THE ECONOMICS OF SUSTAINABLE URBAN WATER MANAGEMENT

THE CASE OF BEIJING

XIAO LIANG

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The Economics of Sustainable Urban Water Management: The Case of Beijing

Economische aspecten van duurzaam stedelijk waterbeheer in Beijing

Thesis

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To My Parents and Husband

Contents

List of Tables and Figures

Tables

Figures

Acronyms

BNU	Beijing Normal University
CBA	Cost Benefits Analysis
DALY	Disability Adjusted Life Year
Gao	Gaobeidian plant
GIS	Geographic Information System
IRR	Internal Rate of Return
Jiu	Jiuxianqiao plant
NGO	Non-Governmental Organization
NPV	Net Present Value
O&M	Operation and Maintenance
Qing	Qingzhiyuan plant
SEPA	State Environmental Protection Agency
SWITCH	Sustainable Water Improves Tomorrow's Cities' Health
WHO	World Health Organization

Acknowledgements

Before I went to the Netherlands, I never thought I would pursue a PhD degree. The Master's programme at the Institute of Social Studies, The Netherlands (2004-2005) aroused my interest in continuing my academic studies. In 2006, I started the PhD programme at UNESCO-IHE Institute for Water Education to study water management. It was a challenge for me to begin the research in water management as my previous academic experience was economics. Fortunately, during the four years spent on my PhD journey, I conquered many difficulties on the path to completion of my PhD thesis. The PhD journey enhanced my ability to deal with problems independently, built my confidence, and extended my knowledge from economics to the environment. For family reasons, my PhD thesis was completed in three cities and countries: Delft (Netherlands), Metz (France) and Hong Kong (China). I would like to acknowledge the people who helped and supported me on this long journey.

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Abstract

A rapidly growing urban population leads to the dramatic increase of water consumption in the world. The water resources available to the human being are limited. Meanwhile climate variability and environmental pollution decrease the quantity of water resources available for human use. It is a significant challenge to provide sufficient water to urban residents in a sustainable and effective way. Facing urban water crisis, researchers point out a paradigm shift in urban water management for sustainable water supply and services. This requires multi-disciplinary approaches, including technical improvements and economic evaluations. Advanced technology can contribute to the solution of problems physically, but it may not ensure sustainable operation of water systems. The obstacles to sustainable water supply and services often are from non-technical problems such as low cost recovery, lack of sound pricing systems and sustainable financing for increasing service coverage. The financial and economic factors could be a large barrier to the operation of water systems.

This research aims to use economics to assess water systems for sustainable urban water management. How to use economics on urban water systems and what contributions can economics bring to sustainable water management are the two main research questions in the thesis.

Since the existing systems are insufficient to achieve the objective of sustainable urban water management, many new systems are being proposed and implemented recently. There are two kinds of water systems: traditional or existing systems, and new or alternative systems. The alternative systems may be technologically feasible to increase water supply or save water consumption, but they may not be financially and economically feasible. Lack of financial and economic viability makes alternative systems less attractive than traditional systems. It is important to know whether the new systems can operate long term and whether the new systems are suitable alternatives to existing systems if one wants to promote sustainable urban water management.

The thesis carries out economic and financial analysis of traditional and alternative urban water systems. A comparative analysis between the traditional and alternative water systems is presented. Through the comparative analysis, the thesis shows whether the alternative system is an economically viable alternative to the traditional system. The case of Beijing is chosen for the study. The main technological measures of water saving in Beijing include wastewater reuse and rainwater harvesting. There are centralized and decentralized wastewater reuse systems. Centralized wastewater reuse systems represent the traditional systems while decentralized systems represent the alternative systems. Groundwater is the main and traditional water resource for agricultural irrigation, and rainwater harvesting is an alternative method to get more water.

The main economic method in the thesis is cost benefit analysis, which is an accepted method to evaluate the environmental projects. Additionally, the thesis employs the methods of linear programming and rough set analysis. In the cost benefit analysis, the concern of different stakeholders having different viewpoints is taken into consideration. Accordingly, an integrated financial and economic analysis is carried out, in which financial analysis is implemented from the point of view of individual participants, while the economic analysis is from the point of view of society. The financial analysis aims to judge whether the individual investor could afford the water system, and the economic analysis is to determine the contribution of the water system to the development of society.

