

*Special Feature on Groundwater Management and Policy*

# The Challenge of Managing Groundwater Sustainably: Case Study of Tianjin, China

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Economic growth has produced great benefits for China, but it has also given rise to mounting environmental problems that threaten the country's sustainable development. Managing groundwater resources effectively is crucial because of the integral role of water in daily life, the economy, and the environment. The situation of water scarcity in China is severe, especially in the northern part, where unchecked exploitation of groundwater has resulted in problems such as dropping water tables, declining infiltration, expanding areas of land subsidence, intrusion of seawater, and salinization of the soil. The amount of water available per capita is only one-quarter the world average and is predicted to drop to severe stress conditions by mid-century. In the late 1990s, there were 3.6 million wells in the northern municipalities of Beijing and Tianjin and the provinces of Henan and Shandong, with most of the water used for crop irrigation. In 1997, however, 99,900 wells were abandoned because they had run dry, and 221,900 new ones were drilled. Deep wells drilled around Beijing now have to go as far down as 1,000 meters to reach fresh water, which is dramatically increasing the cost of water supply. Added to this is the occurrence of widespread land subsidence and concerns about water quality. Among the efforts made to respond to the problem, the Tianjin municipal government was able to increase the industrial water-recycling rate from 40 percent in the 1980s to 74 percent in the 1990s by implementing water conservation measures, and water withdrawals per yuan of industrial production went down by one-third as a result. And in order to protect groundwater resources and control ground subsidence, besides setting quotas, the government set the price of groundwater in 2002 at 1.90 yuan per cubic meter ( $\text{m}^3$ ) and 1.30 yuan per  $\text{m}^3$  in areas with no tap water service, compared to the previous 0.5 yuan per  $\text{m}^3$ . This paper explores some issues of sustainable groundwater management on the basis of a case study of Tianjin. It provides an overview of the severe imbalance between water supply and demand, and then analyzes policies and socioeconomic backgrounds related to groundwater management, such as institutional framework, management policies, population growth and urbanization, as well as the pricing of water.

*Keywords:* Groundwater, Sustainable development, Tianjin, Land subsidence, Water pricing.

## 1. Introduction

Since undertaking economic reforms in 1978, the People's Republic of China has gone through two transitions—one from a command-and-control economy to a market-based economic system, and the other from a rural to an industrial society. These reforms have boosted China's annual economic growth by an average of 10 percent over the past two decades. Although this growth has brought many benefits, it has also given rise to mounting environmental problems that could undermine long-term sustainable development, and the issue of water ranks as the greatest concern.

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It is estimated that there are about 2,800 billion cubic meters ( $\text{Bm}^3$ ) of water resources in China, but the amount actually available is only 2,200 cubic meters ( $\text{m}^3$ ) per capita—one-fourth the world average—mostly because it has the world's largest population at about 1.3 billion. Moreover, it is estimated that this will drop to 1,750  $\text{m}^3$  per capita by the middle of this century, close to the “stress condition” by international standards. China faces the following three serious problems: (1) inadequate, unevenly distributed, and contaminated raw water resources; (2) insufficient supply and treatment infrastructure; (3) and uncoordinated management policies. All of these contribute to water pollution and acute water shortages—one of the most serious environmental and economic challenges that China faces.

This paper is based on a case study funded by the Institute for Global Environmental Strategies (IGES). The general approach of this research was to collect information through a survey of experts and stakeholders, semi-structured interviews with experts, and a comprehensive literature review. Data are presented here on groundwater resource utilization and management in Tianjin, including basic information on closely related socioeconomic and environmental conditions, as well as a review and analysis of related policies.

## 2. Groundwater resources in northern China

Groundwater makes up about one-third of the total estimated water resources in China, making it one of the major sources of water supply, especially in northern China. The volume of groundwater is about 884  $\text{Bm}^3$  per year, of which 353  $\text{Bm}^3$  is exploitable. About three-fifths of this is deposited in the big river basins in northern China (Department of Water Resources 2005).

In the northeast, north, and northwest, the underground water level is dropping because of reduced precipitation and the increased exploitation of underground water by major cities. The drilling of new wells is also contributing to a further drop in levels. In the late 1990s, for example, there were 3.6 million wells in the northern municipalities of Beijing and Tianjin and the provinces of Henan and Shandong,<sup>1</sup> with most of the water pumped out used for crop irrigation. In 1997, however, 99,900 wells were abandoned because they ran dry, and 221,900 new ones were drilled. Evidence suggests that the deep wells drilled around Beijing now have to go as far as 1,000 meters (m) in depth to reach fresh water, which is dramatically increasing the cost of water supply (Water Crisis in China 2003).

