Journal of Environmental Sciences Vol.16, No.5, pp.765—769, 2004 ISSN 1001—0742 CN11—2629/X

Article ID: 1001-0742(2004)05-0765-05 **CLC number**: Q149; X959 **Document code**: A

Scenario simulation of water security in China

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Abstract: Limited water resources, increasing demand, low use efficiency, and serious pollution result in severe water resource difficult in China. The evaluation of addressing water problems and the search for effective countermeasures that ensure sustainable water use are key to China's sustainable development. The "compound water security" consists of food security, life security, environmental security, and economic security. By establishing a conceptual model, the water security of China has been simulated in terms of four scenarios called BAU(the business-as-usual scenario), TEC(the technology and economics scenario), IVL(the institution, values, and lifestyles scenario) and TSD(toward sustainable development) in this paper. The results indicated that water crises, especially water shortages, are being experienced now and will continue to do so for a relatively long time in China and that it is possible to reach a basic balance between supply and demand of water and grain under the TSD developing pattern by a series of approaches including technological innovation, policy adjustments, and behaviour inducement.

Keywords: water resource; water security; scenarios; simulation; China

Introduction

Water scarcity has become a major threat to food security, human health, economic development, and natural ecosystems on a global level (Lubchenco, 1998; Luijten, 2001; Vörösmarty, 2000). Water security assessment is the foundation of water resource management. A great number of researches on methodology and case studies have been released since the First World Water Forum (Brown, 2002; Gleick, 2000; Luijten, 2001; Strzepek, 2000; Vörösmarty, 2000). The basic method consists of modelling and scenario analyses, which can offer a way to consider the long-range future in light of uncertain factors and a way to examine the requirements for a transition to sustainability (Gallopin, 2000; Strzepek, 2000). This is usually viewed in a holistic manner including water supplies and demands which comprise its natural state and different forms of consumption such as domestic, agricultural, industrial, and environmental (Gleick, 2000; Rijsberman, 2000).

Water resource shortage and water pollution are widely believed the most challenging issues in the future development of China (World Bank, 1997; ESCAP, 1997; MWR, 2001). Water resources per capita in China are estimated to be only 2116 m^3, among the lowest in the world. Meanwhile, the spatial and temporal distribution of water resources is extraordinarily uneven: 83.8% are located in the Yangtze River basin and its southern area. With the development of society and the economy, water demands increase rapidly due to such driving forces as high population growth, rapid industrialization and urbanization, the strong desire for a better quality of life, fragmented institutions, and low eco-awareness in policy making. Over the past 50 years, agricultural, industrial, and domestic water consumption has increased 3, 46, and 41 times respectively (MWR, 2001). Uncontrolled water usage has led to a series of ecological problems in China such as rivers drying up, loss of wetlands and lakes, and the rapid decline of the groundwater table. In addition, water pollution is serious. In 2001, total wastewater discharge in China was 42.84 thousand million tons, of which 53.15% was domestic sewage and 46.85% was industrial wastewater. The proportion of discharged industrial wastewater that meets national quality standards was up to 85.6%. But the proportion of urban domestic sewage that is treated is still only 36%. Most sewage is discharged directly into rivers and lakes without any proper treatment (SEPA, 2002). Limited water resources, increasing demand, low use efficiency, and serious pollution result in serious water stress and make the situation of water security difficult.

A basic task for Chinese future development is meeting the increasing water demand due to the fast social and economic development while protecting the water environment from degradation. Strategies for comprehensively balancing water supply and demand, as well as water use for society and nature, are indispensable for the sustainable development of China. The evaluation of scientific mechanisms and of methods for addressing water problems and the search for effective countermeasures that ensure sustainable water use are key to China's sustainable development.

The main objective of this paper is to simulate the water security scenarios of China under different developing patterns. The paper is organized as follows: In the next

Foundation item: The Knowledge Innovation Programme of the Chinese Academy of Sciences (KZCX3-SW-424), the SUSDEV-China Project in the EU INCO-DEV Programme (ICA4-CT-2002-1004), and the Studies of Harmonious Development between Water Conservancy and National Economy (04-03-01)

section, water security and its driving forces are introduced. Section 2 presents a conceptual model, scenarios and simulation methods. The results and conclusions are presented in Section 3 and Section 4.

