CHAPTER 3-4

Challenges and Prospects of Sustainable Water Management in Tianjin

Introduction

Tianjin, one of the biggest cities in the northern China, is badly short of water resources due to its natural geographic and climatic condition. In Tianjin, water availability per capita is 160 m^3, which is only 1/15 of the national average, and 1/60 of the world average. Due to its severe shortage and over-exploitation of groundwater, Tianjin is now facing many problems such as land subsidence and pollution of irrigation wastewater, which will restrict the sustainable development of the social economy. As a new, useful, potential and unconventional water resource, reclaimed water shall be broadly used to improve the unsatisfactory situation of water utilization in Tianjin.

In this paper, based on an analysis of the status quo of water resource use and water management policies in Tianjin, not only are the unreasonable groundwater exploitation and incomplete water management system discussed, but the authors also give a detailed analysis of water management policies in past years, and put forward relative suggestions and recommendations for the sustainable management of water in Tianjin. In the near term, speeding the pace of the popularization of reclaimed water and improving the efficiency of the scientific use of all water resources will be the most important study subjects.

1. Background of Tianjin

Tianjin, one of the four municipalities directly under the central government, is the largest port city in northern China and the center of the economic area around Bohai Bay. Tianjin covers an area of 11919.7 km^2, 6.43% of which is mountainous, mainly in the north. It is located at latitude 38° 33' 57" N - 40° 14' 57" N and 116° 42 '05" E - 118° 03' 31" E, and is only 137 km away from Beijing, capital of China (figure 1). The economy of Tianjin remains with a good momentum of steady and rapid development, with a gross domestic product (GDP) of 293.188 billion CNY and per capita GDP of 28,633 CNY in 2004.

In this region, Tianjin has jurisdiction over 18 county-level divisions, which include three counties (Ninghe, Jixian and Jinghai), six urban districts (namely, Heping, Hedong, Hexi, Nankai, Hebei, Hongqiao), three coastal districts (Tanggu, Hangu, Dagang), four suburban districts (Dongli, Xiqing, Jinnan, Beichen), as well as Wuqing district and Baodi district. The total permanent population of Tianjin in 2004 was 10.2367 million, and the total registered population was 9.3255 million. Figure 2 shows the administrative divisions and population density in Tianjin.

Figure 1. Geographic Location of Tianjin City

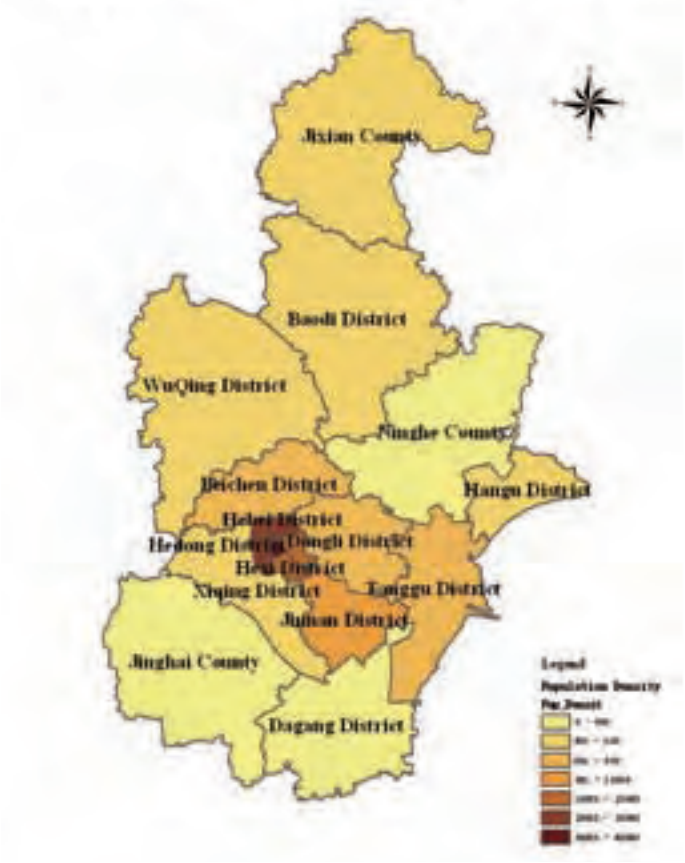

Figure 2. Administrative Divisions and Population Density of Tianjin

Tianjin has a sub-humid continental monsoon climate. The main feature of the climate is that the four seasons are clear cut, which results in a great difference in temperature and a wide variety of sceneries throughout the year. The average temperature during the year is 11.1ºC~12.5ºC, with an average highest temperature over 29ºC in July and an average lowest temperature of -6ºC. And, on average, the annual precipitation is about 550~680 mm, 75% of which is concentrated in June, July and August.

2. State of Water Resources in Tianjin

2.1 Surface Water

Surface water in Tianjin is composed of the following four parts: natural runoff, water resources entering Tianjin city, water leaving the city and entering the sea, and water transferred from other watersheds.

(1) Natural Runoff

The volume of natural runoff closely depends on the amount of precipitation within the area. The average amount of precipitation in Tianjin decreases from north to south, and is greater in the mountain areas than in the plains, ranging between 720–586 mm.

(2) Water Resources Entering the City

These water resources come from discharged water which was not used and held back by the upstream; mainly water from the reservoirs of the plain and mountain areas. The water volume depends on the precipitation, and industrial and agricultural water utilization of the upstream areas.

(3) Water Leaving the City and Entering the Sea

The water leaving Tianjin mainly enters the sea, excepting that of the Ju River coming from mountain areas, which flows to the Haizi Reservoir of Beijing. Since Tianjin is located in the lower reaches of many rivers and the number of water storage projects in Tianjin are few, the water volume entering the sea is influenced directly by the water amount from upstream areas.

(4) Water Transferring from Other Watersheds

a. Water Transferred from Luan River

Transferring water from the Luan River to Tianjin is a large water-transferring project which crosses regions. The project was completed in September 1983 and aims to lessen the pressure of water demand from the city, industry and the harbor. In the past 23 years, this project has provided more than 190 billion m^3 of water and exerted great economic benefits.

b. Water Transferred from Yellow River

Since the drought in Luan River, Yuqiao Reservoir has seriously lacked water; water transferred from Luan River could not satisfy the need of water in Tianjin, which makes it necessary to transfer water from the Yellow River. In the past years, this project effectively relieved the water crisis facing Tianjin, ensured the safety of water for use in domestic life, giving social stability, and thus accelerated the sustainable development of the economy.