The underground water level in the regions of the Yellow, Huai, and Hai rivers has been constantly dropping in recent years, while the area of tunnels created as a result is expanding and the water level in the central aquifers is declining. The tunnels in Hebei Province, the northern part of Henan Province, and the northwestern part of Shandong Province have consolidated to form an area of over 40,000 square kilometers ( $\text{km}^2$ ) under the North China Plain (where Beijing and Tianjin are located). In addition, the groundwater in most northern cities has been polluted by point or non-point sources to some extent, and the quality in some areas is below standards in terms of mineral content, nitrate, nitrite, ammonia, iron, manganese, chloride, sulfate, fluoride, and pH values.

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1. There are four municipalities in the People's Republic of China. As municipalities, Tianjin and Beijing have provincial-level status and come directly under the central government.

### 3. Water resources in Tianjin

#### 3.1. Status of water resources

Tianjin is a semi-arid region in northeast China, located on the downstream portion of the Haihe Basin in the northern apex of the North China Plain. It is bordered by the Mongolian Plateau to the north, the Yanshan Mountains to the northeast, and the Bohai Sea to the southeast. Tianjin covers an area of 11,920 km<sup>2</sup> and is located between north latitude 38°33'57"–40°14'57" and east longitude 116°42'05"–118°03'31", with its boundary bordering on Hebei Province and Beijing, China's capital city. Of the region's total area, the mountainous area measures 727 km<sup>2</sup>, accounting for 6.43 percent, while the plain occupies 94 percent. Tianjin, one of the four municipalities directly under the jurisdiction of China's central government, is the largest coastal city in the north and is also an important trading and industrial center (figure 1).



**Figure 1.** Administrative divisions of Tianjin

Tianjin faces a serious shortage of water supply, with a volume of natural run-off of only about 160 m<sup>3</sup> per capita compared to the national average of 2,200 m<sup>3</sup>, ranking it as one of the most water-scarce regions in the whole country. Accordingly, the government has had to transfer the water from other watersheds, mainly from the Luan River in the adjacent Hebei Province and, in emergencies, from the Yellow River, but even if the water transferred from the Luan River is included, there is still only 380 m<sup>3</sup> per capita available.

For many years now, groundwater and surface water have been the main sources of water in Tianjin, with groundwater accounting for 30 percent of total supply. From 1990 to 2000, average annual consumption of surface water was about 1.6 Bm<sup>3</sup>, while 711 million cubic meters (Mm<sup>3</sup>) of groundwater was drawn from an estimated 832 Mm<sup>3</sup> of available supply. From these figures it might seem as if there is still a surplus of groundwater, but, in fact, serious problems related to over-exploiting groundwater resources have emerged. At the same time as the economy has grown and many lives have been improved, the disparity between water supply and demand has increased significantly. In the southern area, for example, where the amount of deep groundwater that can be sustainably utilized is only 0.18 Bm<sup>3</sup>, the actual volume pumped out is 0.42 Bm<sup>3</sup>—an over-exploitation rate of up to 230 percent.

This has resulted in a number of environmental and geological problems such as dropping groundwater levels, reduced water re-circulation through ground filtration, ground subsidence (sinking land), intrusion of seawater into groundwater supplies, and salinization of the soil. These have occurred along with the pollution of water resources and deterioration of ecosystems, which threatens the sustainability of Tianjin's economic and social development. Managing groundwater sustainably has become an urgent task.

### ***3.2. Data analysis of groundwater use in Tianjin***

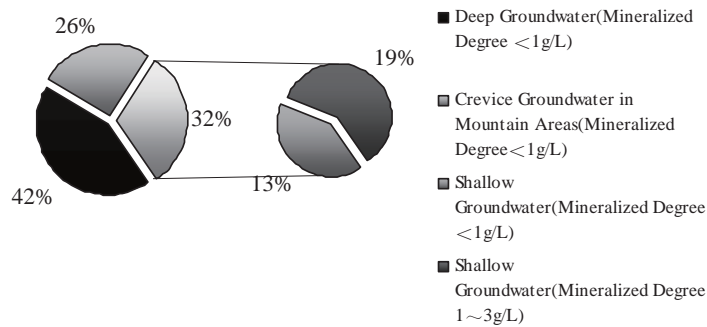
#### **a. Status of groundwater**

One of the two main hydrogeological areas in Tianjin is the mountainous northern portion of Jixian County, which covers 727 km<sup>2</sup>, where water is found in crevices in the bedrock. The other area is under the huge alluvial plain, which is divided by a geological fracture zone, north of which are the 1,598-km<sup>2</sup> freshwater areas, and south of which is the 8,980 km<sup>2</sup>-area of saline water.

