HEIGHTENING URBAN WATER SUPPLY CAPACITY AND RELIABILITY THROUGH RECONSTRUCTING INTEGRATED REGIONAL WATER RESOURCES SYSTEMS

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ABSTRACT

This paper presents essential concept of reconstruction of integrated regional water resources systems (IRWRS), basic status of urban water supply in China, and a case study of solving urban water issues induced by unitary water source through reconstructing IRWRS. Integrated regional water resources systems are defined as water resources systems that consist of water source subsystems, water project subsystems, water utilization subsystems, water management subsystems and the environment of the systems. Lack of enough water sources with sufficient quantity and proper quality is recognized to be one of the most crucial stresses to urban water security. Integrated regional water resources systems with multiple water sources are regarded as an important solution to unitary water source induced urban water scarcity and pertinent issues. The results from the Xi'an Water Resources System show that urban water supply capacity and reliability is capable of being significantly improved through reconstructing IRWRS.

KEYWORDS

Integrated regional water resources system (IRWRS); multiple water sources; water scarcity; water supply capacity and reliability; unitary water source, urbanization.

INTRODUCTION

Urbanization is an essential trend of the developing world. It is generally accompanied by rapid industrialization and population growth in persistently expanding urban areas. One of the most specific phenomena of urbanization is rapid increase in water demand in urban areas. This often causes severe water scarcity and pertinent social, economic and the environmental problems in urban areas. These problems may be aggravated by natural and anthropological factors. Lack of enough water sources with sufficient quantity and proper quality might be one of the most crucial stresses to urban water security.

Traditionally, urban water resources systems are usually isolated systems with unitary water source: groundwater or surface water. This situation is typical in China, where a large number of cities and particularly the urban areas in some large cities only use local groundwater. However, local groundwater in urban areas is limited in quantity and quality by nature and aggravated by human activities (Feng, 2000a, 2000b). The groundwater might suffice for a city's needs fifty years ago, ten years ago, and even five years ago, but may make the city fall in predicament water stresses in few years during its high speed developing stage and cause

severe geo-environmental catastrophes. This situation occurs not only in natural water scarce regions such as North China but also in natural water abundant regions such as South China, and so does in many regions or countries throughout the world.

Unitary water source urban water resources systems are evidently inappropriate for sustainable development of urbanized and urbanizing areas. For sustainable development of water stressed urban areas, urban water resources systems have to be improved or enlarged so that the water supply capacity can keep pace with the increasing demand. This needs to seek efficient and effective solutions.

An important feasible solution to urban water scarcity induced by unitary water source is to heighten urban water supply capacity and reliability through reconstructing integrated regional water resources systems with multiple water sources (Feng et al., 1999; Feng, 2000c). The reason of emphasizing on reconstruction is that there have been many available regional water resources systems. Similarly, the reason of advocating integration is that many available water resources systems and even so-called regional water resources systems are actually isolated in water sources and/or users.

The purpose of this paper is to present essential concept of reconstruction of integrated regional water resources systems, basic status of and major problems in urban water supply in China, and an integrated regional water resources system for solving unitary water source induced urban water problems in Xi'an City, one of the most water scarce large cities in China.

CONCEPT

Integrated regional water resources systems (IRWRS) are water resources systems that consist of water source subsystems (WS), water project subsystems (WP), water utilization subsystems (WU), water management subsystems (WM) and environment of the systems. Water project subsystems include all the projects in the systems such as water source projects, water supply projects, water disposal projects, wastewater treatment and drainage projects. The relationship among these subsystems is shown in Fig. 1. There are obvious interactions among WS, WP and WU. Water management subsystems are the management or operational systems of the other three subsystems and their interactions, as well as the interactions of the subsystems and the systematic environment.

As an integration of the subsystems and their environment, IRWRS have obvious advantages over the traditional water resources systems. In an IRWRS, conflicts between water supply and demand are able to be properly solved on regional scale through scientific spatial and temporal regulation and redistribution of water resources in the system; water resources are able to be more effectively utilized through rational urban-rural sharing and recycle uses; multi-functions of water resources are able to be completely developed through comprehensive utilization; degraded water environment is able to be reasonably restored through appropriate reconstruction; water demands of the society, economy and environment are able to be fairly balanced through optimal allocation among all the water use sectors; water supply capacity and reliability are able to be considerably improved in not only the urban subsystem but also the entire regional system through effective reconstruction of water supply project subsystem.