Because of the geographic conditions and the uneven distribution of water resources in the different seasons and different areas of Tianjin, as well as the reservoirs constructed in the upstream area, the water amount entering Tianjin has changed a lot in the past years. Especially in the southern area of Tianjin, the water volume entering is almost zero, except in some flooding periods. In addition, the frequent occurrence of drought in Tianjin—including the periods of 1957–1958, 1960–1963, 1965–1968, 1971–1972, 1974–1976, 1980–1989, 1992–1993, and 1997–2000—is also an important factor leading to severe water shortage. However, this situation has been changed and improved in some degree by the completion of the water transfer project from Luan River to Tianjin since 1983.

2.2 Groundwater

The groundwater of Tianjin has been formed in the control of comprehensive factors such as substratum construction, the rock character of the strata, hydrology, meteorology and the erosion of transgression and regression. On the basis of the types of groundwater, there are two large hydrogeological divisions: the mountain areas with crevice water in the bedrock, and the alluvial plain area. The mountain areas can be divided in to two parts by their physiognomy, aquiferous characters, and groundwater type: that is, mountainous area ($II_{1\text{-}i}$) and intermountain basin area ($II_{4\text{-}i}$).

The alluvial plain areas can be divided into the following four parts by the mineral degree and geohydrologic condition: fully fresh groundwater area in flood-alluvial basin ($I^1_{1\text{-}i}$); fresh groundwater area in alluvial plain ($I^2_{1\text{-}i}$); brackish groundwater area in alluvial-marine plain ($I_{2\text{-}i}$); and salt groundwater area in marine plain ($I_{3\text{-}i}$). The divisions of groundwater with different mineral degree can be seen in figure 3.

The geological condition in mountain areas is relatively simple as compared with alluvial plain areas. Groundwater in mountain areas is mainly crevice water, with good natural replenishment, so this area still has exploitable potential, a dynamic balance in past years, and is mainly used for agriculture and daily life. In intermountain basin area ($II_{4\text{-}i}$), the groundwater can be still exploited to some degree for its good natural runoff conditions.

However, the geological conditions in alluvial plains are more complicated, especially in salty water areas. The artesian aquifer water in this region can be divided into five categories, from top to bottom, namely artesian aquifer I (with a depth of aquifers of 20–30 m), salty artesian aquifer S (40–220 m below the ground level from north to the southeast, only in salty water areas), artesian aquifer II (180–228 m from north to south of Tianjin), artesian aquifer III (290–315 m), and artesian aquifer IV (370–429 m). Because of the central industries and a shortage of surface water supply, the groundwater in fresh groundwater areas in the alluvial plain ($I^2_{1\text{-}i}$) has already been overexploited. While the brackish groundwater area in the alluvial-marine plain ($I_{2\text{-}i}$), the salt groundwater area in marine plain ($I_{3\text{-}i}$), and the brackish or salt water in the shallow aquifer have been exploited on a rather small scale for their high mineral degree and salt concentration, the fresh groundwater in deep artesian aquifer (in artesian aquifer II and III) has been overexploited as seriously as that of the alluvial plain to meet the needs of social economic development, thus inducing geological problems.

In Tianjin, groundwater abstraction started at the beginning of the twentieth century, with the first motor well dug in Tanggu in 1907. More and more groundwater was exploited accompanying the development of industry and agriculture, as well as city expansion. In 1967, the exploited volume reached 70 million m^3, with 60% focused on the artesian aquifer II. During that period, the geological environmental problems came into appearance with the overexploitation of artesian aquifer II. Groundwater exploitation climbed and peaked in the years 1965, 1968, 1972, 1989 and 1999 because of bad drought. Surface water decreased, thus groundwater was overexploited. Since the water transferred from Luan River came into urban areas and Tanggu District in 1983, the government took steps toward exploitation control with the plan of subsidence control that was put into practice. In the same year the government took some measures, and some water saving projects boomed, which has resulted in a decreasing trend in groundwater abstraction since then. But groundwater exploitation is often affected by precipitation, so the exploited volume may have increased in some years, but the average abstracted volume was under control.

Figure 3. Groundwater Resource Divisions in Tianjin
Source: Plan of Groundwater Source Exploitation in Tianjin, 1997/1998

2.3 Water Supply and Utilization in Tianjin

For many years, groundwater and surface water have been the main sources of water, with groundwater accounting for about 30% of the total water supply (figure 4). Two other unconventional water resources, reclaimed water and desalted water, also play an important role in Tianjin's water supply. The total volume of water used was 2.206 billion m^3. The largest water consumption in Tianjin is for agriculture, accounting for 55.2% of the total; second is industrial production, while the rest of the water is mainly used for daily life and landscape, as shown in figure 5.

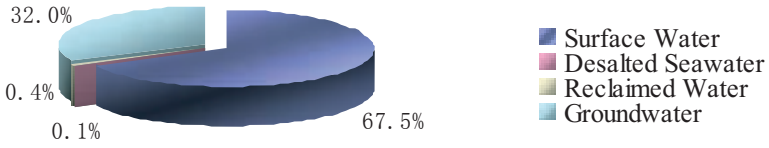

Figure 4. Proportion of Water Supply by Water Resources in 2004
Source: Report on Environmental Quality of Tianjin, 2001-2005

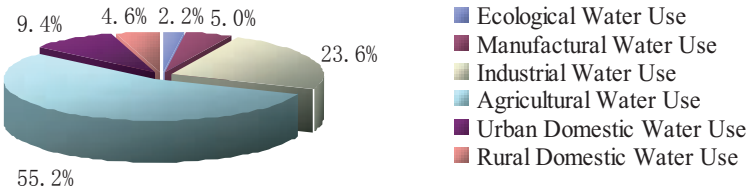

Figure 5. Proportions of All Kinds of Water Use in 2004
Source: Report on Environmental Quality of Tianjin, 2001-2005

3. Issues and Discussion on Groundwater in Tianjin

3.1 Dynamic Characteristics of Groundwater Level

Groundwater level varies significantly in the different areas of Tianjin, each with their own degree of water exploitation. In all of the freshwater areas, for instance, there is still a balance between exploitation and yield, and the groundwater level has not much changed over the years. In contrast, the water table in the saltwater regions has continually dropped because of the severe shortage of surface water resources and its heavier demand on groundwater. This overexploitation 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 fresh groundwater level is more than 30 m below the ground, and the deepest is down more than 100 m. Figures 6 and 7 show the changes of groundwater level in Tianjin.