The research shows that the alternative water systems are economically feasible while they are not financially feasible. However, the traditional water systems are both economically and financially feasible. Comparing the economic and financial feasibility between the traditional and alternative water systems, the traditional water systems are better than the alternative systems. It implies that the new water systems are not viable alternatives to the traditional water systems because the new systems are not financially feasible.

Through the case of Beijing, the thesis demonstrates how to use economics in managing urban water systems. This is the first integrated and quantitative analysis of the economic, environmental and social effects of new water systems. The economic, environmental and social effects are all determined by monetary values, which is rare in the existing literature.

The thesis shows that economics contributes to identifying the non-technical problems in water systems and can help decision makers to make choices that are consistent with the long-term well being of the community. Three practical contributions of the research are as follows. 1.Using economics to identify and quantify the effects of water treatment systems on economics, environment and society; 2.Using economics to discern the factors that significantly hinder long term plant operations; 3.Using economic tools to learn the advantages and disadvantages of different water systems from an economic perspective. The theoretical contribution of the research is that it proves the importance of considering the viewpoints of different stakeholders in the cost benefit analysis. Doing cost benefit analysis from different stakeholder perspectives can provide complete and accurate information for helping decision makers to choose the most suitable alternative.

Samenvatting

Economische aspecten van duurzaam stedelijk waterbeheer in Beijing

Door de snelle bevolkingsgroei in de steden neemt de waterconsumptie wereldwijd sterk toe. De bestaande watervoorraden zijn beperkt en door de veranderlijkheid van het klimaat en de milieuvervuiling neemt de hoeveelheid water die voor menselijk gebruik beschikbaar is af. Het is een grote uitdaging om stadsbewoners op een duurzame en effectieve manier van voldoende water te voorzien. Met het oog op een dreigend tekort aan water in de steden wijzen onderzoekers op een paradigmaverandering op het gebied van stedelijk waterbeheer om een duurzame watervoorziening en dienstverlening te waarborgen. Dit vereist een multidisciplinaire aanpak met onder andere technische verbeteringen en economische evaluaties. Geavanceerde technologie kan bijdragen aan de praktische en technische oplossing van problemen, maar is geen waarborg voor het duurzaam functioneren van watervoorzieningsystemen. Het zijn vaak niet-technische problemen, zoals een lage kostendekking, een gebrek aan goede prijssystemen en aan duurzame financiering van een steeds groter dienstverleningsgebied, die een duurzame watervoorziening en dienstverlening in de weg staan. Dergelijke financiële en economische factoren kunnen het functioneren van watervoorzieningsystemen ernstig belemmeren.

Dit onderzoek analyseert watervoorzieningsystemen voor duurzaam stedelijk waterbeheer vanuit een economisch perspectief. De twee belangrijkste onderzoeksvragen van dit proefschrift zijn hoe stedelijke watervoorzieningsystemen vanuit een economisch perspectief onderzocht kunnen worden en in hoeverre economische theorieën en methoden kunnen bijdragen aan duurzaam waterbeheer.

Omdat het doel van duurzaam stedelijk waterbeheer met de bestaande systemen niet bereikt kan worden, worden er de laatste tijd veel nieuwe systemen voorgesteld en ingevoerd. Er zijn twee soorten watervoorzieningsystemen: de traditionele of bestaande, en de nieuwe of alternatieve systemen. De alternatieve systemen zijn mogelijk in technologisch opzicht geschikt om de watervoorziening uit te breiden of water te besparen, maar ze zijn wellicht financieel en economisch niet haalbaar. Als alternatieve systemen financieel en economisch niet haalbaar zijn, zijn ze minder aantrekkelijk dan traditionele systemen. Als men duurzaam stedelijk waterbeheer wil bevorderen, is het belangrijk om te weten of de nieuwe systemen op de lange termijn goed kunnen functioneren en of ze een geschikt alternatief vormen voor bestaande systemen.

In dit onderzoek is een economische en financiële analyse van traditionele en alternatieve stedelijke watervoorzieningsystemen uitgevoerd. Dit proefschrift bevat een vergelijkende analyse van de traditionele en alternatieve watervoorzieningsystemen. Hieruit blijkt of het alternatieve systeem een economisch haalbaar alternatief is voor het traditionele systeem.

