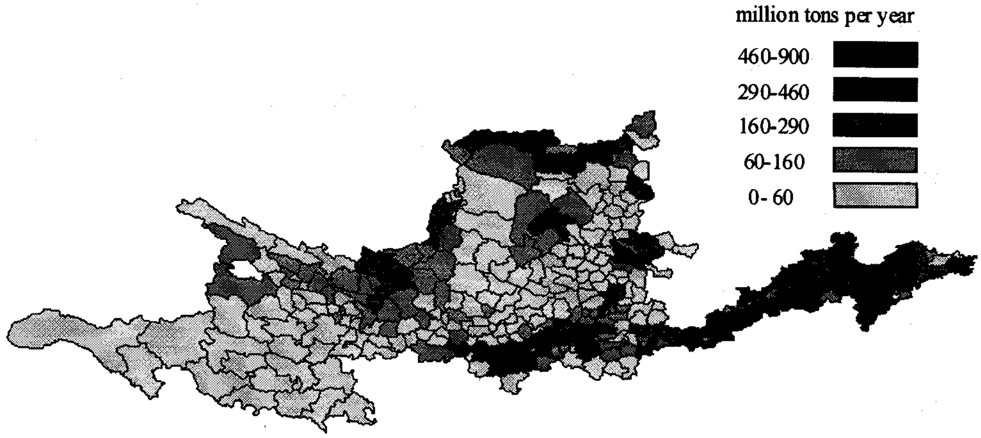


Figure7.Estimated water consumption in cities and counties for agriculture sector

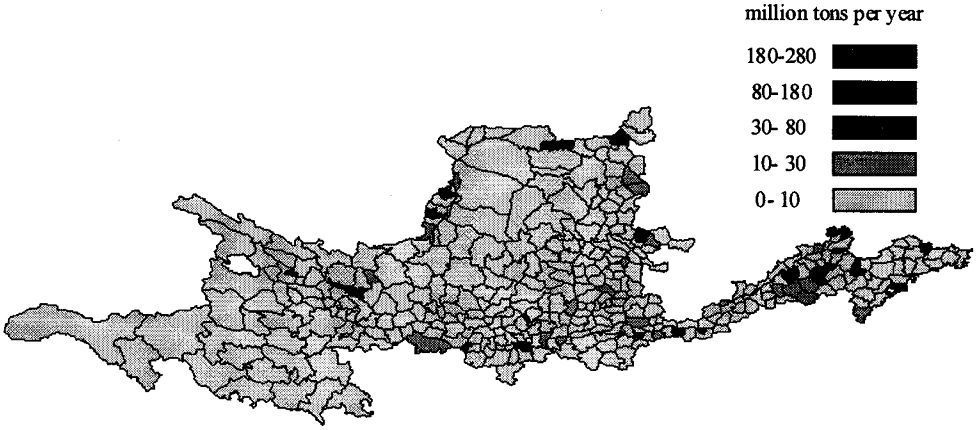


Figure8.Water consumption in cities for non-agriculture sector in 1992

Figure 7 shows agricultural water consumption. It is clear that most water for agriculture is consumed in the downstream region. This is the region in which agriculture has been intensively carried out since the earliest times in China and the irrigation system is well developed. The water for non-agricultural use, which is equivalent to the sum of the water for urban life and the total water for all of the industrial sectors, is shown in Fig. 8. Non-agricultural water is consumed mainly in urban areas throughout the basin. The cities of Lanzhou, Paotou, Taiyuan, Husian, and Jinan are the major consumers of non-agricultural water consumption.

# 5. Discussion

If the current trends of increasing water demand continue and effective countermeasures are not instituted, the present forecast suggests that the total water demand in China will eventually increase beyond the amount of available water resources. In some provinces, the demand is expected to far exceed the naturally endowed. It should be noted that in cases where the water resources are totally used up, the actual demand might be even larger than such total shortages would indicate. The situation along the eastern-seaboard including such huge cities as Beijing, Tianjin and Shanghai is particularly serious. The data for water resources currently used in evaluating the risk for each province is based on data from research carried out in 1980. To obtain more precise data on water availability, it is necessary to conduct a basin by basin analysis taking regional conditions into account.