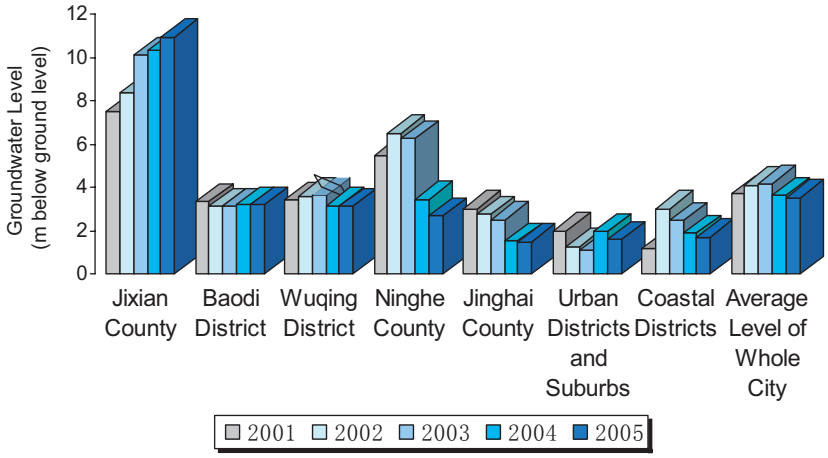

Figure 6. Change of Shallow Groundwater Level in Tianjin
Source: Report on Environmental Quality of Tianjin (2001-2005)

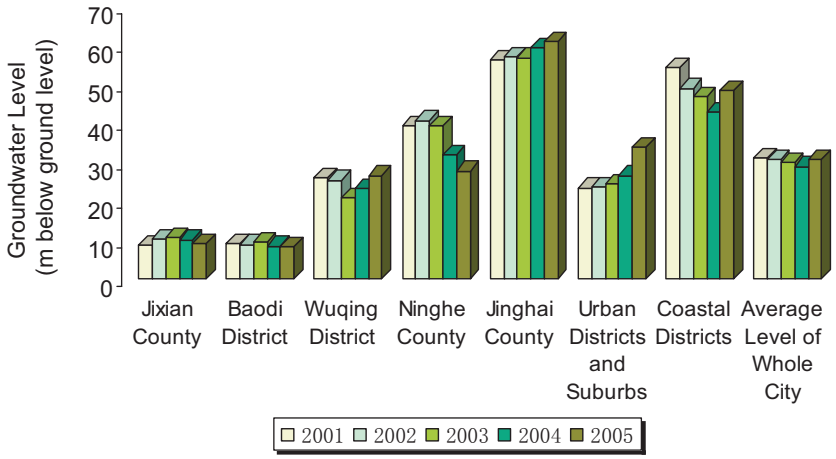

Figure 7. Change of Groundwater Level in Artesian Aquifer II in Tianjin
Source: Report on Environmental Quality of Tianjin (2001-2005)

3.2 Groundwater Level and Land Subsidence

Groundwater resources are not evenly distributed in Tianjin. All fresh groundwater lies in the northern areas and is abundant, but there is little industry and the population density is very low. The saline water areas in the middle-south and southeast, on the other hand, have high population densities and centralized industrial production, which has resulted in a shortage of water resources.

The increase in the water demands of the residential, industrial and part of the agricultural production sector has resulted in a continuous drop in groundwater levels. Looking at the average annual use of groundwater in each district or county from 1991 to 2002, groundwater exploitation already exceeded available groundwater volume in all districts/counties except for Jixian, Ninghe, Jinghai, and Baodi (figure 8).

It has been proven through practice that groundwater exploitation in the long term is the main factor leading to land subsidence. The significant use of groundwater has led to the problem of surface subsidence, especially in the southern part of Tianjin, where the deeper aquifer (which is hard to access and recharge) continues to be overexploited for residential, industrial and agricultural purposes because of the lack of surface water. Furthermore, statistical data shows that a total affected area of about 7,300 km^2 has suffered from the problem of land subsidence, to differing degrees. Especially in urban areas, the districts of Tanggu, Hangu, Dagang, and industrial areas downstream of the Haihe River, some centers of land subsidence have formed already (figure 9). Some statistical data shows that the biggest cumulative

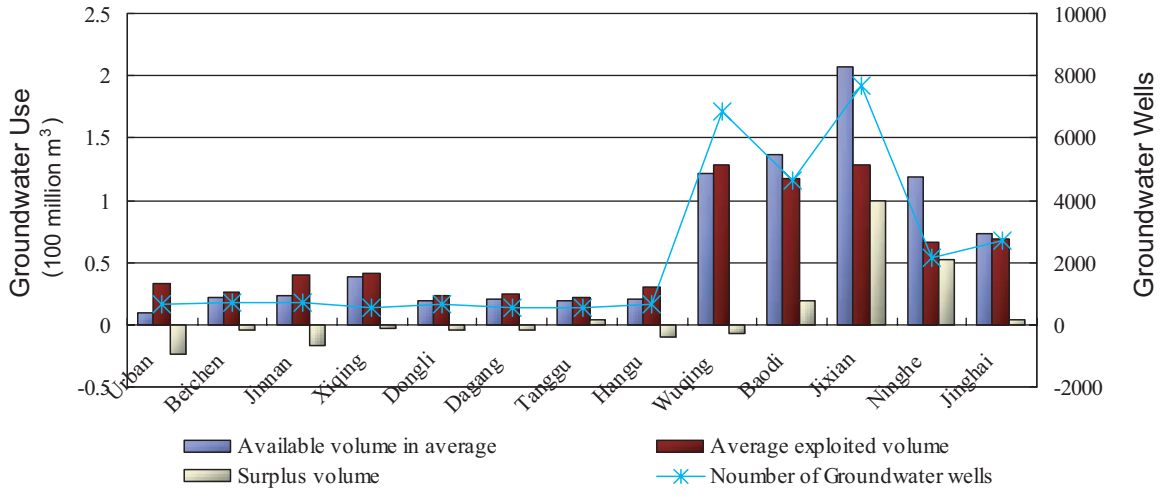

Figure 8. Average Volume of Groundwater Used from 1991 to 2002 and Groundwater Wells in Tianjin by District