Het onderzoek heeft plaatsgevonden in Beijing. In deze stad zijn hergebruik van afvalwater en opslag van regenwater de voornaamste technologische maatregelen om water te besparen en op te slaan. Er bestaan gecentraliseerde en gedecentraliseerde systemen voor het hergebruik van afvalwater. De traditionele systemen zijn gecentraliseerd en de alternatieve systemen zijn gedecentraliseerd. Grondwater is de belangrijkste en traditionele bron voor de irrigatie van landbouwgrond, en de opslag van regenwater is een alternatieve manier om meer water te verkrijgen.

De belangrijkste economische onderzoeksmethode in dit proefschrift is kosten- batenanalyse, een gebruikelijke methode om projecten op milieugebied te evalueren. Daarnaast is gebruik gemaakt van lineair programmeren en rough set-analyse. In de kosten- batenanalyse wordt rekening gehouden met de belangen van verschillende belanghebbenden die uiteenlopende gezichtspunten hebben. Op deze manier is er een geïntegreerde financiële en economische analyse uitgevoerd. De financiële analyse gaat uit van het oogpunt van de individuele deelnemers, terwijl de economische analyse uitgaat van het maatschappelijk gezichtspunt. Het doel van de financiële analyse is om te beoordelen of het watervoorzieningsysteem betaalbaar is voor individuele investeerders, en met de economische analyse wordt de bijdrage van het watervoorzieningsysteem aan de ontwikkeling van de maatschappij bepaald.

Uit het onderzoek blijkt dat de alternatieve watervoorzieningsystemen wel economisch, maar niet financieel haalbaar zijn. De traditionele watervoorzieningsystemen zijn echter zowel economisch als financieel haalbaar. Uit de vergelijking van de economische en financiële haalbaarheid van de traditionele en alternatieve watervoorzieningsystemen blijkt dat de traditionele watervoorzieningsystemen beter zijn dan de alternatieve. Dit betekent dat de nieuwe watervoorzieningsystemen geen bruikbaar alternatief zijn voor de traditionele watervoorzieningsystemen omdat de nieuwe systemen financieel niet haalbaar zijn.

Dit proefschrift toont op basis van de situatie in Beijing aan hoe economische inzichten en onderzoeksmethoden toegepast kunnen worden op het beheer van stedelijke watervoorzieningsystemen. Dit is de eerste geïntegreerde en kwantitatieve analyse van de economische, milieu- en maatschappelijke effecten van nieuwe watervoorzieningsystemen. De economische, milieu- en maatschappelijke effecten worden allemaal herleid tot hun economische waarde, wat zelden voorkomt in de bestaande literatuur.

Dit proefschrift toont aan dat de economische wetenschap een bijdrage levert aan het vaststellen van de niet-technische problemen van watervoorzieningsystemen en beleidsmakers kan helpen keuzes te maken die op de lange termijn het welzijn van de gemeenschap dienen. Het onderzoek levert drie praktische bijdragen:

1. Het gebruik van economische inzichten om de economische, milieu- en maatschappelijke effecten van waterbehandelingssystemen vast te stellen en te kwantificeren.

2. Het gebruik van economische inzichten om de factoren aan te wijzen die het functioneren van watervoorzieningsinstallaties op de lange termijn ernstig hinderen.

3. Het gebruik van economische methoden om de voor- en nadelen van verschillende watervoorzieningsystemen te ontdekken vanuit economisch perspectief.

De theoretische bijdrage van dit onderzoek is dat het aantoont hoe belangrijk het is om de gezichtspunten van verschillende belanghebbenden in aanmerking te nemen in de kosten- batenanalyse. Het uitvoeren van een kosten- batenanalyse vanuit het gezichtspunt van verschillende belanghebbenden kan volledige en juiste informatie opleveren die beleidsmakers kan helpen om het geschiktste alternatief te kiezen.