Table 9. Periods of cutoffs at Lijin (days)
Data Source: Chen, 1998

| | Feb. | Mar. | Apr. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1972 | | | 4 | | 15 | | | | | | | 19 |
| 1973 | | | | | | | | | | | | |
| 1974 | | | | 5 | 4 | 11 | | | | | | 20 |
| 1975 | | | | 1 | 12 | | | | | | | 13 |
| 1976 | | | | 8 | | | | | | | | 8 |
| 1977 | | | | | | | | | | | | |
| 1978 | | | | | 5 | | | | | | | 5 |
| 1979 | | | | 5 | 7 | 9 | | | | | | 21 |
| 1980 | | | | 2 | 5 | | 1 | | | | | 8 |
| 1981 | | | | 12 | 24 | | | | | | | 36 |
| 1982 | | | | | 10 | | | | | | | 10 |
| 1983 | | | | | 5 | | | | | | | 5 |
| 1984 | | | | | | | | | | | | |
| 1985 | | | | | | | | | | | | |
| 1986 | | | | | | | | | | | | |
| 1987 | | | | | | | | | 17 | | | 17 |
| 1988 | | | | | 4 | 1 | | | | | | 5 |
| 1989 | | | 5 | | 5 | 14 | | | | | | 24 |
| 1990 | | | | | | | | | | | | |
| 1991 | | | | 15 | 1 | | | | | | | 16 |
| 1992 | | 2 | 6 | 18 | 30 | 26 | 1 | | | | | 83 |
| 1993 | 4 | 16 | 9 | 3 | 26 | | | | 2 | | | 60 |
| 1994 | | | 12 | 18 | 30 | 1 | | | 13 | | | 74 |
| 1995 | | 29 | 10 | 30 | 30 | 23 | | | | | | 122 |
| 1996 | 16 | 30 | 20 | 22 | 30 | 15 | | | | | 3 | 136 |
| 1997 | 22 | 20 | 7 | 16 | 30 | 31 | 21 | 26 | 28 | 21 | 4 | 226 |
| total | 42 | 97 | 73 | 155 | 273 | 131 | 23 | 26 | 60 | 21 | 7 | 908 |

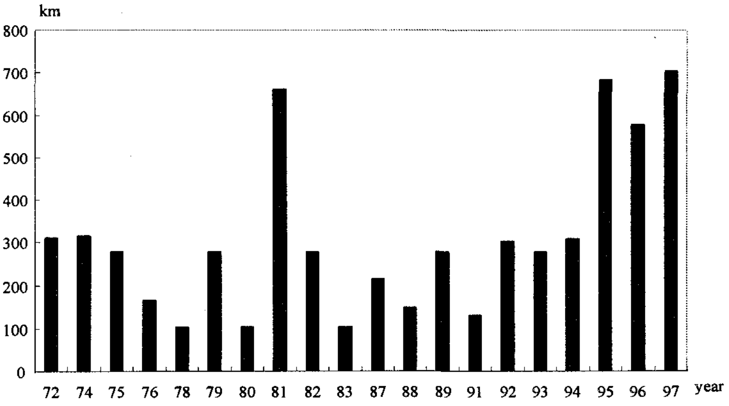


Figure 9. Length of cutoffs period for 1972-1997 (km)
Data Source: Chen, 1998

The present study also provides a first step towards identifying the factors related to the cutoffs in the Yellow River basin. Cutoffs in the lower reaches of the Yellow River were observed for the first time on April 23rd, 1972 (Chen, 1998). Since then, the river flow has dried up often and the cutoffs are getting worse. The length of the river experiencing cutoffs has gradually become longer. The cutoffs after 1995 are especially noteworthy (Fig. 9). Furthermore, the duration of cutoffs has also been getting longer. Up to 1991, cutoffs had started to occur in April. Beginning in 1992, the cutoffs have occurred in February or March. At the same time, the end of the cutoff has shifted from August to December (Table 9).

Regions with abundant water resources areas are geographically separated from areas of extensive consumption. The most abundant areas of water resources are in places with low temperature, where water resources exist in the form of glacial ice or snow. Water in these areas is utilized during warmer seasons. On the other hand, almost all precipitation in the Yellow River basin falls between June and September. These seasonal changes in the source of water resources lie at the root of stable river flow. Once this pattern is disturbed, more serious cutoffs can occur in the short-term (Zuo *et al.*, 1989). Recently, chronic water shortages have been observed throughout the year. There are two other factors that might cause frequent cutoffs other than climate fluctuations. One is a scarcity of the absolute amount of water resources due to the less precipitation. According to " *The situation and measure of a cutoff in the Yellow River lower stream of a river*" (Chen, 1998), the average precipitation over the Yellow River basin from 1990 to 1997 is 10 to 21% less than before. Another factor involved in the cutoffs is the increasing amount of water consumption accompanying rapid economic growth. In order to manage water resources efficiently, a strategy for long-term water resources development should be planed based on long-term supply and demand forecasts.

For forecasting, it is important to establish the surface flow model first, thus making it possible to determine the amount of spatial transfers of water resources. The amount of agricultural water eventually diverted to water for urban use will be determined by policy. The national planning embodied in the "South-to-North Water Transfer Project", in which water resources will be artificially transferred between basins (Benshu, 1995), should be examined carefully with respect to the long-term demand/supply balance. Reducing the amount of demand with water-saving technology, such as water recycling, can be expected for water demand in the industrial sector. In contrast, there is serious concern about the inability to meet the demand for water for urban life due to massive increases in the urban population, improvements in the living standards, the dissemination of flush toilets, *etc.*

Moreover, factors such as water quality cannot be ignored. Since high-quality water is required for some uses such as drinking water and high-tech manufacturing, the actual amount of total water available to meet these needs is even further restricted. Pollution by domestic wastewater from cities upstream is causing a deterioration of water quality for urban life in downstream cities (in Shanghai, for example). Also, when used for agriculture, the treated effluent may pose a problem due to excess nitrogen content. Future studies of water issues in China should attempt to integrate the various factors described above into the assessment model.

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