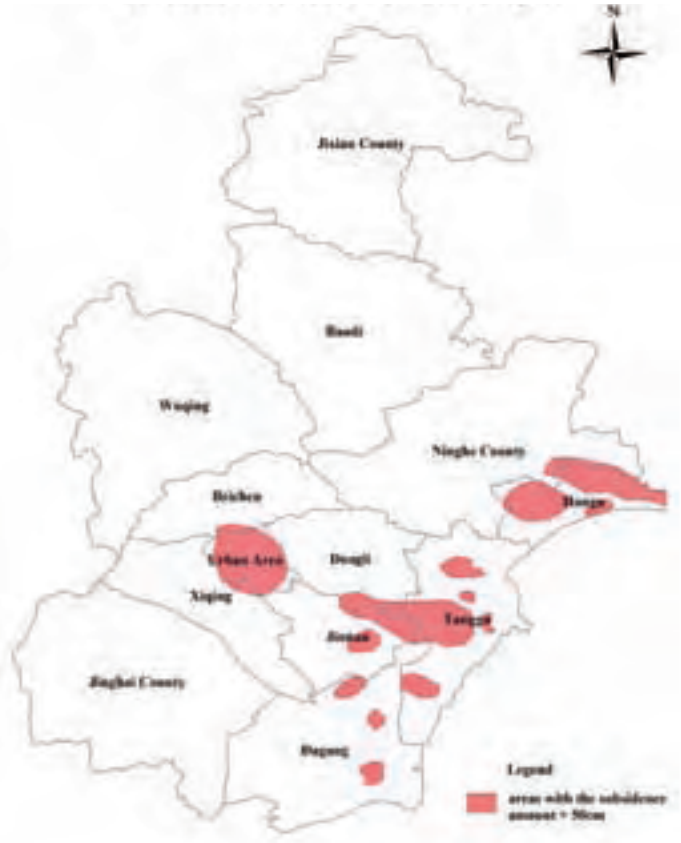

Figure 9. Centers of Land Subsidence in Tianjin Greater than 50 Centimeters
Source: "Study Report on Conceptual Planning for the Coustruction of Ecological city of Tianji", 2005, Unpublished.

amount of land subsidence from 1959 to 1994 in Tanggu subsidence center was about 3m, and that of Hangu district is about 2.6 m.

3.3 Groundwater Pollution

Groundwater quality in Tianjin is not the same in each area. In the northern part of the plain area (the districts of Jixian, Baodi, and Ninghe) it is relatively good and can meet category III (five categories in total, category V being the worst) of the national groundwater standard on the whole, except for the fluorine level exceeding the prescribed limit. Meanwhile, in the southern and eastern area of the plain area (Wuqing urban district and suburban districts, Jinghai costal area), water quality is not good. About 10-30% of samples do not comply with the groundwater quality standard for mineral degree, pH, chlorine, nitrite, and sulphate.

Among the parameters of groundwater quality, the concentration of fluorine is the one to which special attention should be paid. Fluorine is distributed widely in groundwater in Tianjin. Many people in certain areas of Tianjin have suffered serious diseases caused by drinking water with a high concentration of fluorine for a long time. Recently this situation has improved through measures taken for fluorine removal. There are many ways for removing fluorine from groundwater in Tianjin. For instance, in Dagang District, two methods were used: one was to look for groundwater wells with low fluorine levels and setting up fluorine removal equipment (used for both large scale and family life). The second way was to remove fluorine by coagulation sedimentation, adsorption filtration, electrodialysis, membrane, etc. At present people in these areas are not suffering from the diseases any more.

4. Status Quo of Reclaimed Water in Tianjin

So-called "reclaimed water" is the kind of water that comes from wastewater, which can meet a certain water quality standard and be used for industrial production, agriculture irrigation, daily life, etc., after being treated by the secondary or deep treatment process of wastewater. When considering the sustainable use of water in Tianjin, reclaimed water has the most potential as a beneficial alterative water resource when compared to groundwater. Reclaimed water can, for example, reduce the volume of wastewater drained to rivers; release the pressure on the water drainage system in the city; and is very good in terms of environmental protection. In Tianjin, an average amount of 0.5–0.6 billion tons of wastewater is discharged every year. It is a promising and stable source for water reuse. And, from the perspective of technology, wastewater treatment technologies have proved to be quite feasible. Wastewater can be treated to meet any kind of water needs through the conventional methods of in-depth water treatment technology include filtering, micro filtering (MF), Reverse Osmosis (RO), etc. In addition, the utilization of reclaimed water can avoid the long-distance water transmission needed for other water transfer projects, thus the cost of the reclaimed water is reduced. Also, the scale of regenerating and reutilizing wastewater can be very flexible according to the situation. Large-scale plants for water regeneration can be built on the outskirts of the city, and small-scale plants or systematic equipment dealing with wastewater can be also built in the residence communities and public buildings.

4.1 Pilot examples of Reclaimed Water Use in Tianjin

Relative research on wastewater reuse has been undertaken since the 1980s in Tianjin, and a great deal of progress has been made in this field. Although there is no large-scale utilization of reclaimed water in Tianjin at present, systems of wastewater recycling and reutilization have been built in many places, of particular note being the Jizhuangzi reclaimed water use project and the reclaimed water project in the Technologic-Economic Development Area (TEDA)[1] of Tianjin. Here below we will introduce the two projects in detail:

(1) Jizhuangzi Reclaimed Water Use Project

Jizhuangzi reclaimed water use project, the project with the broadest use and most advanced techniques among the pilot projects in China, includes a wastewater treatment plant, a reclaimed water plant and a water transportation network.

Jizhuangzi wastewater treatment plant, the first large-scale urban wastewater treatment plant in China, was put into service in 1984 with a design scale of 26,000 m^3 per day, and mainly treats wastewater from Heping District, Hexi District, and Nankai District. In this plant, a technique called Anaerobic-Oxic (A/O) dephosphorization craft is used. After being treated by the primary treatment, such as grit and sedimentation, the wastewater enters an activated sludge reactor. The former part of this tank is anaerobic and the later is oxic, where the phosphor compound will be removed by large proportions and the wastewater can be purified. Then the effluent will be transported to Jizhuangzi reclaimed water plant.

