Can China Cope with Its Water Crisis?—Perspectives from the North China Plain

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Introduction

China has been going through a remarkable economic expansion and transformation since the late 1970s with an average annual growth rate of nearly 10%. In a provocative book published in 1995, the American agricultural expert and environmentalist Lester Brown pointed to the fact that China has less than 10% of the world's farmland but must feed more than 20% of the world's population (Brown 1995). With rapid industrialization and population growth of around 14 million a year, he contended that China's potential grain deficit could be so large that it would overwhelm the export capacity of the United States and other exporting countries and lead to fierce price wars.

More than 15 years later, Brown's worst-case scenario has not materialized, but partly in response to this alarming prediction, the Chinese government has made concerted efforts to increase grain production and has mostly managed to feed its people by stabilizing grain prices, cutting taxes and giving subsidies to grain growers, limiting the loss of arable lands, and improving farming practices. Nevertheless, the long-term prognosis on China's grain production and consumption is not optimistic, partly because of the increasing difficulty of finding sufficient water resources to support irrigated agriculture. Thus, a greater concern of today is whether the unprecedented economic growth in China over the past three decades can be sustained as water shortage and environmental pollution continue to worsen.

China has been battling water shortages in its northern and western provinces for a long time. Burgeoning economic growth and widespread environmental pollution have aggravated the water storage problem. China's State Council warned in a December 2007 drought-fighting directive that after taking water-saving measures into account, China's water use will reach or approach the total volume of exploitable water resources by 2030. Can China cope with its water crisis ahead? The answer to this question clearly has huge implications for China and the rest of the world.

Water Resources of China

When it comes to the distribution of water resources, China is a tale of two halves. The annual precipitation of China as a whole averages around 640 mm (26 in). However, the average annual precipitation generally ranges from 600 mm to more than 2500 mm in southern China, whereas it is mostly less than 600 mm to as low as 25 mm in northern and northwestern China. Using the boundary between the Yangtze River watershed in the south and the Yellow River watershed in the north and northwest as an approximate divider, the exploitable water resource per capita in south China is roughly four times that of north and northwest China. Thus, the greatest threat of water shortage occurs in north and northwest China, whereas the greatest concerns in south China are flooding and pollution.

Although the total amount of exploitable water resources in China is approximately the same as in the United States (Shiklomanov 1998; Gleick 2004), the amount per capita for China of about 2200 m^3 per year is less than one-fourth that for the United States, because China's current population at 1.3 billion is more than four times that of the United States. In addition, the problem of inadequate water supplies in north and northwest China is further exacerbated by severe imbalance in the spatial and temporal distribution of water resources. In the North China Plain (NCP), the amount of water resource per capita is less than 500 m^3 per year (Liu et al. 2008), which reaches the level of "absolute water scarcity" according to the widely used Falkenmark indicator or "water stress index" (Falkenmark et al. 1989). Furthermore, more than 70% of the annual precipitation occurs during the summer monsoon season in the NCP.

Water use for all of China increased steadily from the middle of the 1950s to the 1990s, in response to rapid economic development and population growth following the founding of the People's Republic of China in 1949 (Figure 1). However, the increase has slowed significantly in recent years in spite of continued growth in the gross domestic product (GDP). This reflects increased water use

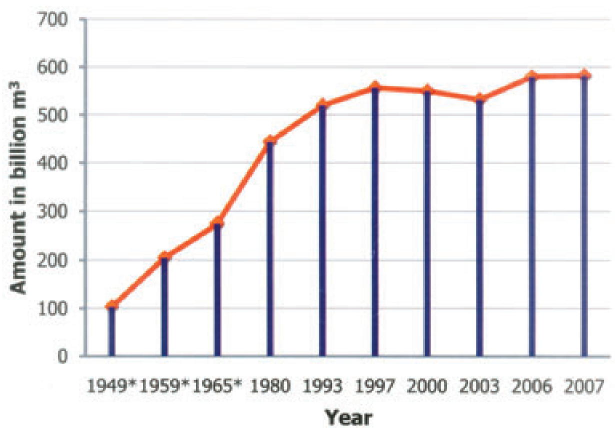

Figure 1. Water use statistics for China over the past 60 years (source: China Ministry of Water Resources; *, estimated).

efficiency (WUE) in Chinese industry and agriculture. Also, China's water use is probably approaching the limit of more readily exploitable water resources. The projection is that China will need 700 to 800 billion m^3 of water supplies by 2030 (Liu and Chen 2001), when the Chinese population is expected to peak at 1.6 billion. Over the next decade and beyond, China faces the daunting challenge of meeting increasing water demands while protecting the environment and ecosystems from further damage (Zheng et al. 2009).