1 Water security and its driving forces

1.1 The concept of water security

The concept of "compound water security" (Wang, 1996) covers food security, life security, environmental security, and economic security. Food security means providing enough water so that agriculture can satisfy the growing population's increasing demand for food quantity, quality, sufficiency, and accessibility. Life security means providing all citizens with sufficient clean water and protecting them from water-borne diseases and plague. Environmental security means maintaining the eco-integrity of the water eco-sphere, including landscape, water, and soil conservation, watershed management, and the balance of water metabolism, to enhance the nature services so that the viability of the natural ecosystem is guaranteed and biodiversity conserved. Economic security means raising the efficiency of water use so that it can sustain stable growth of the national economy.

1.2 Driving forces

The main driving forces of water security include population growth, urbanization, economic development, technology, market economics, and environmental awareness.

Population growth: Medium-term growth projections indicated that China's population will reach 1.35 thousand million in 2010 and 1.42 thousand million in 2025. The annual population growth rate will continue to decline over the next 25 years, the modeling time period of this study. The majority of the population increase will affect rural areas.

Urbanization: In 2001, some 0.46 thousand million people lived in cities(NBSC, 2000), and it is expected that by 2025, about 0.76 thousand million people, half the total population of China, will live in urban areas. Much of this urban growth will be the result of internal migration as more rural citizens, especially the younger generations, abandon traditional rural life for that of the cities. And due to the rapid development of rural industries, the growth of small towns in rural areas will further accelerate.

Technology: Rapid development and application of technology in the fields of information science, biotechnology, water saving, water purification, and new technologies related to water use and water exploitation will become major driving forces in attempts to balance China's water demand and supply.

Economic development: As the most populated developing country, China is under very high economic pressure to speed up its economic development (ESCAP, 1997).

Environmental awareness: Increasing awareness of natural ecosystems' importance to future development will generate pressure to improve the quality of return flows to rivers, lakes, and wetlands. Many of these changes will be accomplished through enforcement of regulations and through changes in awareness.

2 System model and simulation methods

2.1 Conceptual model

Based on water security and driving force analyses, the related quantified index and variables were defined. Then, the relationships between these variables were formulated and a conceptual model constructed(Fig.1).

The basic formulas are as follows:

$$SW = WS \cdot WD^{-1}, \quad WD = WDL + WDA + WDI, \quad WDL = N \cdot \mu \cdot \alpha + N \cdot (1-\mu) \cdot \beta,$$

$$WDA = A \cdot \gamma \cdot q, \quad WDI = I \cdot \lambda, \quad WS = WSS + WSG + WSR + WSW + WSD + WST,$$

$$SG = GS \cdot GD^{-1},$$

in which SW is the index of water security in the target year; WD and WS refer to the total water demand and the total water supply; WDL, WDA, and WDI are the domestic water demand, agricultural water demand, and industrial water demand respectively; N, A, and GI are the total population, farmland area, and gross industrial production in the target year; μ, α, β, γ, q, and λ refer to the urbanization ratio, rural domestic water use, urban domestic water use, irrigated area ratio, irrigated water quota, and the industrial water efficiency value; WSS, WSG, WSR, WSW, WSD, and WST mean the water supply resulting from surface water, ground water, rain water utilities, waste water treatment and reuse, salt water desalting, sea water desalting and transfer water. SG, GD and GS are the indexes of food security, the total demand of grain, and the total supply of grain in the target year respectively.

2.2 Scenarios development

Four scenarios were developed to simulate the future water securities according to the current tendency and according to a sustainable pattern in this paper (Gallopin, 1999; 2000; Alcamo, 2000).

BAU (the business-as-usual scenario) describes a situation and trends in which current policies on water resources management and development and lifestyle continue in essence unchanged. Under this scenario, no major changes take place in the alterative trends of 16 decision-making variables including population growth rate, the increasing ratio of urbanization, the decreasing ratio of cultivated land area, the decreasing ratio of grain-planted area, the decreasing ratio of grain replanting, the increasing ratio of per capita urban domestic water use, the increasing ratio of per capita rural domestic water use, the increasing ratio of the grain yield per hectare, the increasing ratio of land-irrigated share, the increasing ratio of irrigated water quota, the decreasing ratio of the share of irrigated water in agricultural water consumption, the increasing ratio of gross industrial production, the increasing ratio of industrial water-