In the reclaimed water plant, there are two different kinds of treatment process. The first one is the traditional process designed for industrial use which contains the processes of coagulation, sedimentation, ordinary filtration and disinfection. The design scale of the traditional treatment process is about 30,000 m^3/day, and the reclaimed water will be used for industrial cooling or industrial production, such as in paper mills or at the thermal power plant in Chentangzhuang industrial area. Another treatment technique is CMF+O_3. The process of this technique is almost the same as that of the traditional technique, but introduces an advanced filtration called continuous micro-filtration (CMF) that is adopted to replace the ordinary filtration and a process of ozone oxidation between CMF and disinfection. That is the very reason the water quality is much better than that of the traditional work process. In this project, the design scale of the new treatment process is about 30,000 m^3/day, whose effluent water will be transferred to many resident areas such as Meijiang, Meijiangnan, Weinanwa, etc., and be used for toilet washing, greenbelt watering, landscape and so on.

(2) Reclaimed Water Use Project in TEDA

TEDA wastewater treatment plant was put into service in December 1992 and its design scale is 100,000 m^3/day. In

1. The establishment of Tianjin Economic and Technological Development Area (TEDA) was given government approval on December 6, 1984. One of the country's first state-class development areas, TEDA has developed into one of the country's most influential hotbeds for high-tech and new industries. Notably, it has its own policies in this zone and several privileges in economic development.

this plant, a technique of DAT-IAT (Demand Aeration Tank - Intermittent Aeration Tank) is used to treat wastewater. In general, wastewater intermittently feeds into the DAT, then the effluent from the DAT enters the IAT continuously and completes other working procedures including reaction and sedimentation.

In the TEDA reclaimed water plant, which is located beside the TEDA wastewater treatment plant, an international advanced in-deep water treatment process called "double-membrane" is used, with a purified technique of continuous micro-filtration (CMF) in water pretreatment, and a desalination technique of RO in the main treatment process. In this process, matter—including SS, bacteria, and organisms whose diameter is larger than that of the membrane—will be held up, and the water is purified. The total scale of the TEDA RWP is 30,000 m^3/day, of which 10,000 m^3/day of the entire treated water is used for industrial production and daily life use, and 20,000 m^3/day, being treated only by CMF, is used for city landscape and green watering.

4.2 Quality standards for different application of reclaimed water

With the rapid development of wastewater reuse in China, associated standards were issued by the national government and taken into effect gradually in order to guide the reasonable use of reclaimed water. It is stated that the quality of reclaimed water must meet different national criteria depending on its special utilization. For instance, when reclaimed water is used for agriculture, the items in the "Standard for Irrigation Water Quality" (GB5084-92) should be taken into account; when it is used for fishery water, the standard of the "Water Quality Standard for Fisheries" (GB 11607-89) should be met; and for scenic water, the "Environmental Quality Standard for Surface Water" (GB 3838-2000) should be met.

And now, for the purpose of carrying out the policy of "water pollution prevention and control, water resources exploitation and utilization"; improving the efficiency of urban wastewater reuse; and promoting the proper utilization of water resources, a standard set called "The Reuse of Urban Recycling Water" has been developed, of which three new national criteria on the reuse of urban recycling water were specially issued by the Standardization Administration of the People's Republic of China (SAC) in December 2001 and have been in effect since 1 May 2003. Table 2 shows some standards about reclaimed water use and some criteria of the relative standards; and Table 3 shows relevant standards which will be put forward in the near future.

Table 1. Water Quality Standards for Different Applications of Reclaimed Water

Reclaimed Water (RW) for different Uses	Standards of Water Quality
RW used for non-potable household consumption, including toilet washing, garden greening, car washing, etc.	• "Water Quality Standard for Non-potable Household Consumption" (CJ/T 48-1999) • "The Reuse of Urban Recycling Water—Water Quality Standard for Urban Miscellaneous Water Consumption" (GB/T 18920-2002)
RW used for Scenery and Recreation	• "Water Quality Standard for Scenery and Recreation Area" (GB 12941-91) • "The Reuse of Urban Recycling Water—Water Quality Standard for Scenic Environment Use" (GB/T 18921-2002)
RW used as cooling water	• Recommend Water Quality Criterion of Reclaimed Water Used as Industrial Cooling Water in the "Urban Wastewater Reuse Design Code" (CECS 61:94)
RW used for groundwater recharge	• "The Reuse of Urban Recycling Water—Water Quality Standard for Groundwater Recharge" (GB/T 19772-2005)
RW used for agriculture irrigation	• "Standard for Irrigation Water Quality" (GB 5084-92)
RW used for fishery	• "Water Quality Standard for Fisheries" (GB 11607-89)

Table 2. Reclaimed Water Quality Standards to be Issued

Reclaimed Water for different Use	Standards of Water Quality
RW used for agriculture irrigation	• "The Reuse of Urban Recycling Water—Water Quality Standard for Agriculture Irrigation"
RW used for industry	• "The Reuse of Urban Recycling Water—Water Quality Standard for Industry"
RW used as supplementary water	• "The Reuse of Urban Recycling Water—Water Quality Standard for Supplementary Water"

5. Water Management Mechanism and Associated Policies in Tianjin

5.1 Institution framework

The current institutional framework for water resources management in China consists of the following levels: national, river basin, and regional. In some places, they are interconnected. The Ministry of Water Resources (MWR) is the main organization under the State Council in charge of the integrated management of water resources. This department, however, has not been given all of the related responsibilities; several other ministries join 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). Each of them is in charge of different aspects and has different responsibilities.

In Tianjin, a majority of water affairs (including groundwater) are managed by the Tianjin Water Conservancy Bureau, which is responsible for water resources management and water saving, such as providing comprehensive management for water resources; drawing up long-term water supply plans and integrating them into a municipal economic and social development plan; and monitoring, evaluating and managing water resources within the municipality.