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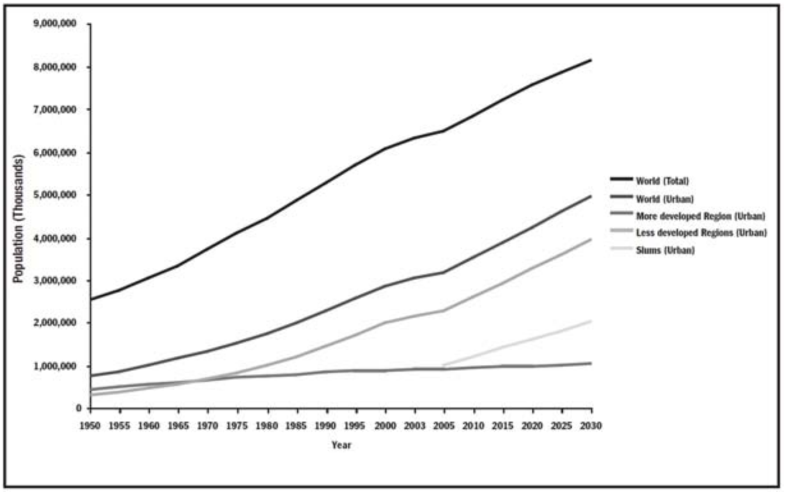
1 Introduction

1.1 Problems in Cities

Global urban water utilization by people increased over 20 times in 100 years. In 1900, it was $200\times10^8\,m^3$; in 1950, it was $600\times10^8\,m^3$; in 1975, it was $1{,}500\times10^8\,m^3$; and in 2000, it was $4{,}400\times10^8\,m^3$ (Bao and Fang 2007). It is predicted that urban water utilization by people in the year of 2050 will equal total global water utilization in 2004 (Song et al. 2004).

Figure 1.1
Urban Population Growth

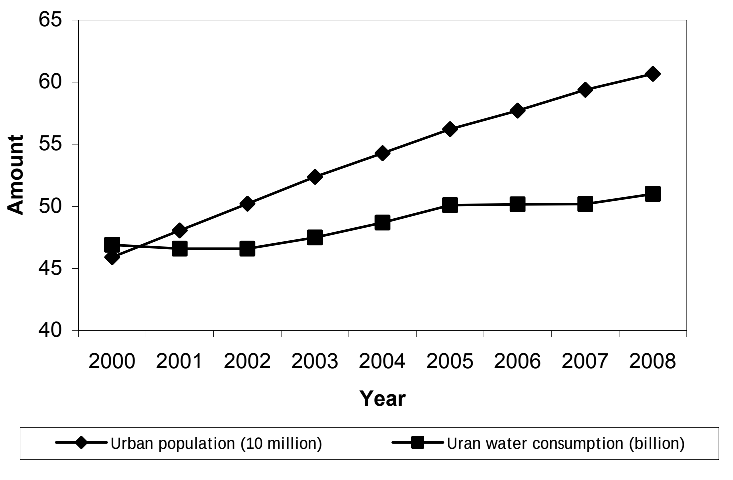


Source: Rees (2006)

A rapidly increasing urban population is an important factor causing the increase of water consumption in the world. Forty years ago, the urbanized population represented only 37 per cent of the total world population, but presently around 50 per cent of the world's population inhabits urban areas (Rees 2006). Figure 1.1 shows that the urban population is growing rapidly, especially in the developing regions. The urbanized population proportion in the developing regions may increase from 42 per cent to 57 per cent by the year of 2030 (Jenerette and Larsen 2006).

Rees (2006) thinks that the urban population may be more than 60 per cent of the total population by the year 2025. The number of mega-cities with more than five million residents is expected to increase globally from 46 to 61 between 2015 and 2030 with disproportionate increase in Asia and Africa (UN 2004). In China, approximately five cities have populations over ten million. Figure 1.2 indicates the growth of the urban population and urban water utilization in China, which shows that Chinese urban water consumption increases gradually while the urban population swells.