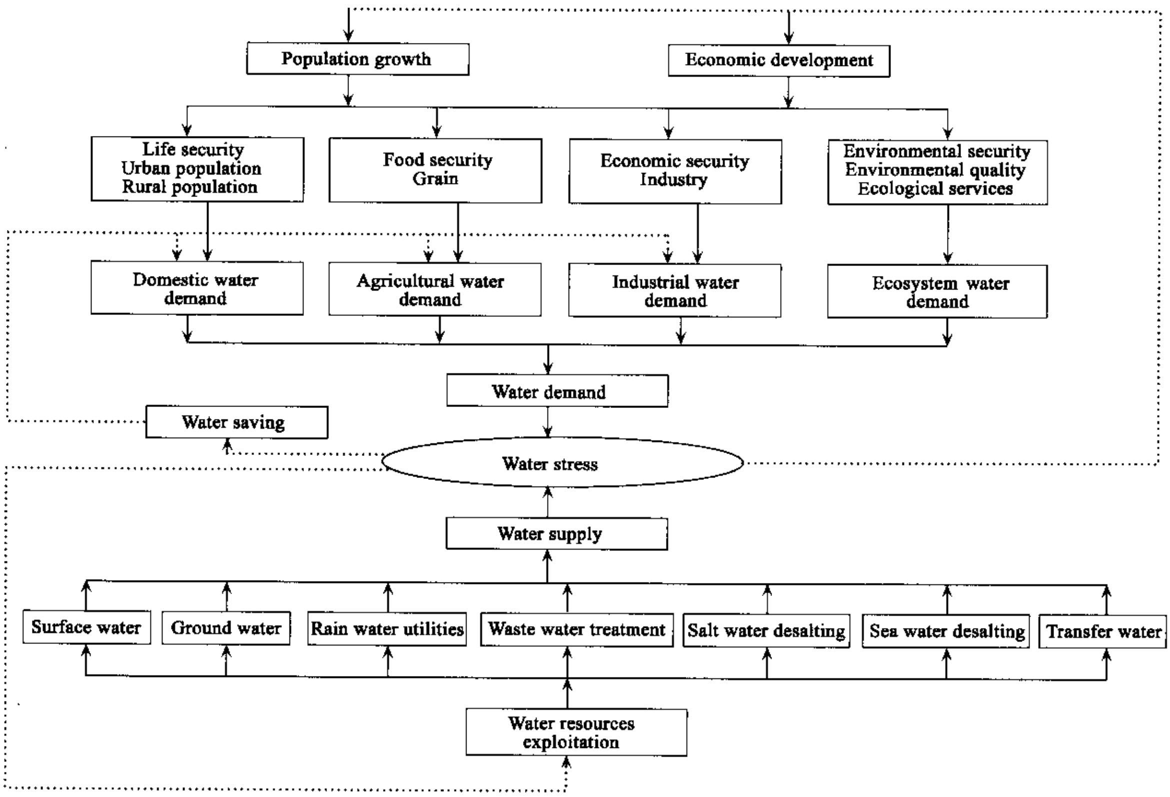

Fig.1 Conceptual model of water security in China

recycling proportion, the share of high-water-consumption industries, grain demand per capita and water supply. The values of these variables are determined by establishing statistical trend functions or correlative research results, respectively.

TEC(the technology and economics scenario) indicated a water situation in which mainly relies on technological innovation and transfer, on the condition that current tendencies of economic development, population growth, and water resource management continue without impediment. Water pricing, based on economic principles, will lead to rapid diffusion of technologies, increased capital investment and reduced water demand(Rijsberman, 2000). In TEC, it is expected that the development of technology in the fields of information technology, communications, and biotechnology, as well as in new technology related to water use and water exploitation in agriculture and industry, will speed up and widely applied. This trend can be described by 5 regulative decision-making variables that include the increasing ratio of industrial water-recycling proportion, the decreasing ratio of irrigated water quota, the increasing ratio of the grain yield per hectare, the decreasing ratio of the share of irrigated water in agricultural water consumption, and the increasing ratio of land-irrigated share.

IVL(the institution, values, and lifestyles scenario) describes a situation in which a revival of human values, strengthened international cooperation, heavy emphasis on education, international rules, increased solidarity, and changes in lifestyles and behavior take place. In IVL, it is expected that some effective and eco-friendly rules and measures will be introduced such as reforming water resource management policies, industrial structure adjustments, food and planting structure changes, and environmentally sound values and behaviour. This can be represented by 6 regulative decision-making variables including the increasing ratio of per capita urban domestic water use, the increasing ratio of per capita rural domestic water use, the increasing ratio of gross industrial production, the share of high-water-consumption industries, grain demand per capita, and water supply.