5.2 Associated water management policies and their effects

Measures for water management can be found in various water resource laws and regulations both at the national level and local level. Regarding their different effects, some pivotal laws/regulations are listed as follows:

(1) Water Right

"Water Law of PRC" (2002) : The "*Water law of PRC*" was enacted on 10 October 2002 and aimed to exploit, use, save and protect water resources reasonably; to control water pollution; and to realize sustainable water use to meet the needs of the social economic development of the country. In this law, it was definitely defined that:

- the proprietary rights of water resources belong to the nation;
- the legal rights and interests of organizations and individuals that exploit and utilize water resources should be protected according to the law. Also, organizations and individuals have an obligation to protect water resources;
- the nation possesses the proprietary rights of water resources. Any organization or individual involved in exploitation and utilization directly from river, lake or groundwater resources is required to apply for a license and pay a certain amount of water resource charge, except in cases of rather small amounts of water being used in daily life or livestock feeding;
- water management institutes should be set up in important river or lake basins to carry out their duties in water management and supervision;
- measures for water saving should be put into effect in industrial production, agriculture irrigation, water transfer and domestic water consumption.

In addition, the "*Management Regulation for Water-taking Permission and Water Resource Fee Charging*" issued by the State Council has been in effect since 15 April 2006. This regulation not only gave more detailed information about the application process and allowed an amount of water-taking, it also stated the principles of water resource fee charging and the special use of those fees for water conservancy projects. On the local level, associated regulations about water-taking permission had also been issued to realize the better implementation of the national water management laws.

(2) Water Pollution Control

"Water Pollution Control Law of PRC" (1984) : This law is suitable for water pollution control in all surface water (including rivers, water canals, and reservoirs, but not the seas) and groundwater in the territory of PRC. It regulated that:

- all organizations and individuals have the responsibility to protect our water environment, and have the right to supervise or impeach polluting behaviors to the water;
- water quality standards should be enforced on wastewater discharge;
- EIA or SEA should be done in the establishment of associated projects;

- wastewater discharge fees should be collected and be used in a reasonable way;
- wastewater discharge is prohibited in special places such as water resource places, etc;
- water quality monitoring should be carried out regularly.

In Tianjin, in addition to the national laws, some local regulations were carried out by the local government. For instance, "Measures for Water Pollution Control in Tianjin" (2003), "Measures for Protecting Water Transferred from Yellow River to Tianjin" (2002), "Regulation of Water Pollution Control of Water Transferred from Luan River" (2002) stated a great number of special measures to protect water resources from various types of pollution in the process of water exploitation, utilization and transportation.

(3) Water Charge/fee

"Management Rules for the Charging of Groundwater resource fee in Tianjin" (1987) : It was taken into effect on 1 June 1987 and stated that:

i. groundwater used for agriculture irrigation and daily drinking in the country is temporarily free;
ii. a groundwater fee should be added if the abstracted amount is out of the plan;
iii. those fees should be charged by Tianjin Water Conservancy Bureau, and used for groundwater management, water transfer projects, science study associated with the groundwater.

"Notification of Adjusting the Standard of Groundwater Resource Fee" (2002) : This rule was issued by Tianjin financial bureau and Tianjin price bureau on 8 November 2002. It stated that: the price of groundwater resource fees should be increased to 1.3 CNY/m^3 for those water users without a tap water supply or 1.9 CNY/m^3 in the areas which can access the tap water supply system, from the previous 0.5 CNY/m^3.

"Notification from Tianjin Price Bureau about the adjustment of the water fee" (2007) : This notification is not a single one but a set of files. It was revised in 2002, 2005 and 2007 and is issued by the Tianjin Price Bureau. In the newest file, taken into effect on 1 March 2007, it is stated that:

i. the charge of the water supplied to the water companies is increased to 1.03 CNY/m^3;
ii. the selling price of tap water from water companies is composed of four parts, namely, basic water fee, wastewater treatment fee, water resources fee and water added fee for urban public utility. Within these, the water resources fee for residential use is 0.25 CNY/m^3, while for others it is 1.03 CNY/m^3 ; wastewater treatment fee for residential use is 0.80 CNY/m^3, while it is 1.20 CNY for others; and the water added fee used for urban public utilities accounts for 10% of the total tap water fee.
iii. the fee for tap water used for daily life is 3.40 CNY/m^3 ; 6.20 CNY/m^3 for administrative agencies or social groups, industry, business, transportation, construction and hotels; while 20.60 CNY/m^3 for special sectors (e.g. chemical industry);
iv. the water resources fee from the tap water fee is used for the south-to-north water transfer project fund.

"Notification about the sell price of the reclaimed water from Jizhuangzi reclaimed water plant" (2003) : This rule has been in effect since 1 November 2003. According to this notice, with a target to encourage reclaimed water use and based on the operating conditions of Jizhuangzi reclaimed water plant, the sell price of the reclaimed water from Jizhuangzi RWP is set as follows (see table 3). It is much cheaper compared to the tap water price of 2.9 CNY/m^3.

Table 3. Sell Prices of Reclaimed Water from Jizhuangzi Reclaimed Water Plant

Category	Price (CNY/m^3)
RW used for residents	1.10
RW used for school, hospital, kindergarten, etc.	1.20
RW used for industrial production	1.30
RW used for landscape, watering, road washing, etc.	1.50
RW used for car washing, building construction, etc.	1.50

Source: Notification about the selling of price of the reclaimed water from Jizhuaugzi reclaimed water plaut.
Note: The Notification became ettective from Nov, 2003.

According to the "Notification from State Council about advancing the adjustment of water price and promoting water saving" issued by China State Council on 9 April 2004, the price of reclaimed water should be set rationally. This notification states that a privileged price for electricity and tax should be granted to reclaimed water production enterprises.

(4) Groundwater Abstraction

In some plans such as the "*Plan of Groundwater Source Exploitation in Tianjin*" (1997), it was proposed that:

- in the northern mountainous area with good replenishment and exploitable potential, groundwater abstraction can be increased by some appropriate degree;
- in the southern part of Tianjin with shallow salt groundwater aquifer, such as the urban areas, Hangu district, and Tanggu district, due to sensitivity in land subsidence and stable surface water supply, deep groundwater is forbidden to be further abstracted;
- in some areas with alternative water resources and serious land subsidence, the abstraction of groundwater should be reduced by 5% year by year;
- in addition to the limitation of groundwater exploitation, other measures should be also taken including water saving, water transfer, water reuse, groundwater recharge, etc.

(5) Reclaimed Water Use

Considering the serious water shortage in Tianjin, the city government attached great importance to the development of the reclaimed water use project.