The exploitable groundwater includes the crevice groundwater in mountainous areas and deep and shallow groundwater (figure 2), but the largest amount of exploitable groundwater is found deep underground, accounting for 42 percent of the total (figure 3). This is the main source of water used in agricultural, industrial, domestic, and ecological activities (figure 4).

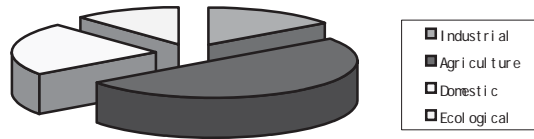


**Figure 2.** Geographical distribution of water resources in Tianjin



**Figure 3.** Percent of different sources of available groundwater, by volume

Note: g/L = gram per liter.

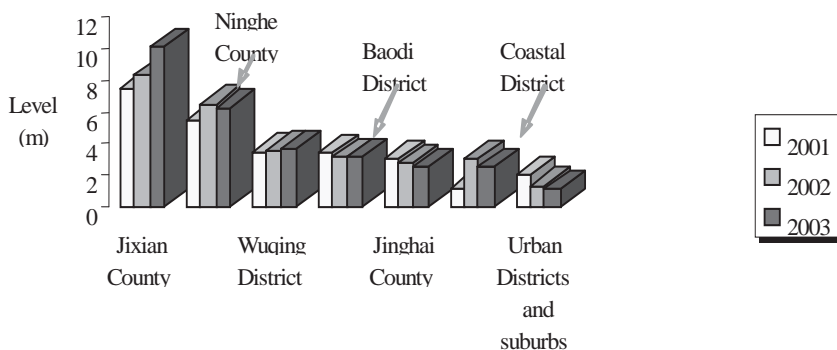


**Figure 4.** Distribution of groundwater consumption in Tianjin by volume, 2002

**b. Dynamic characteristics of groundwater levels**

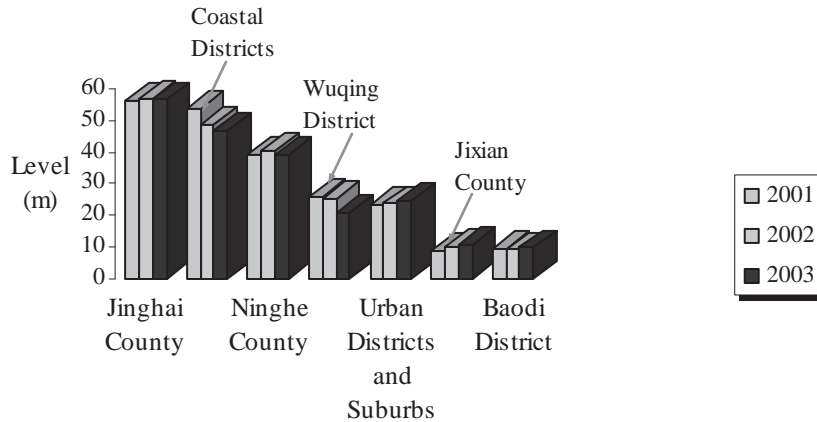
Groundwater levels vary significantly in space-time distribution, since depth conditions and the degree of exploitation are so different over a large area. In all of the freshwater areas, for instance, there is still a balance between exploitation and supply, and the groundwater level has not changed significantly over the years. In contrast, however, the water table in the saltwater regions has continually dropped because of the heavier demand. This over-exploitation has resulted in the creation of several huge tunnels under urban areas in the districts of Tanggu, Hangu, Dagang, Wuqing, and Jinghai County, where the deep freshwater levels are all more than 30 m below ground, and the deepest is down more than 100 m.

The data show that the depth of shallow groundwater in most areas is characterized by fluctuating decreases, as shown in figure 5. In the citywide areas the depth is gradually lower from north to south, while agricultural irrigation in these areas has led to intense exploitation of groundwater, exacerbated by low rainfall and uneven distribution.



**Figure 5.** Variation of shallow groundwater levels in Tianjin, 2001–2003

Artesian Aquifer II in the plains is the main deep aquifer used as a water source for agriculture and industrial production, especially in Jinghai County, Ninghe County, Wuqing District, and Baodi District. Figure 6 shows that the trend in water level in the aquifer is in descent. The water level fell relatively slowly, 5 m over eight years (1991–1998), but then it dropped sharply to more than 20 m in only five years (1999–2003). The main cause was a lack of precipitation on the plain since 1998 in northern China, meaning less recharge water going back into the aquifer than the amount pumped out. This serious imbalance between supply and demand is now at the point where groundwater is severely over-exploited.