TSD(the toward sustainable development scenario) is regarded as an integration of TEC and IVL, which all of technological innovation, institutional reform and behavioral enhancement could be simultaneous in the future. In this scenario, all controlled parameters are changed according to the scenario TEC and IVL discussed above.

2.3 Simulation methods

In the simulation, the base year is 2001 and the target years are 2010 and 2025. The main parameters and variables of base year are derived from statistical data. Some uncertainties were identified in BAU, TEC, IVL, and TSD scenarios in the target years. These refer to trends or events that are currently very difficult to anticipate such as improvements in water resource exploitation and utilization, water-saving irrigation technology, water-saving techniques in industry, water resource management policies, relative laws, industrial structure adjustments, food and planting structure changes, environmentally sound values and behavior, investment in R&D for water resource exploitation and utilization, grain importation, and so on. The parameters in scenarios simulation can be calculated by relative kinds of decision-making variables, and the values of these variables can be determined through establishing statistical trend functions or citing the data of correlative research and reports respectively. A few parameters are unchanged in the four scenarios because of the continuity and stability of some national laws and policies such as population growth, urbanization, farmland, and industrial development. Some basic parameters and their values from the scenarios of BAU, TEC, IVL, and TSD are listed in Table 1. After validation, the system model was programmed in STELLA 5.0(SEIB and TI, 1997). The water security of China was assessed in the different scenarios.

3 Results

The simulation results of BAU, TEC, IVL, and TSD scenarios are as follows (Table 2).

Table 1 The basic parameters and their values used in scenarios

Parameters	2001	2010				2025			
		BAU	TEC	IVL	TSD	BAU	TEC	IVL	TSD
Population growth rate, %	0.87	0.65	0.65	0.65	0.65	0.32	0.32	0.32	0.32
Urban population share, %	37.7	44.6	44.6	44.6	44.6	48.8	48.8	48.8	48.8
Farmland area, 10^6 hm^2	127.6	112.4	112.4	112.4	112.4	107.4	107.4	107.4	107.4
Industrial production value growth rate, %	14.0	7.0	7.0	7.0	7.0	5.0	5.0	5.0	5.0
Grain demand per capita, kg	410.0	428.6	428.6	420.8	420.8	451.0	451.0	442.6	442.6
Per capita urban domestic water use, L/d	218.0	234.0	234.0	230.0	230.0	262.5	262.5	255.3	255.3
Per capita rural domestic water use, L/d	92.0	102.2	102.2	100.5	100.5	126.5	126.5	122.0	122.0
Irrigated area ratio, %	42.0	50.0	51.0	52.0	52.0	62.0	63.0	64.0	64.0
Irrigated water quota, m^3/hm^2	7185.0	6930.0	6570.0	6930.0	6570.0	6630.0	6270.0	6630.0	6270.0
Industrial water reuse ratio, %	52.0	56.6	57.7	56.6	57.7	65.8	71.1	65.8	71.1
The industrial water efficiency value, $m^3/10^4$ RMB Yuan	78.0	60.6	61.0	60.6	61.0	31.1	26.8	31.1	26.8

Table 2 The modeling results of BAU and TSD

Index	2010				2025			
	BAU	TEC	IVL	TSD	BAU	TEC	IVL	TSD
GDP, 10^{12} USD	2.32	2.32	2.14	2.14	4.82	4.82	4.45	4.45
GDP per capita, USD	1720	1720	1585	1585	3398	3398	3134	3134
Domestic water demand, 10^9 m^3	82.1	82.1	80.6	80.6	100.0	100.0	97.0	97.0
Agricultural water demand, 10^9 m^3	428.4	406.2	436.2	413.5	441.5	431.0	441.5	431.0
Industrial water demand, 10^9 m^3	221.9	211.1	221.9	211.1	270.8	220.7	270.8	220.7
Water demand, 10^9 m^3	732.4	699.4	738.7	705.2	812.3	751.7	809.3	748.7
Water supply, 10^9 m^3	646.0	656.0	646.0	656.0	720.0	740.0	720.0	740.0
Water deficiency percentage, %	13.4	6.6	14.4	7.5	12.8	1.6	12.4	1.2
Water security index	86.6	93.4	85.6	92.5	87.2	98.4	87.6	98.8
Total grain production, 10^6 t	548.1	554.1	548.1	554.1	588.9	617.9	588.9	617.9
Grain yield, kg/hm^2	4876.4	4929.7	4876.4	4929.7	5483.0	5753.4	5483.0	5753.4
Grain per capita, kg	406.0	406.0	410.4	410.4	414.7	414.7	435.2	435.2
Grain demand, 10^6 t	578.6	578.6	565.1	565.1	640.4	640.4	628.5	628.5
Grain balance, 10^6 t	-30.5	-24.5	-17.0	-14.0	-51.5	-22.5	-39.6	-10.6
Grain deficiency ratio, %	5.3	4.2	3.0	2.5	8.0	3.5	6.3	1.7
Food security index	94.7	95.8	97.0	97.5	92.0	96.5	93.7	98.3