For the purpose of encouraging reclaimed water use, the "*Management Regulations on Water Drainage and Reclaimed Water Use*" issued by the People's Congress of Tianjin was taken into effect on 1 December 2003; the "*Rules of Constructing Reclaimed Water Supply System in Residential Area of Tianjin*" and the "*Technologic Rules for Reclaimed Water Supply System in Residential Area of Tianjin*" were proposed by Tianjin Construction Committee, which aims to regulate the water users who must use reclaimed water; and state that newly constructed buildings must build their own special pipe for reclaimed water or their own water reuse system.

The "*Plan of the Reclaimed Water Use in Urban Areas of Tianjin*" (2000), and "*Overall Plan for Reclaimed Water Irrigation in Agriculture*" (not issued) proposed a particular plan about the reclaimed water used both in urban areas and rural areas, as well as the future construction of reclaimed water plants and pipe networks.

(6) Others

"Temporary Measures of Groundwater Management in Tianjin" (1987) : In 1987, the Tianjin government enacted the "*Temporary Measures of Groundwater Management in Tianjin*", making an active effect to exploit and utilize water resources rationally, and to prevent ground subsidence. So far, the municipal government has listed the regulations of "*Administrative Measures of the Groundwater Resources in Tianjin*" in the government's legislation program in 2004, to thereby perfect the existing "*Temporary Measures of Groundwater Management in Tianjin*" and to manage Tianjin's groundwater resources in a much better way.

"Water Saving Regulations of Tianjin" (2002) : On 19 December 2002, the Standing Committee of the Tianjin People's Congress passed the "*Water Saving Regulations of Tianjin*", which stipulated that 'a management method of total control on the amount of water use should be implemented in Tianjin', and a 'water reusing system and other water saving measures such as multiple use of water should be adopted and carried out'.

"The 11th Five-Year Plan of Tianjin to Establish a Water-saving Society" (2005) : "*The 11th Five-Year Plan of Tianjin to Establish a Water-saving Society*" (2005) defined the meaning of water saving, which is: to improve the efficiency of water resources utilization by reducing inefficiency and low efficiency of water utilization; to improve the economic and ecological outputs of water utilization by optimizing and adjusting the industry structure and scientific allocation of water resources; to exploit and utilize alternative water resources to reduce the one-off volume of freshwater used; to reduce water demand by virtual water trade. It also proposed a prospect about the different application of various alternative water resources in Tianjin.

6. Challenges and Recommendations to Sustainable Water Management in Tianjin

6.1 Management Mechanisms

Presently in Tianjin, in addition to the Water Conservancy Bureau, water is also managed by many other authorities including the Construction Committee, the Municipal Bureau, and the Geology and Mineral Resources Bureau. The Water Conservancy Bureau takes charge of the water supply and drainage; the Water Conservancy Bureau, and the Geology and Mineral Resources Bureau administrate groundwater according to region and water temperature; the Construction Committee is responsible for the control and corresponding work of ground subsidence caused by groundwater exploitation; and reclaimed water use is under the control of the Municipal Engineering Bureau. They failed to reach an accordant management in water affairs, and every unit conducts their own management according to their own policies. As a result, the whole situation falls into disorder and it is very difficult to achieve the harmonized allocation and development of the water resources as a whole.

Considering the decentralized management of water resources in Tianjin, a kind of 'team to guide the work of water resources utilization in Tianjin' should be set up by the municipal government to: manage and allocate the utilization of the water resources by integrated planning; be in charge of the examination and operation of the projects, the water fees and water quality supervision; manage the facilities and pipe networks; develop relative policies or regulations concerning water use and water quality; establish associated plans for emergent situations; and other relevant issues. Also, a system of mediating water affairs should also be established as soon as possible.

6.2 Water Price and Economic Stimulating Policy

In Tianjin, the price of tap water has been rising year by year. In the past, the surface water price in Tianjin was about 1.0 CNY/ton, and the price of groundwater was about 0.5 CNY/ton, while the price of reclaimed water was 1.3 CNY/ton, on average. As a result, business companies would like to use the surface water and groundwater rather than reclaimed water. To protect groundwater resources and control land subsidence, the Tianjin municipal government adjusted its standard pricing system after 2002, and the price was set at 1.90 CNY/m^3 and 1.30 CNY/m^3 in areas without tap water service. However, there is no information available yet to show if the new pricing has affected market mechanisms to allocate groundwater resources wisely according to the present socioeconomic conditions in Tianjin. Further research is needed to validate its effectiveness in moving towards sustainable groundwater management.

In addition, because of the early stage of reclaimed water use, there are not that many relative fostering policies. It is regulated so that the section of city water supply is charged a value-added tax of 6%, but as reclaimed water does not belong to this category, a tax of 17% is used for reclaimed water, which leads to the weak competitive power of this industry. For the purpose of quickening the utilization of reclaimed water, a rational price system must be formed to demonstrate the price advantage of reclaimed water. Prices of tap water and well water will be boosted gradually to extend the price gap between reclaimed water and other water resources. And, particular policy supports should be offered to reclaimed water companies concerning credit, revenue and other aspects. The government should offer appropriate allowance to those reclaimed water companies who cannot sell the water at its cost temporarily, and necessary allowance should be granted to the use of reclaimed water in agriculture. For those companies which use reclaimed water according to the relevant regulations, they should be awarded for saving water and treated as environment-protecting companies, and their construction and operation fees should also be remitted and cut down.

6.3 Reduce Groundwater Abstraction and Pollution

As mentioned above, Tianjin has suffered from land subsidence since the 1980s. It has been proven that reducing groundwater exploitation is one of the most effective measures in controlling land subsidence. In Tianjin, according to the degree of groundwater exploited and land subsidence, groundwater exploitation is forbidden entirely in some places; and for others, groundwater exploitation should be reduced gradually or placed under strict controls. Also, adjusting the aquifer of groundwater exploited and groundwater recharge are also good methods to release the pressure of land

subsidence in Tianjin. However, how to solve the problem of groundwater over-abstraction in drought years with low precipitation and small natural runoff is still a big question and challenge to the Tianjin government.
Pollution in groundwater mainly comes from polluted surface water and wastewater, pesticides, and fertilizer distributors used in agriculture irrigation, which should all be strictly controlled in the future. Still, perfecting the existing water monitoring system, enhancing the monitoring of groundwater level, quality, and quantity in different aquifers is also a good suggestion to improve Tianjin's groundwater management.