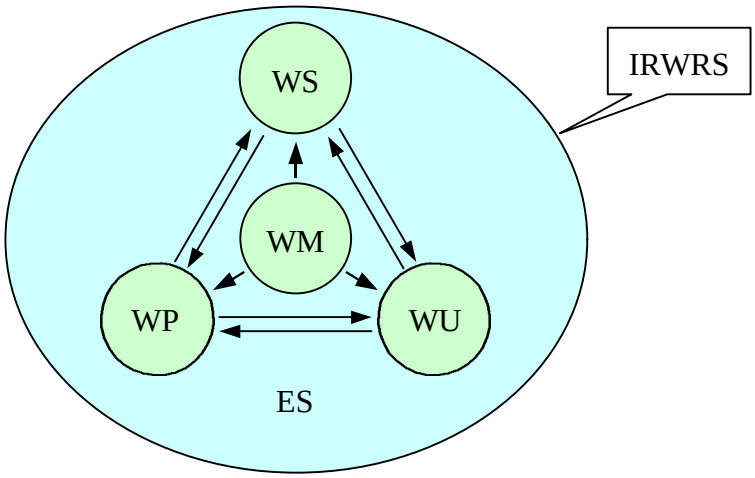

Fig. 1. Relationship among the subsystems, WS, WP, WU and WM in an IRWRS, where WS stands for water source subsystem; WP stands for water project subsystem, WU stands for water utilization subsystem, WM stands for water management subsystem; ES stands for the environment of the system; and IRWRS is the abbreviation of integrated regional water resources system.

Notwithstanding the advantages, IRWRS associated with urban water supply should consider several important aspects. They are scientific assessment of water resources available for the city and pertinent users, in particular, the traditional users such as agricultural irrigation; reliable prediction of water demands for different developing stages based on sustainable macroeconomic development planning of the city and whole the region of the system concerned; integrated water resources planning based on rational allocation of available water to and highly effective utilization by all the water use sectors involved; intensifying protection of water sources and water environment; combined utilization of the water from different sources; optimal operation of water resources systems; appropriate development of water resources under the constrains of economic effectiveness, technological feasibility, environmental security and human acceptability; participation of the public and especially women in water resources management; and capacity building of water resources management institutions. All of these are basic requirements of reconstruction of IRWRS. Otherwise, any inadvertence would inevitably cause new conflicts between the urban and the new water source related sectors. Particularly, any inadvertent share or occupation of the water resources originally used by the suburban or nearby rural areas would severely impact local agriculture and food security, critical urban-rural contravention and non-solidarity, and even social stability. Therefore, in reconstruction of IRWRS for the purpose of solving urban water issues, local rural and controversial water uses have to be ensured, the priorities of water uses of different sectors have to be well balanced and in particular the priority of agricultural water uses has to be emphasized, and the importance of environmental water uses has to be considered as well.

Reconstruction of the available regional water resources systems implies to integrate these systems for the purpose of improvement of urban water supply capacity and reliability through more effective utilization of the water resources in the regional water resources systems that could not be effectively used before. This transformation from isolated to integrated water resources systems requires conceptual, theoretical and technological innovation and transformation from hydrosovereignty to hydrosolidarity. It is not only an

integration of the water supply systems, but also all the system components, including water sources and their protection, water storage and supply projects and their operation and maintenance, water-saving technology and water demand management, effective utilization of water resources, effective protection and restoration of water environment, authoritative and qualified water management institution, powerful water law and related regulations, etc.

ESSENTIAL SITUATION OF URBAN WATER SUPPLY IN CHINA

China has made remarkable achievements in its economic development and modernization and received international acclaim since 1978 with the onset of reform (Elizabeth Economy, 1997). Correspondingly, the pace of urbanization has been speeding up. The population in urban areas in China increased from 172 million in 1978 to 370 million in 1997. The percentage of urban to total population increased from 17.9% to 29.9% during the period of the two given years. GDP (Gross Domestic Products) of industry increased 19.8 times during the period. The average annual growth rate of industrial products was up to 10.5%. At the same time, the number of cities in China increased to 668 in 1997 from only 191 in 1978 (State Statistical Bureau, 1998).

Rapid urbanization in China causes serious conflicts between urban water demand and supply. Firstly, in the process of urbanization, water demand for residential uses inevitably increase with rapid population growth. On the one hand, people living in cities require persistent improvement of their living quality. In relation to water demand, popularization of piped water provides chances for wide uses of house showers and washing machines in cities. They are highly water-consumed compared to traditional living surroundings. On the other hand, with the improvement of living quality, the people living in cities desire more public water-related recreational facilities. It usually leads to rapid construction of water-related municipal infrastructures, such as swimming pools, water amusement parks, water landscapes, green land irrigation and municipal sanitation. Secondly, rapid industrialization in urbanized and urbanizing areas inevitably causes rapid increase in industrial water demand. According to a scenario of urban water resources planing, 270 cities in China suffered from moderate to severe water shortages in 1990. They were 57.8% of the total cities. Residential and industrial water demand in 1990 was 23.03 km^3 while predicted demand in 2010 is 71.37 km^3 (Water Resources Bureau of Ministry of Water Resources, 1995).