Figure 1.2
Growth of urban population and urban water consumption in China



Source: The Bulletin of Chinese Construction (2000-2008)

Global water resources available to humans are limited. Only 2.5 per cent of the earth's 139×1016 m^3 of water is fresh water and less than one-third is available for human use (Postel et al. 1996). In China, renewable water resources equal only 2,205 m^3 per capita per year, which is one-fourth of the average world level (FAO, Water resource, Development and Management Service 2003). Per capita water availability in the 3-H basins of north China (Hai, Huai and Huang) is around 500 m^3 per year, which is well below the 1,000 m^3 per year standard for water stress (World Bank 2007). In Beijing, the total availability of water resources per capita per year is only 300 m^3, which is 1/8 of the national average and 1/32 of the world's average (Wang and Wang 2005). The limited water availability results in the shortage of water supply in cities.

Climate variability and environmental pollution lead to water scarcity in cities. Water crises affect not only arid areas but also some regions with normally plentiful water resources. For instance, some parts of Europe, have suffered successive droughts over the last few years, with the result that certain watercourses have dried up (Lazarova et al. 2001). The southwestern area of China, which used to have rich water resources, suffered a sudden drought in 2010 leading to severe water scarcity. Moreover, environmental pollution decreases the availability of clean water, increasing the pressure of urban water supply. Rapid industrialization around the cities leads to serious water pollution in the cities. Consequently, the clean water available to the urban residents diminishes. For example, due to pollution in many of the lakes that comprise the main domestic water source, many residents of the rural areas of Wuhan city cannot access clean water.

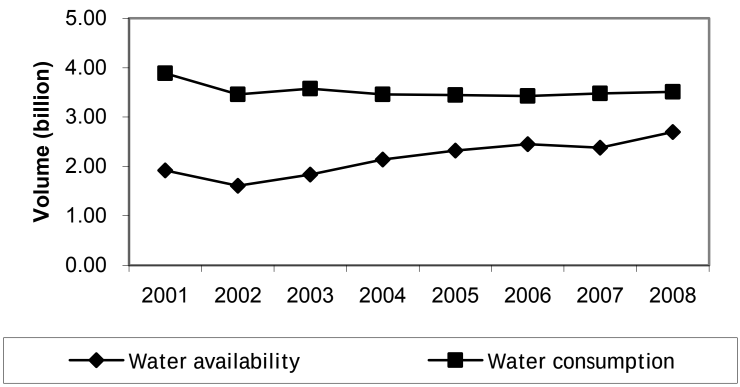
Rapid population growth, limited water availability, climate variability and environmental pollution together place significant pressure on urban water management, especially in arid areas. Urban population growth increases the demand for water, but water resources remain limited. Meanwhile climate variability and environmental pollution decrease the quantity of water resources available for human use.

1.2 Water Scarcity in Beijing

The thesis studies the context of Beijing, China because Beijing is a typical case of urban water scarcity. Increasing population, continual droughts and depletion of groundwater stocks pose a challenge to provide sufficient water to Beijing's residents in a sustainable and effective way.

The critical issue is that water consumption within Beijing is more than the water available to Beijing. Figure 1.3 illustrates that water consumption is almost one billion cubic metres more than the water available although the gap between water consumption and water availability decreases gradually.

Figure 1.3
Water availability and water consumption in Beijing

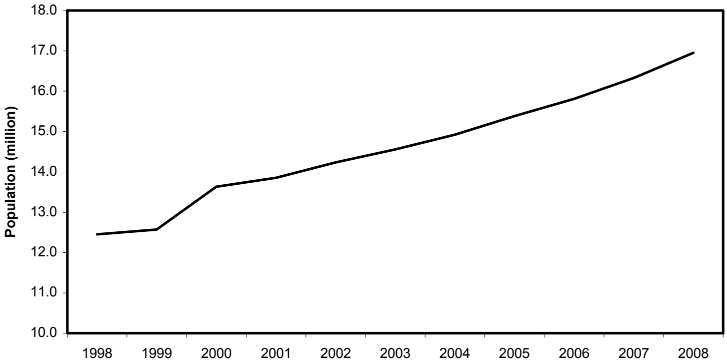


Source: Beijing Statistical Yearbook (2001-2008)

Water scarcity in Beijing is caused by two important factors: 1) Beijing has a large and increasing population; 2) Beijing is located in the arid area of China.