6.4 Promote the Use of Reclaimed Water

(1) Infrastructure Constructions of Reclaimed Water
In Tianjin, there are several reclaimed water use projects, which can provide a large volume of reclaimed water. However, because of the faultiness of the water pipe network, the reclaimed water cannot be transferred to other places, so it has to discharge into the drainage system of the city and cannot be reused.

In order to solve these problems many measures can be undertaken. For instance, pipe network construction must be considered in the design of the overall road system and development of residential communities in the city. If pipes for reclaimed water were buried first, the future destruction of the roads for setting the pipes could be avoided. Watercourses used to transfer reclaimed water should be maintained properly to make sure that water can be drained smoothly; and the sullage in the bottom of river ways should be cleaned regularly to avoid secondary pollution during the reclaimed water transfer.

(2) Supporting of Science and Technology
At present, to realize the wide use of reclaimed water, there is still a lack of support from mature techniques. Water quality standards, examination, monitoring and other relevant technical problems have not been standardized either. There exist a lot of questions, for example regarding what crops can be irrigated with reclaimed water; how to design a program to achieve safe irrigation; what the irrigation regulations should be; and how to assess the impacts of reclaimed water irrigation on the soil, groundwater and crops.

The development of utilization of reclaimed water must depend on the development of science and technology. When reclaimed water is used in agriculture, ecology, municipal works and industry, attention should be paid to the study of the water purification, water stability and the insurance, management, techniques related to the facilities. In addition, model projects of utilizing reclaimed water in agriculture should be built as soon as possible to make clear what crops can be irrigated by reclaimed water, how to design a safe irrigation process, how to set the irrigation regulations and how to assess the ecological influence of reclaimed water irrigation on soil, groundwater, crops and how to regulate the techniques of water storage. At the same time, analysis and assessment of the benefits and risks should be made in time, for effective control and management. In this way, safety concerning the utilization of reclaimed water will be improved and ensured.

6.5 Supervision System and Public Participation

It is necessary to make the public realize the severe situation of water scarcity and the necessity of water saving. As a result, various activities have been held in schools, communities and companies to raise public awareness. And, in order to realize effective and justified water management in Tianjin, an effective supervision system, not only including the government and institutes at different levels but also involving the participation of the public, should be set together with the integrated management team of water resources.

6.6 Alternative Water Resources

Instead of abstracting groundwater, there are some other alterative water resources which can partly compensate for the water shortage in Tianjin. Listed below is detailed information about the alternative water resources in Tianjin:

(1) South to North Water Transfer Project

The south-to-north water transfer project consists of three water-transferring lines and Tianjin will benefit from the east route and middle route of this project. This project is scheduled to be completed by 2020, and by then, according to the "*The 11th Five-Year Plan of Tianjin to Establish a Water-saving Society*", 400 million m^3 of water will be transferred to Tianjin every year, all of which will be used for urban areas.

(2) Brackish Water

The so-called "saline water" refers to water with a mineral degree of more than 2g/l. According to the mineral degree, saline water can be divided into brackish water (2-3g/l), semi-saline water (3-5g/l), salt-water (5-10g/l) and brine (>50g/l). Brackish water can be used in long-term agricultural irrigation, especially during the drought period in spring. After salt-water is mixed with freshwater, it also can be used as irrigation water if the salt contained in the mixed water is less than 5g/l.

In Tianjin, large scale applications of brackish water irrigation have not started, but scientific research has been going on since the 1970s. Currently, in the Dagang District of Tianjin, "double pipes" are used for the water supply from Luan River and groundwater. Brackish groundwater and water with a high concentration of fluorine is used for daily life use (except for as drinking water) instead of fresh water. Also, pilot research of brackish water irrigation has been started in the western Jinghai District, in which an area of about 16,667 m^2 (in small-scale) was used for brackish water irrigation experiments, and another area of 1,000,005 m^2 was used for the enlarged scale experiment (bench scale research). In this study, the effect of brackish water irrigation for winter wheat was tested and primary progress was made in the past years. In addition, in the eastern Jinghai District, a partial wetland can be formed through a controlling of land subsidence by the proper exploitation of shallow groundwater, which will improve the local ecologic environment and bring large economic and environmental benefits.

(3) Desalted Seawater

Tianjin has been leading the field in the research of seawater circulating cooling technology and seawater exploitation in China. The utilization of seawater plays a very important role in the exploitation of non-traditional water sources.
At present, there are two successful projects utilizing seawater directly and one seawater desalination project in Tianjin. One project utilizing seawater directly is the seawater once-through cooling process of the Electricity Plant in the north Dagang District. Another project is the Seawater Purifying Plant in Tanggu District. These practical experiences can be extended to other costal area of Tianjin. However, the benefits of seawater desalination are not certain due to its relatively high cost compared to other water resources.

7. Conclusions and Prospects

Over the past years, water shortages have become a common occurrence in Tianjin due to its geographic conditions and the uneven distribution of water resources in different areas, as well as in different seasons. To meet the needs of economic development and daily life use, a large amount of groundwater was exploited in the past, which has led to severe land subsidence in some areas of Tianjin, especially in the south. However, thanks to the strict limitation of groundwater exploitation, as well as the completion of the water transfer project from Luan River to Tianjin in 1983, the serious pressure on water supply has been released greatly, and the groundwater level has also ascended. Still, this phenomenon of land subsidence is also a big problem in Tianjin's sustainable water management and more attention should be paid as to how to solve this problem through further scientific research.

The development and utilization of alternative water resources is also a good method to realize sustainable water utilization in Tianjin. Since the 1980s, relative research about wastewater reuse has been done in Tianjin. Some pilot reclaimed water use projects have been put into effect and provide water in the wide use of reclaimed water for urban miscellaneous consumption and industrial production. However, wastewater reuse for agriculture should be increased in the future. Thus, the exploitation of groundwater used for irrigation could be reduced, which would be good to control

land subsidence.

Although much progress has been made in the water management of Tianjin, and many policies and regulations have taken into effect, the challenge of unseasonable water management mechanisms should be improved by speeding the pace of popularizing reclaimed water, improving the efficiency of the scientific use of all water resources, as well as forming an integrated water management system. In addition, an effective supervision and monitoring system in Tianjin will be an important subject that needs to be studied in the near future.

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