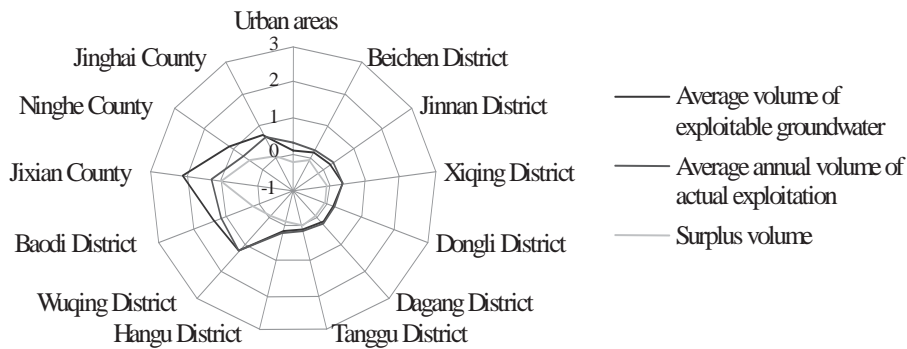


**Figure 6.** Changes in depth of Artesian Aquifer II, 2001–2003

### c. Ground subsidence

Groundwater resources are not evenly distributed in Tianjin. The entire freshwater supply lies in the northern area where water resources are abundant, but there is little industry and the population density is very low. The saline water areas in the central-south and southeast, on the other hand, have high densities, which has resulted in a shortage of groundwater resources.

Increasing demand for domestic, industrial uses, and partly for agricultural production, has resulted in a continuous drop in water levels. Looking at the average annual use of groundwater in each district or county from 1991 to 2002, it is obvious that, except for Jixian, Ninghe, Jinghai, and Baodi (where there were small surpluses), the groundwater in the rest of the districts is already over-exploited (figure 7).



**Figure 7.** Average volume of groundwater used from 1991 to 2002 (in 100 Mm<sup>3</sup>)

This severe over-exploitation of groundwater has led to the problem of surface subsidence, especially in the southern part of Tianjin, where the deep-level groundwater (which is difficult to access and recharge) continues to be over-exploited for residential, industrial, and agricultural purposes because of the lack of surface water. Furthermore, as shown by the statistical data from 1971 to 1997, the total over-exploited volume of deep groundwater in the northern areas is up to 5.6 Bm<sup>3</sup>; the average annual volume over-exploited was 250 Mm<sup>3</sup> from 1995 to 1998. This has led to 50-m descent of the groundwater level in the most serious cases (figure 8), causing the total area of ground subsidence to grow to 7,300 km<sup>2</sup>, in which several centers of subsidence have formed in urban areas, including the districts of Tanggu, Hangu, and Dagang, and industrial areas downstream on the Hai River. The average trend of these centers is shown in figure 9.

In addition to the pressures on groundwater supplies outlined above, 180 geothermal wells have been drilled since 1995 (105 are in urban areas), pumping out a volume of 24 Mm<sup>3</sup> per year. Since the underground geothermal water is relatively deep and the amount of recharge is tiny, wells should be treated individually, which means an equal volume of cooled water should be returned to the original water-bearing layer after exploiting the geothermal energy. In fact, the current amount of recharge is less than the 12 percent of the volume pumped out. Most companies that use geothermal water do not re-circulate the water they use, resulting in it simply being discharged as run-off. As a result, the groundwater level is sinking by 3–6 m per year. If the situation continues, the geothermal water supply will run dry.

Having realized the importance of protecting underground water supplies, Tianjin's municipal government unveiled a long-range plan for subsidence control in 1990. Although it is being implemented in six stages, there is still a slight subsidence occurring in each subsidence center. As far as urban areas are concerned, with an average constant subsidence of 20 millimeters (mm) per year, the outlook is not optimistic.