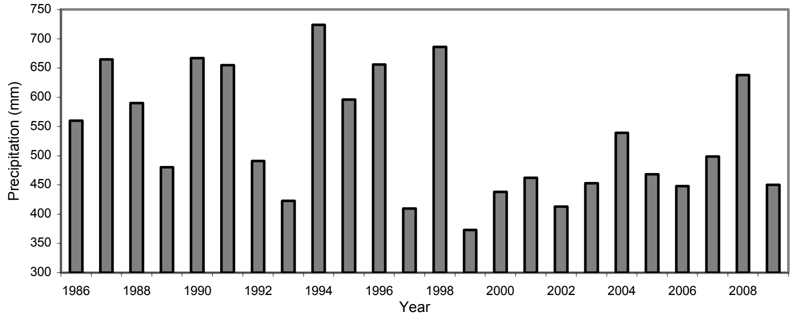
Beijing, the capital of China, is the second largest city after Shanghai and the political and financial centre of China. Important national governmental and political institutions, including the National People's Congress, are located in Beijing. Because of the dramatic economic development during the last 30 years, Beijing has been urbanizing rapidly, with an average annual increase of 2.48 per cent. Beijing is experiencing rapid economic development. Recently the average annual GDP growth rate was about nine per cent. Figure 1.4 shows that the population of Beijing increased, from 12.5 million in 1998 to 17 million people in 2008, an increase of nearly 1.5 times in ten years.

Figure 1.4
Population growth in Beijing from 1998 to 2008



Source: Beijing Statistical Yearbook (1998-2008)

Figure 1.5
Precipitation rate in Beijing from 1986 to 2009

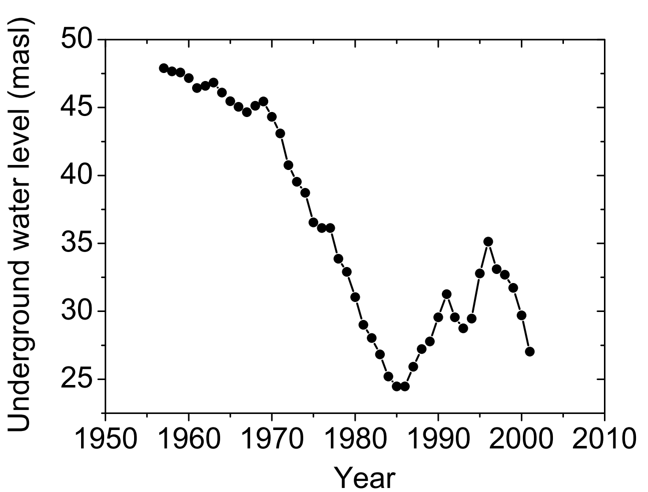


Source: Beijing Water Resources Bulletin (1986-2009)

Arid regions around the globe are most often associated with physical scarcity. Northern China, including Beijing is an area of physical water scarcity (Seckler et al. 1998). Beijing lies at the northern tip of the roughly triangular North China Plain, at an altitude of 20-60 metres above sea level. Beijing's climate is semi-humid monsoonal with a mean annual temperature of 10 to 12 centigrade. Mountains to the north, northwest and west shield the city from the encroaching desert steppes. The average altitude of the surrounding mountains is 1,000-1,500 metres. The Dongling Mountain located at the border of the Hebei province is the highest point in Beijing, with an altitude of 2,303 metres. Because of its geographical location, Beijing has low average rainfall. Beijing's average precipitation is 550 mm per year, 80 per cent of which falls between June and September (Beijing Water Authority 1986-2009).

Figure 1.5 illustrates the decrease in precipitation since 1999. The average precipitation between 1986 and 1998 was around 600 mm per year while the average precipitation between 1999 and 2009 was about 470 mm per year. In recent 10 years, precipitation decreased by 20 per cent, which led to less groundwater recharge.