In order to meet increasing water demand in urban areas, China has been constructing and improving urban water supply systems. However, the speed of building urban water supply capacity has not yet kept pace with the increasing water demand due to relatively long construction periods of water projects, inadequate investments allocated to the projects, and some societal, economic, political and legislative reasons. The unbalance between the water demand and supply leads to water deficit in urban water resources systems. In the urban water resources systems of the aforementioned 270 water scarce cities, estimated total water deficit of residential and industrial uses will be up to 35.30 km^3 by 2010 if there were no new projects to be put into service and only the currently available water supply projects in 1990 were used. Moreover, if all the planned new water supply projects for urban areas including those to be reconstructed and improved in the planning period were completed and put into full service, the deficit could not be completely filled and would still be in the range of 10.25 km^3 by 2010 (Water Resources Bureau of Ministry of Water Resources, 1995). In fact, the number of water scarce cities may currently be counted at over 300 and up to 400. The countrywide urban water deficits are much higher than above figures.

In the improvement of urban water supply capacity and reliability, a large number of urban water resources systems have been enlarged and become IRWRS, such as the water resources systems for urban water supply to Beijing, Tianjin, Taiyuan, Xi'an, etc., in which Xi'an is a typical example in solving unitary water source induced urban water scarcity.

THE XI'AN WATER RESOURCES SYSTEM

The City and Its Water Problems

Xi'an, the capital city of Shaanxi Province, is one of the most water scarce large cities in China (Fig. 2). As an administrative region, Xi'an City consists of its urban, suburb and rural areas, in which the area of urban and suburb together is called capital district. Population in the capital district grown from 0.48 million in 1949 to 2.76 million in 1995. People lived in the urban area increased from 0.19 million to 2.09 million during the period. The city's GDP increased over 10 times in last two decades. With rapid societal urbanization and economic industrialization of the city, water demand in its urban area dramatically increased to over 500 Mm^3/yr (million cubic meters per year) in 1990s from less than five Mm^3/yr fifty years ago. Water scarcity has become one of the most crucial restrictions to the city and even the province's development (Shaanxi Statistical Bureau, 1996; Feng et al, 1999; Feng, 2000b).

In order to meet increasing water demand in urban area of the city, in the past several decades, local groundwater as only water source was withdrawn in high intensity on large-scale. By 1990s, the amount of over-withdrawal local groundwater from self-controlled wells in the urban area of less than 300 km^2 was up to 0.14 Mm^3/day or 51.10 Mm^3/yr on average. This caused enormous over-withdraw of groundwater and persistent lowering of groundwater level, and induced severe geo-environmental catastrophes, such as disastrous ground subsidence and crack with the maximum subsidence of over 2,300 mm at the center of the subsiding area of about 200 km^2, evident deterioration of water environment, and unexpected economical loss. Water scarcity once became the most severe stress to the city with a daily water deficit of over 0.40 Mm^3 during the extreme drought period of 1994 to 1996 (Feng et al, 1999; Wang & Lu, 1999).

The Integrated Regional Water Resources System

For solving the severe water scarcity and water scarce induced social, economic and environmental problems, some possible solutions have been proposed. Of them reconstruction of IRWRS has been recognized to be the essential measure to the city (Feng et al, 1999, Feng, 2000c). An urban-rural combined and multi-water-source integrated regional water resources system has been under construction and part of the system has already been built up and put into operation.

The IRWRS for Xi'an City is commonly called Xi'an Water Resources System or Xi'an Water Supply System (Feng et al, 1999; Feng, 2000a). In planning, the system consists of all the water sources and users involved. The water sources include all the groundwater and surface water sources in the system. The groundwater sources include all the aquifers being capable of providing groundwater using all the wells that supply water to the urban area. The wells include over 500 self-controlled wells that are arbitrarily distributed in the urban area and managed by individual users, and seven riverside groundwater sources with intensive well groups that are managed by the city's water supply authorities, and all other wells distributed

in rural area and small towns such as the county seats. Surface water sources are all the rivers, streams and creeks belong to upstream of the Wei River within Xi'an City and the Shitou River in another prefectural administrative region. There are three reservoirs for urban water supply in the surface water subsystem. They are the Shibianyu Reservoir, the Shitouhe Reservoir and the Jinpen Reservoir respectively. The Jinpen Reservoir is under construction and the other two have already been in operation for years. The channel and pipe conveying surface water from its sources to the urban area were built up and the first drop of the surface water was transferred into the urban area through the system in June 1996. The IRWRS is shown in Fig. 2, which illustrates main surface water sources and water supply projects.