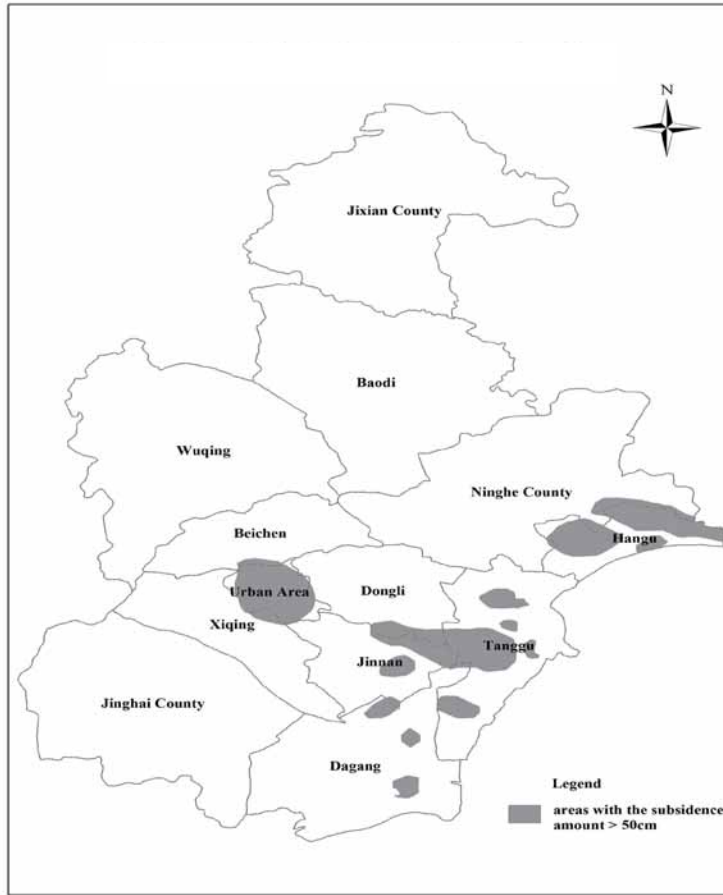


Figure 8. Centers of land subsidence in Tianjin greater than 50 centimeters per year

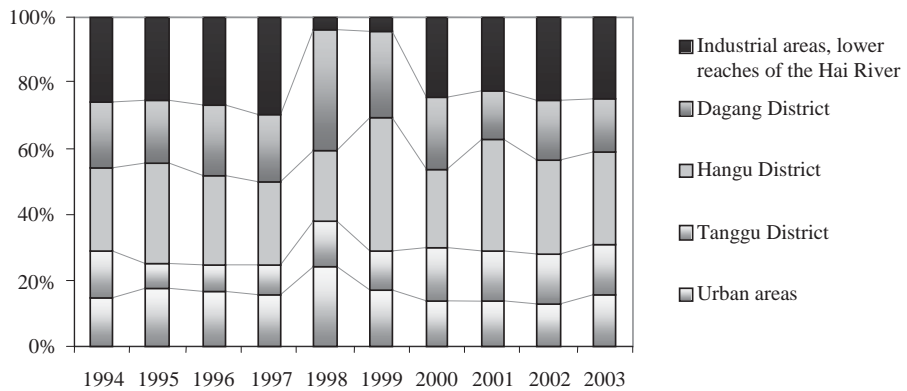
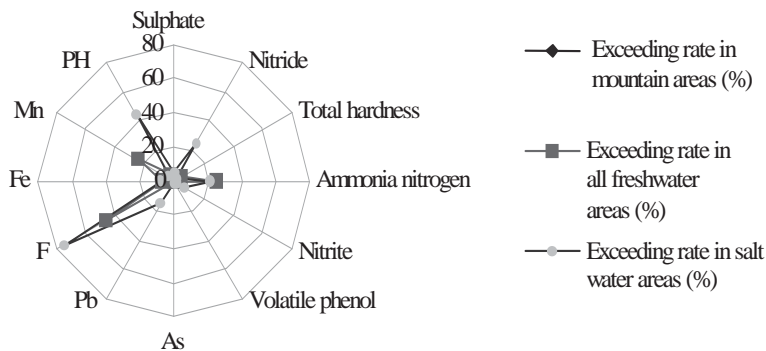


Figure 9. Percent of average annual variations in centers of land subsidence

**d. Quality of groundwater in Tianjin**

The following twelve parameters were selected to assess groundwater quality in the main layers of exploitation: pH, ammonia nitrogen, nitrite, volatile phenol, arsenic, total hardness, lead, fluorine, iron, manganese, sulfate, and nitride. Figure 10 indicates the rate at which these parameters were exceeded compared to standards under the Quality Standard of Groundwater (GB/T14848-93) (Tianjin Environmental Protection Bureau 2002)

The figure indicates that the quality of groundwater in the mountain areas was the best and that none of the standards was exceeded. The hydrochemistry structure was calcium•magnesium bicarbonate ( $\text{HCO}_3\text{-Ca}\cdot\text{Mg}$ ), and every parameter met with the standard for drinking water. The quality of groundwater in freshwater areas was also good. The hydrochemistry structure was primarily bicarbonate ( $\text{HCO}_3$ ), although some standard parameters were exceeded upstream of Wuqing County, where there were concentrations of fluorine, ammonia-nitrogen, iron, manganese, and total hardness because of irrigation with wastewater and the subsequent infiltration of some organic substances. In the saline water areas, on the other hand, the main hydrochemistry structure was sodium bicarbonate ( $\text{HCO}_3\text{-Na}$ ), chlorine-sodium bicarbonate ( $\text{HCO}_3\text{-Cl-Na}$ ), and chlorine bicarbonate-sodium ( $\text{Cl-HCO}_3\text{-Na}$ ). Several standard parameters, such as chloride, sulfate, total hardness, and total soluble solids, were exceeded in varying degrees at rates of 26.32 percent, 5.26 percent, 1.05 percent, and 26.32 percent, respectively. The most serious pollutants in this area were fluorine and high pH.