Groundwater Depletion in the NCP

The NCP refers to the region bordered to the north by the Yanshan Mountains, to the west by the Taihang Mountains, to the south by the Yellow River, and to the northeast by the Bohai Gulf (Figure 2). The NCP is the political and cultural center of China and one of its most important economic regions. It is also one of the most densely populated regions in the world. The total area of NCP is about 140,000 km^2 with a population of approximately 130 million. The region accounts for approximately 12% of China's GDP and more than 10% of China's total grain production. In recent years, groundwater has provided more than 70% of the NCP's total water supply to support agricultural irrigation, rapid economic development, and population growth (Liu et al. 2010).

The Quaternary aquifer of the NCP is traditionally divided into two main aquifer units referred to as the "shallow" aquifer and "deep" aquifer. During the 1950s, the shallow water table was 0 to 3 m beneath the land surface in most places. Increasing groundwater withdrawal since the 1960s to 1970s, however, has caused continuing depletion in both shallow and deep aquifers (Figure 2). By the end of the 1990s, water levels in both shallow and deep aquifers were declining at a rate of more than 1 m/year.

Recent field investigations and water level monitoring data have shown the following: (1) the maximum depth to water in the shallow aquifer exceeds 65 m, and the area where the water table is 10 m or deeper beneath the land surface covers more than 40% of the entire plain; and (2) the maximum depth to water in the deep aquifer has reached 110 m, and the area where the hydraulic head is lower than the sea level covers more than 50% of the entire plain.

Groundwater depletion in the NCP has caused severe adverse effects on the environment and ecosystems, including:

- Rivers drying up.
- Land subsidence.

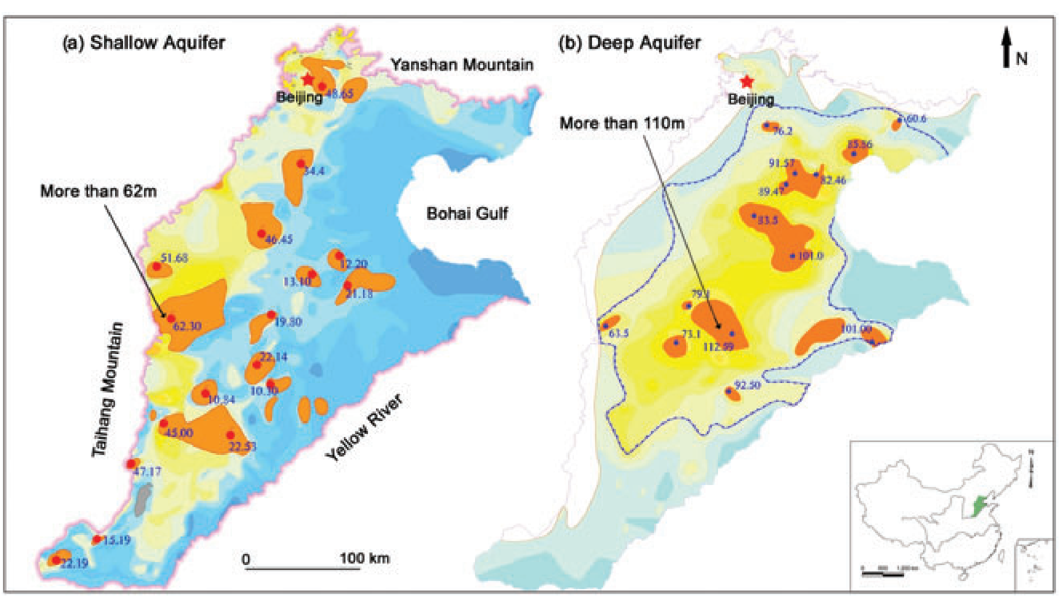

Figure 2. Cones of depression in the shallow (a) and deep (b) parts of the alluvial aquifer in the North China Plain in 2008 (source: Modified from China Geological Survey 2009).

- Sea water intrusion.
- Groundwater quality deterioration.

The annual runoff of the Haihe River, the primary river in the NCP, has decreased threefold since the 1950s, and more than 4000 km of the river channels have dried up. Wetlands have shrunk from 10,000 km^2 in the 1970s to less than 2000 km^2 at present. The maximum cumulative amount of land subsidence exceeds 3 m near the coastal city of Tianjin, while the total area where cumulative land subsidence is greater than 200 mm has reached 60,000 km^2. The direct and indirect economic loss stemming from land subsidence has been estimated by the China Geological Survey to approach 330 billion RMB (RMB is the Chinese currency unit; US$1 is approximately equivalent to 6.8 RMB at the 2009 exchange rate).