Role of the System in the City's Water Supply

Since the surface water outside the urban area was conveyed in the urban area of Xi'an City in 1996, its water supply status has been obviously improved. Notable social, economic and environmental benefits have been obtained. The groundwater table in the urban area has evidently recovered since then by gradually closing the self-controlled wells. Even so, some problems in the city's water resources system still need to be carefully solved. One crucial problem is rational allocation of the surface water in the system. This problem is recognized to be crucial because the allocation is not a simple share of the water among all the users involved under general rules but should take into account of the priorities of the original users that probably be neglected in the new system. Meanwhile, environmental water use should be considered as an important guarantee for environmental security in the system.

For the purpose of rational water allocation in the IRWRS, a series of simulating operation of the system under several restrictions and constrains are carried out (Feng et al, 1999; Feng, 2000a). A more detailed study is being dealt with. Some primary outputs of the study show that the IRWRS may considerably improve the water supply capacity and reliability of Xi'an City without negative effects on original users and even obvious improvement of the original water supply status in the originally isolated surface water systems, i.e. the small watershed systems. The simulation uses daily runoff records during the period of 27 hydrological years started in October 1968 and ended in September 1995. The irrigation water demands for original users are ensured within the design frequency of 75% and are proportionally reduced while actual frequency of the surface water in a given hydrological year is greater than 75% in order to ensure domestic uses in the urban area. Also, a quantity of stream flow that is equivalent to minimum ten-day daily average discharge that its exceedance probability is equal to 90% is considered as downstream environmental uses along and inside the rivers and streams for riverine ecosystems.

Results show that while the probability of reliability of the water supply to the urban area is equal to and greater than 95%, the design frequency of urban water supply, the ensured water supply would be 580-620 Mm^3/yr including 220 Mm^3/yr of groundwater from the riverside groundwater sources and part of the self-controlled wells in the urban area. The lower amount is the water supply before the Jinpen Reservoir is completed and the higher amount is the water supply after the Jinpen Reservoir is put into operation. The estimated amount of water supply will be capable of satisfying the increasing water demands in the next two decades in the urban area of Xi'an City and original users involved. While the Xi'an Water Resources System is completely reconstructed, it will play more important roles in the city's water security and sustainable development.