**Figure 10.** Parameters exceeding the water quality standard in 2002

### ***3.3. Potential socioeconomic impacts on sustainable groundwater management—Discussion of the case in Tianjin***

#### **a. Institutional framework and policies**

##### ***Institutional framework***

The Chinese metaphor “nine dragons, one river” describes the current state of water resources management in China—the nine dragons representing the ministries responsible for water resources, but there is poor coordination among the “nine dragons” (Hou 2001).

The current institutional framework for the management of water resources in China consists of the following three main levels: national, river basin, and regional. In some cases, they are interconnected. The Ministry of Water Resources (MWR) is the main department under the State Council in charge of integrated management. This department, however, has not been given all of the related responsibilities. Several other ministries have joined the national effort for water resources management and share some of them. These include the Ministry of Construction (MC), the National Environment Protection Agency (NEPA), the Ministry of Land and Resources (MLR), and the State Development Planning Commission (SDPC).

The principal responsibilities of the MWR are as follows: providing integrated management of water resources, including precipitation, surface water, and groundwater; developing national and/or inter-provincial water plans; managing water-use permits and collecting fees; leading water conservation efforts at the national level by directing industry and managing demand; and directing national soil and water conservation efforts. The MWR is also in charge of national flood control and drought relief programs.

The principal responsibilities of the MC include coordinating management programs for urban water supply and demand at the national level and directing municipal utilities and water treatment efforts. In addition, it oversees the development, utilization, and protection of groundwater in urban planning.

The MLR was formed as a result of the integration of the former Ministry of Geology and Minerals, the National Land Administration Bureau, the National Navigation Bureau, and the National Mapping Bureau. It was given some of the responsibilities of the former ministries such as surveying groundwater; identifying over-exploited areas and areas suitable for development; planning, managing, protecting, and making reasonable use of ocean resources; as well as establishing a series of laws and statutes for management of ocean resources.

The responsibilities of NEPA were prescribed in Chapter 1, Article 4, of the Law of the People’s Republic of China on Prevention and Control of Water Pollution (1996), which states that the “environmental protection departments of the people’s governments at various levels shall be the organs exercising integrated supervision and management of prevention and control of water pollution. Navigation administration offices of the communications departments at various levels shall be the organs exercising supervision and management of pollution caused by ships. Water conservation administration departments, public health administration departments, geological and mining departments, municipal administration departments, and water sources protection agencies for major

rivers of the people's governments at various levels shall, through performing their respective functions and in conjunction with environmental protection departments, exercise supervision over and management of prevention and control of water pollution."

The SDPC is a department under the State Council responsible for coordinating water supply and demand involving major industries. Its responsibilities related to water management focus on the development of rural areas, including the formulation of economic development strategies. The SDPC is also supposed to try to balance the needs of agriculture, forestry, and water conservation; establish development policies and programming for weather, aquatic, and farming products; and implement national ecological environment restoration plans. The institutional framework and divisions of responsibility at the national level show they are mainly involved with comprehensive guidance and supervision in national issues such as water planning, water and soil conservation, flood control and drought relief.

The whole system of water resources management is in a fragmented state, however, with too many different departments involved, making it very difficult to achieve an integrated system. Water supply, drainage, and pollution control are disjointed, and the water supply industry is closed to market forces, thus making it difficult to distribute water resources efficiently. The Tianjin Environmental Protection Bureau (Tianjin EPB), the Tianjin Water Resource Bureau (Tianjin WRB), the Tianjin Construction Committee (TCC), the Tianjin Bureau of Planning and Land Resources (Tianjin BPLR), and the Tianjin Municipal Bureau (TMB) are all supposed to manage groundwater resources. Before 2000, for example, surface water and rural groundwater resources were managed by Tianjin WRB, urban groundwater was managed by the TMB, while managing hydrothermal resources above 40° Celsius were the responsibility of the mineral resources sector managed by the Tianjin BPRL. Since it is practically impossible to divide up water resources into a groundwater sector and a surface water sector with any real chance of effectiveness, the result of this dispersion of authority is a lack of integration or coordination of groundwater and surface water use.