It is clear that the groundwater overexploitation in the NCP is unsustainable. Considering the importance of the NCP to Chinese society and economy, the Chinese government has funded numerous field and modeling studies to explore and identify effective approaches to mitigate the serious consequences of groundwater depletion. Some of these studies are reviewed by Zheng et al. (2009) and Liu et al. (2010).

Management Options in the NCP

Several options for dealing with water scarcity and achieving more sustainable groundwater supplies have been implemented or considered. It should be recognized, however, that any comprehensive solution to sustainable water management requires consideration of social, political, economic, and institutional factors.

Water Conservation

The Chinese government has recognized that the fundamental solution to resolving the water scarcity problem in the NCP and elsewhere is to build a water-saving society. Industry in China still uses 3 to 10 times more water for a unit output than the developed countries (Wang et al. 2004). Thus, there is significant potential for water conservation. One obstacle is the high capital investment required to improve WUE in many outdated manufacturing facilities. Agriculture is the largest water user industry in the NCP and other parts of China. Therefore, increasing the efficiency of agricultural water use is a major focus of water conservation efforts. The Chinese government has also used education and public outreach to help raise the public's awareness of water conservation.

Changes to Agricultural Practice

The NCP is the major grain producing region of China, and nearly 70% of the total water resources go to irrigation. The most effective means to reduce agricultural water use is by reducing the irrigated acres of less water-efficient crops and the length of their growing season, which is starting to occur in the NCP. However, with the Chinese government's emphasis on food security, a significant shift in agricultural production is unlikely in the near term. Most water savings may have to come from other measures.

Wheat and maize, the two major water-consuming crops in the NCP, are the major objects of study in improving agricultural WUE. According to Zheng et al. (2003), the ways to improve WUE of wheat include: (1) breeding and planting drought-resistant, water-saving, and high-yield varieties; (2) using water-saving irrigation practices, instead of flood irrigation; and (3) controlling cultivation. Increasing irrigation efficiency by deep percolation will not save water by itself, as this water recharges groundwater (Kendy et al. 2004). The key to water saving is to reduce evapotranspiration through proper close planting, straw mulching, and coupling water and fertilizer application.

Rainwater Harvesting

Rainwater harvesting is a traditional practice common in the mountainous area west of the NCP. River projects can only supply a local area and groundwater is not available everywhere, while rainwater falls on the entire area. Therefore, rainwater utilization is very important for the development of mountainous regions (Zhang and Liu 1999). Rainwater harvesting includes using roofs and courtyards to collect water (mainly for domestic use), natural slope collection (for irrigation of crop and cash plants), bare rock collection (in calcareous sandstone and slate), roads as catchments, harvesting of springs (mainly in granite and gneiss strata), rainwater in weir pits and ponds, micro watershed collection, and micro runoff reforestation.

Desalination

As an alternative water supply source, desalination of sea water and brackish water has gained acceptance in recent years. Various distillation and membrane technologies are available for sea water and brackish water desalination, including multiple-effect distillation (MED), multistage flash distillation (MSF), reverse osmosis (RO), and electrodialysis (ED). Improved desalination technologies and accumulated management experiences provide favorable conditions for the potential application of desalination in China. According to Zhou and Tol (2004), the unit cost of US$1.0/m^3 for sea water desalination using MSF is suggested for potential application in China. In addition, a unit cost of US$0.6/m^3 for brackish and waste water could be an effective economic instrument to conserve water. Currently, the unit cost of desalination ranges from US$0.6 to 1.2/m^3, depending on different technologies and scale. Although it is still quite expensive, desalination can provide a reliable water supply and will be ultimately economically feasible. The coastline in the NCP is nearly 600 km, and sea water desalination and multipurpose utilization will be an important way to relieve fresh water shortage in the coastal cities.