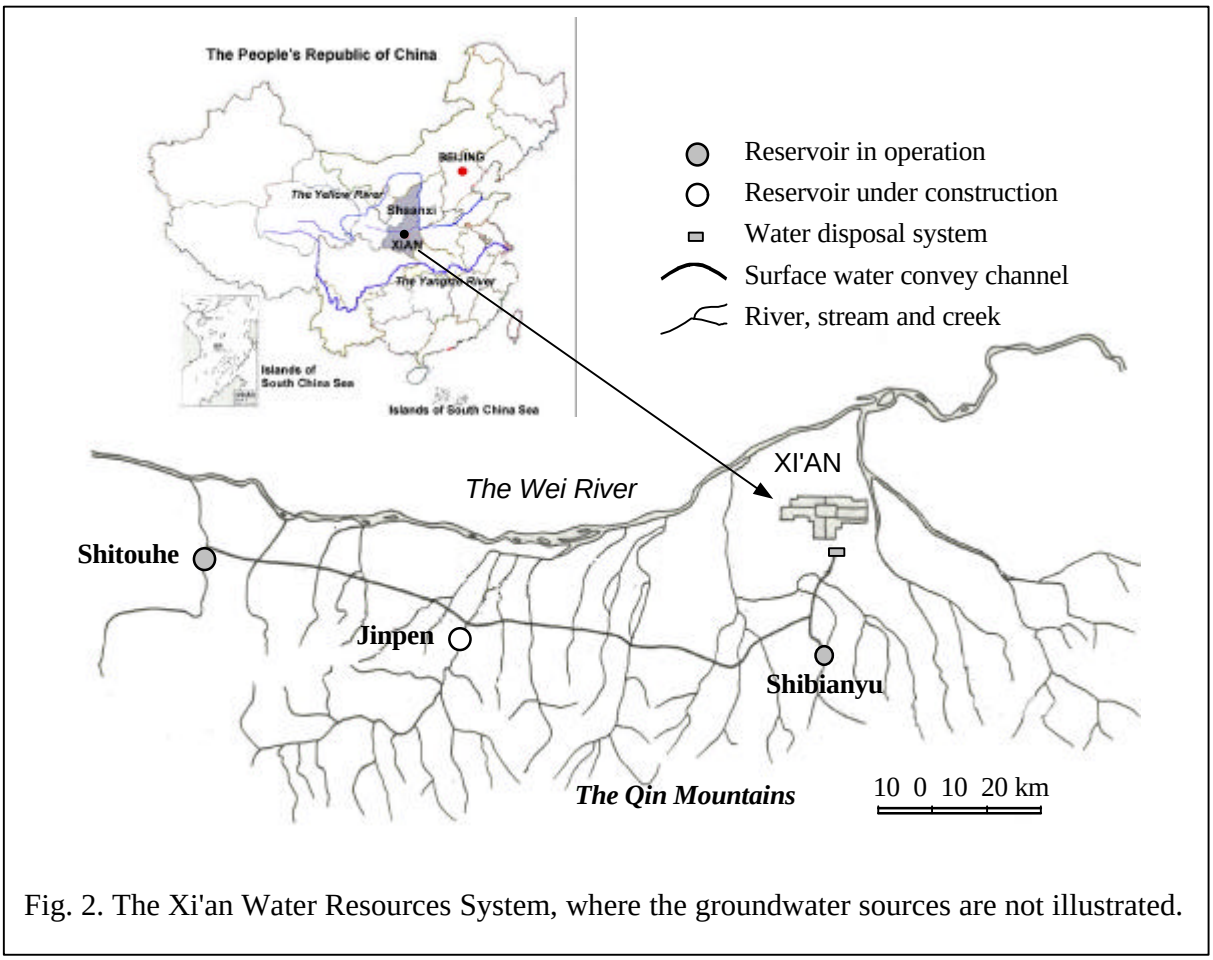

Fig. 2. The Xi'an Water Resources System, where the groundwater sources are not illustrated.

CONCLUSIONS

The developing world is moving towards urbanization. As an obvious consequence of urbanization, water scarcity and even water crisis in urban areas are becoming serious social, economic and environmental issues that severely impact regional sustainable development.

Seeking for feasible solutions to urban water issues on a regional range would be very important for urban water security and regional sustainable development.

Lack of enough water sources with sufficient quantity and proper quality has been one of the most crucial stresses to urban water security. Integrated regional water resources systems with multiple water sources are recognized to be an essential solution to unitary water source induced urban water scarcity. This measure has played and is playing important roles in urban water supply in China and overall the world.

Water issues in urban areas are complicated multi-cross-boundary problems concerning almost all aspects of the society, economy and environment. Although IRWRS have obvious advantages over the isolated ones, the heightening of urban water supply capacity and reliability should not be the cost of benefit loss of original users and particularly of the traditional users. Special solutions to possible impacts of the integrated regional water resources systems on traditional users should be further investigated in detail.

RFERENCES

Elizabeth Economy (1994). Reforms and Resources: The Implications for State Capacity in the PRC (Case Study of China).

Feng, Guozhang and Li, Peicheng (1999). Optimal Water Regulation and Allocation in the Urban Water Resources Systems of Xi'an. *A technical report to the National "95" Keystone Sci-Tech Research Program* 96-912-05-02-01.

Feng, Guozhang, (2000a). A model of simulating water distribution and allocation for regional water supply system. *Water Resources and Hydropower Engineering*, 31(9), 15-17.

Feng, Guozhang (2000b). Impacts of and solutions to urbanisation on agricultural water resources. In *Challenges Facing Irrigation and Drainage in the New Millennium* (ed. by Deason et al.), Vol. I, 185-204, Fort Collins, USA.

Feng, Guozhang (2000c). Promoting economic development of Shaanxi through intensifying construction of the blue engineering. *Shaanxi Water Resources*, (5), 4-7.

Shaanxi Statistical Bureau (1996). Statistical Yearbook of Shaanxi. China Statistical Press, Beijing.

State Statistical Bureau (1998). China Statistical Yearbook. China Statistical Press, Beijing.

Wang, Gushi and Lu, Bo (1999). Analyses of water-related geo-environmental issues in urbanization of Xi'an City. In *Proceedings of the Conference on Water Resources Development and Utilization in Shaanxi Province* (ed. by Water Resources Bureau of Shaanxi Province and Water Resources Society of Shaanxi Province).

Water Resources Bureau of Ministry of Water Resources (1995). A Brief Report to the Water Resources Planning of Water Supply for National Major Water-Short Cities.