Although the Tianjin WCB took over most affairs related to water resources after 2000 when Tianjin re-organized its governmental structures, the administrative functions dealing with mineral springs and geothermal water were still with the Tianjin BPLR, with the result that the Tianjin WCB has still not integrated the management of mineral spring water and geothermal water resources into its operations.

### ***Management policies***

Provisions for management of groundwater can be found in various water resource laws and regulations both at the national and local level (table 1).

The Tianjin municipal government has enacted or implemented some regulations for groundwater management on the basis of national law. In 1987 it issued a regulation, Temporary Measures of Groundwater Management in Tianjin, in an effort to ensure that groundwater resources are used more rationally and to prevent further land subsidence. In 2004, it was updated with another regulation, Administrative Measures of the Groundwater Resources in Tianjin. In 1995, the Specification of Geothermal Resources in Tianjin, which regulates geothermal water resources, was placed under the administration of the Geology and Mineral Resources Bureau, a decision, which spoiled the former,

relatively rational management of the Water Conservancy Bureau in its supervision of geothermal water resources.

**Table 1.** National and local laws and regulations related to groundwater

National laws	National administrative regulations	Local laws	Local administrative regulations
Water Pollution Control Law of PRC (1984)	Groundwater Management Regulations (1985)	Implementation of the Water Law of PRC in Tianjin (1994)	Temporary Measures of Groundwater Management in Tianjin (1987)
Soil and Water Conservation Law of PRC (1991)	Implementation Measures of Water Use License System (1993)	Water Saving Regulations of Tianjin (2002)	Specification of Geothermal Resources in Tianjin (1995)
Water Law of PRC (2002)	—	—	Management Standard of Water Use Quota in Tianjin (2003)
			Administrative Measures of Groundwater Resources in Tianjin (2004)

*Note:* PRC = People's Republic of China.

In 2003, the Management Standard of Water Use Quota in Tianjin was approved, which stipulated quotas for domestic, industrial, and agricultural water consumption. The Domestic Water Consumption Quota covers 15 aspects of domestic water use and involves 34 different quotas for water consumption. For example, the domestic water consumption quota is 70–120 liters per capita per day. The Industrial Products' Water Consumption Quota covered quotas on the water consumption of manufacturing 307 kinds of industrial products, and the Agricultural Consumption Quota set the water consumption quota for rural residents at 50–130 liters per capita per day. All of these regulations or policies have had a positive impact upon more sustainable management of groundwater in Tianjin.

## **b. Population growth and urban development**

### ***Conflicts between supply and demand***

Whether or not water supplies can meet growing industrial, commercial, residential, and agricultural demands, exacerbated by population growth and urban development, is a critical issue in most cities. A practical solution would be to integrate demand management with water supply management in order to clarify whether conservation measures are adequate (more efficient use) and whether other measures—such as water transfers to uses with higher economic returns or other benefits, i.e., water pricing, recycling, and reuse—could help achieve more economical solutions to water shortages. Unfortunately, most cities in China lack the capacity to implement such integrated measures, so conflicts often develop between the many and varied users, the administration, and the actual supply of water.

For example, the Tianjin Water Tap Company (under the Urban Construction Committee) is a state-owned enterprise responsible for ensuring that a sufficient supply of good quality tap water is distributed

to end users in urban areas. At the same time, the WRB is in charge of administering water supplies in rural areas, where agriculture depends heavily on a consistent water supply to achieve high productivity levels. There are, however, many individually constructed dug wells in rural areas that cannot be effectively supervised or controlled. Moreover, in the borderlands between urban and rural areas, water management issues are even more complicated and confusing. As a result, water is often wasted in outlying rural areas while in extremely short supply at the same time in adjacent urban areas in desperate need of additional water supplies. From a business point of view, individual enterprises aim to sell as much of their product as possible. For the Water Tap Company, for example, its product is water, and it would like to encourage customers to use more of it. During periods of water shortage, however, all users must limit the amount they use. These situations would be more easily managed if a fee were levied on water use above designated limits. This would be difficult to enforce, however, if the same limit is not also enforced in adjacent areas, given the lack of a strong integrated management scheme. One way to address these problems of wasting water resources in the future would be to strengthen the effectiveness of water demand management.

### ***Rapid urbanization***

In order to provide jobs for a growing and underemployed rural labor force and to narrow the income disparity between urban and rural residents, China's central government recently began advocating rapid urbanization and industrialization of rural areas in northern China (Fu 2001). The resulting growth in urban land area is creating new problems for water supplies because a city's surface tends to be impermeable to rainwater. Instead of seeping into the ground and recharging the aquifer immediately below the city, precipitation simply runs off through the sewer system. Combined with over-pumping the groundwater beneath a city and the reduced recharge and excess discharge, this causes the water table beneath the city to deform into a funnel shape, called a cone of depression, which in many cases extends laterally far beyond the city limits (Liu et al. 2001).