Under the BAU scenario, the Chinese economy will continue to grow during the next 25 years. Although cultivated land in China will reduce mainly due to the restoration of natural ecosystems, irrigated areas in 2025 will account for 62% of total cultivated land, and the grain yield will increase by 30%. The predicted increase in water demand will come mainly from industry and households, all of which will double over the next 25 years. The water supply potential can be expected to improve slowly and the rapid economic development will lead to increased water stress. This water shortage will be increasingly severe during the period from 2001 to 2015 because the demand for water for economic development will exceed water supply. After 2015, this stress will be slightly reduced thanks to significant social, economic, and technical progress. The conclusions presented here are based on the average hydrological regime. If some large-scale drought disasters were to occur in China, water shortages would be critical, and the grain yield would fall below the security line, which is represented by an import share of 8% of total grain provision.

Scenario TEC and Scenario IVL have demonstrated the influences of technical progresses, policy adjustments, and behavior inducements on water supply and demand in China. The results showed that only technology solution and institutional reform can not ensure the water security in China.

Under the TSD scenario, as a result of investment in hydrographical projects and technical improvement, the water supply potential can be expected to increase gradually. Water exploitation from alternative resources such as salt and rain water could amount to 36.1 thousand million m^3 in 2010 and 59.0 thousand million m^3 in 2025. Due to the extensive development of new water-saving techniques in agricultural and industrial sectors (Jin, 2001), especially water-saving agricultural techniques, the total water demand in 2025 is projected to be 11.6% less than in BAU, which industrial, agricultural and domestic water demand will decrease by 18.5%, 9.0% and 3.0% respectively. With the rapid development of water-saving technologies and improvements in policy-making, management, investment, lifestyle, and eco-awareness, there will only be very slight water and grain shortages in 2025. In this scenario, the simulation suggests that "zero growth" of water demand could be achieved before 2030 without sacrificing food and ecological security and while ensuring moderate economic growth and living quality improvement.

4 Conclusions

Water crises, especially water shortages, are being experienced now and will continue to do so for a relatively long time. However, it is possible to reach a basic balance between water supply and demand under the TSD scenario's developing pattern. According to this simulation, the water shortage in 2025 will be 9 thousand million m^3, only about 1.2% of the demand. If the trend were to continue, "zero-growth" of water use would be reached before 2030. If suitable countermeasures are taken, China's food problem will not influence the food security of the world. According to this simulation, the grain deficiency will be only about 10.6 million tons in 2025, i.e. the import share will be about 1.7%. From the points of view of water saving, sustainable development, and grain storage, a moderate amount of grain import is necessary. According to estimations, the import share will be between 5% and 10%.

The main methods enabling water security include policy adjustments, technological innovation, bio-technological development, behaviour inducements, and effective management and cooperation. Government at different levels plays an important role in sustainable water management. Suitable grain and other product imports will help to ameliorate the increasingly serious water crisis, while feasible industrial arrangement and reasonable water resource allocation will decrease the water consumption. Public awareness of the water crisis is very important. According to the scenario analysis, if the increase of domestic water use is slowed, about 1.5 thousand million m^3 and 3.0 thousand million m^3 of water could be saved in 2010 and 2025 respectively.

Sustainable water use and management is an integrated system. The combined effects of water pricing, demand management, water saving technologies, and biotech solutions to food production have sharply reduced the water-use intensity of most human activities. Although per capita water resources in China are only one third of the world average and the spatial and temporal distribution is extremely uneven, there are also promising opportunities for the exploitation of alternative water resources and for water saving. By adopting the strategies described above, China will be able to feed its projected 1.42 thousand million inhabitants in 2025 and to guarantee them an improved quality of life despite limited water resources and without having to resort to significant imports of grain. The key to successful adaptation lies in technological innovation, institutional reform, changes in lifestyle, water diversion, ecological engineering, and intelligent governance. Today, China is at a crossroads, and its water-related fortune is in its own hands.

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(Received for review October 14, 2003. Accepted February 10, 2004)