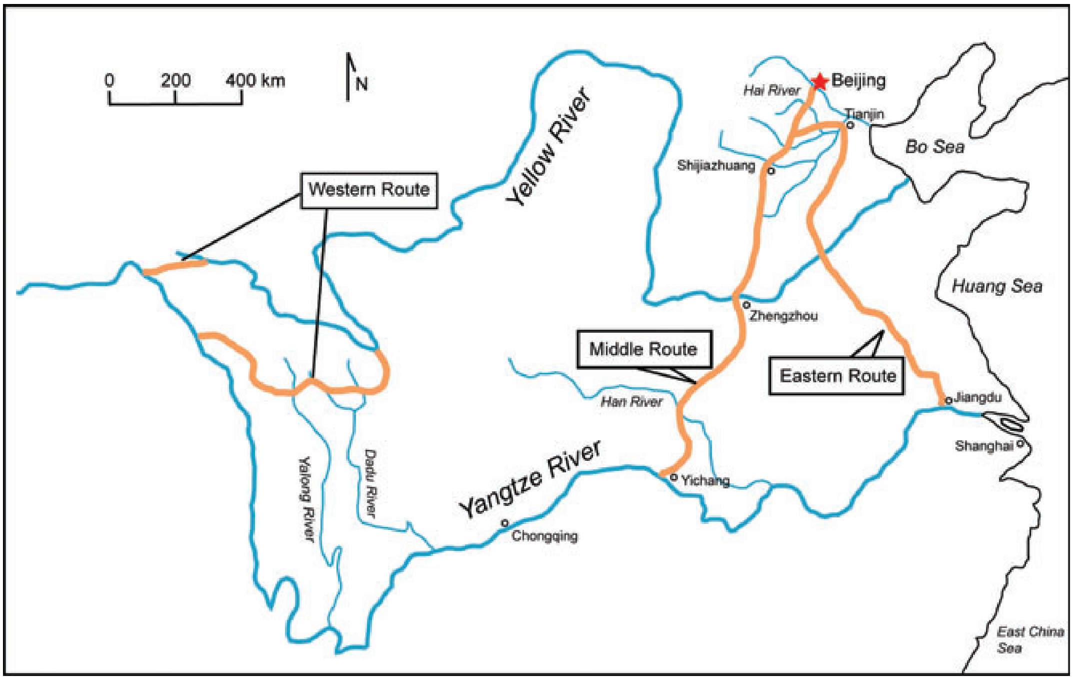

Figure 3. Illustration of the south-north water transfer project (source: modified from Liu and Zheng 2002).

Price Reform

Price reform can reduce water consumption. In major cities in the NCP including Beijing, residents now pay several times less for water compared with those in the United States and other developed countries. The Chinese government has been raising water prices in major cities to conserve water. However, the price reform is restricted to major cities because the Chinese government is reluctant to increase the burden on low-income rural populations. Because the largest water use is for agriculture in rural areas, the overall impact of price reform in just major cities will be quite limited on overall groundwater sustainability.

Water Transfer

While considering other options, the Chinese government is heavily relying on the South-to-North Water Transfer Project (SNWT) to mitigate water stress in the NCP. SNWT is a plan to divert water from the upper, middle, and lower reaches of the Yangtze River to the northern and northwestern parts of China. The SNWT includes three water diversion routes: the western, middle, and eastern routes, among which the middle and eastern routes will impact the NCP region (Figure 3) (Liu and Zheng 2002). By the target year of 2050, the total water volume to be diverted will be 45 billion m^3, including 15 billion m^3 from the eastern route, 10 billion m^3 from the middle route, and 20 billion m^3 from the western route (Liu and Chen 2001). The total cost of the project is expected to exceed US$60 billion.

The eastern route started delivering water in 2010. The total length of the diversion canals is about 1150 km, and 13 pumping stations are required for a total lift of 65 m. The middle route was scheduled to be completed around 2010, but it has been pushed back for 4 years. The western route is still in the planning stage and is intended to relieve water shortage in regions west of the NCP.

The SNWT could provide a critical water supplement to some local areas of the NCP, but it will probably not abate the groundwater declines across the whole region (Kendy et al. 2007). More importantly, with the unprecedented scale and long distance for water transfer across major watersheds, there could be significant adverse consequences on the environment and ecosystems. For example, climate change could lead to reduced flows of the Yangtze River, which in turn would affect the amount and salinity of water available for diversion and may reduce fisheries in the river and its highly productive floodplains as well as the ecological health of the estuary to which it discharges. With such long distances along the diversion canals, polluted inflows and return flows could be major concerns. Energy consumption is a significant issue for the eastern route. Moreover, institutional controls must be in place to ensure water of adequate quantity and quality reach the intended destination.

Conclusions

This article briefly reviews China's water resources and factors that contribute to water scarcity in north and northwest China. The NCP illustrates the challenges facing China as it deals with increased water demands and severe groundwater depletion. Although a number of management options have been implemented or considered to mitigate the adverse environmental consequences of groundwater overexploitation in the NCP, none of these options would be adequate individually. The key to securing sustainable water supplies for the NCP and elsewhere in the world is a comprehensive solution that fully considers scientific, social, economic, political, and institutional factors.

Acknowledgments

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