Most municipal water used for drinking, sanitation, bathing, and cooking is eventually discharged into sewage systems rather than evaporating as it would naturally. Improving the efficiency of urban water use would reduce the need to pump out groundwater without decreasing local recharge, and thus could reduce the size of the cone of depression. By treating and reusing urban wastewater, urban water depletion could be greatly reduced. Careful consideration of the water demands of urban landscapes (low water-consuming native vegetation versus trees and lawns) could further reduce delivery requirements. The scope for improving the efficiency of industrial water use is especially worthy of consideration.

On the positive side, Tianjin has increased its industrial water-recycling rate from 40 percent in the 1980s to 74 percent in the 1990s by implementing industrial water conservation measures. As a result, from 1984 to 1994, water withdrawals per yuan of industrial production went down by one-third (Bai and Imura 2001). This success can be traced to how Tianjin was able to get the sector to consume less water by encouraging water-efficient industries such as metallurgical, automotive, and electronics producers, and discouraging water-inefficient industries such as textile manufacturers.<sup>2</sup> As a result, the

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2. Textile manufacturing is a high water-consuming sector compared to the automotive or electronics sectors.

ratio of water use to industrial production has decreased steadily in the city since the mid-1980s (Bai and Imura 2001).

Increasing the efficiency of urban water use or treating water would also improve water quality, change groundwater flow paths, and reduce the depth of the cones of depression. The relative merits of urban versus agricultural land use, in terms of the falling regional water table, depend on the quantity of water each sector withdraws from the hydrological system. It is commonly accepted, however, that urban land use utilizes much less water than crop evapotranspiration. Replacing agricultural landscapes with urban landscapes could stem the decline of regional groundwater, but may then create other significant sociopolitical challenges.

### **c. Water pricing**

In Tianjin, the price of tap water has been rising annually. The price for commercial purposes has risen to 3–6 yuan per m<sup>3</sup>; but up until 2002 the price of groundwater was only 0.5 yuan per m<sup>3</sup>—scant compensation, considering the scarcity of water resources. This, among other factors, has contributed to the devastating over-exploitation of groundwater. The price charged for groundwater should reflect the reality that the supply is not infinite but, in fact, is very scarce. In order to protect groundwater resources and control ground subsidence, the Tianjin municipal government adjusted its standard pricing system after 2002, and the price was set at 1.90 yuan per m<sup>3</sup> and 1.30 yuan per m<sup>3</sup> in areas with no tap water service. There is no information available yet to show if the new pricing has affected market mechanisms to allocate groundwater resource wisely according to the present socioeconomic conditions in Tianjin. Further research is needed to validate its effectiveness in moving towards sustainable groundwater management.

#### ***Is raising the price of groundwater a good idea?***

The initial customer response to a commodity price increase is usually to reduce consumption of that commodity. To encourage water conservation, many people advocate raising the price of water to better reflect its actual cost (Anderson and Leal 2001; Lampton 1983; Zhang and Zhang 1995). It is not clear, however, that such a policy change would necessarily slow the trend of declining groundwater levels. In the case of irrigation water, farmers are likely to invoke practices that reduce the amount of water they pump, but some studies suggest that seepage reductions concomitant with pumping reductions do not necessarily result in a net change in the rate of groundwater depletion. Water price increases would therefore only impose undue financial burdens on already cash-strapped farmers without solving the problem. Logistical difficulties with pricing water volumetrically and monitoring deliveries make a pricing policy for irrigation water difficult to implement. Industrial water users are more logical targets for price increases than irrigators because of the advantages of making industrial water use more efficient, as discussed above. Moreover, with much larger profit margins than farmers, industry is more able to pay, thereby improving the chance that such a program would be successful.

## 4. Conclusions and future research

Effectively managing water resources is a crucial factor in achieving sustainable development in China because of the importance of water and the seriousness of water scarcity. This paper introduced the dilemmas and initiatives of Tianjin, which demonstrate on-going efforts to improve the social and economic growth of the area while endeavoring to minimize the environmental problems related to groundwater depletion. As sustainability is a function of balancing various economic, environmental, ecological, social, and physical goals and objectives, solutions must inevitably involve multi-objective tradeoffs in a multi-disciplinary and multi-participatory decision-making process. The next step that needs to be taken is to examine various alternative decision-making models to move towards more sustainable groundwater management in conjunction with social and economic forces, which will hopefully be carried out in the near future with a focus on water rights and water price issues.

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