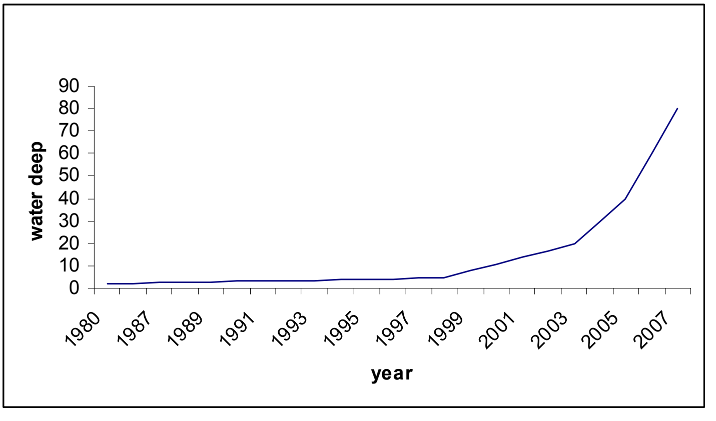
Figure 1.6
Change in underground water level in Beijing (masl = metres above sea level)



Source: Kaden (2007)

Groundwater is the main water source in Beijing, the city sources 70 per cent of total water supply from groundwater. However, overexploitation of groundwater due to increasing water demand and lower groundwater recharge both contribute to depletion of underground water stocks. Underground water levels in Beijing show significant decline since the mid-1950s (Figure 1.6). In rural areas of Beijing, the minimum depth of a well to access groundwater is around 80 metres deep while 20 years ago farmers could get groundwater from a well of only two metres depth. Figure 1.7 reflects the change in the depth of a well located in a village of the Huairou district of Beijing. It indicates that the depth of the well in 2007 was around 40 times deeper than in 1980. In some extreme cases, pumps no longer bring up groundwater and irrigation water has to come from 10 km away. The depletion of underground water stocks further complicates the difficulty of supplying sufficient water in Beijing.

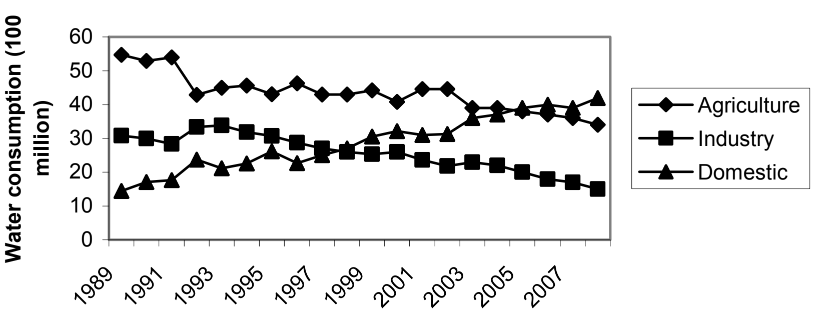
Figure 1.7
Change in well depth in a village within the Huairou district of Beijing



Source: Interviews with the farmers of the village

There are around 30,000 industries in Beijing, which accounts for 70 per cent of its GDP. Yet industrial sector water consumption accounts for only 15 per cent of total water consumption, domestic use and agricultural productions are the major water consumers accounting for 42 per cent and 34 per cent respectively according to data from 2008. The proportions of water consumption by agriculture, industry and domestic uses have changed in recent decades. Figure 1.8 shows the change in water consumption in agriculture, industry and for domestic use from 1989 to 2008. It shows that the water consumption of agriculture and industry are decreasing gradually while domestic water consumption is increasing steadily. Given the limited water supply and increasing population, more water is transferred from agricultural and industrial uses to domestic consumption. Accordingly the proportion of water consumption by agriculture, industry and domestic use has changed. Figure 1.8 shows that before 1998, agricultural water consumption was much greater than industrial and domestic water consumption, accounting for around 50 per cent of total consumption. Domestic consumption accounted for the smallest percentage of water usage. In 1998, domestic water consumption started to overtake industrial consumption although agricultural consumption is still the largest percentage. In 2006, domestic water consumption was greater than that of agriculture, becoming the largest water consumer. Domestic water consumption in Beijing rose from 1.4 billion m^3 in 1989 to 4.2 billion m^3 in 2008; agricultural water consumption decreased from 5.4 billion m^3 in 1989 to 3.4 billion m^3 in 2008; and industrial consumption declined from 3 billion m^3 to 1.5 billion m^3 during the same period (Figure 1.8).

Figure 1.8
Water consumption of agriculture, industry and domestic in Beijing



Source: Beijing Statistical Yearbook (1989-2008)

1.3 Chinese Urban Water Management

Because conventional urban water management has not adapted to the trends of urban development, new approaches to urban water management are proposed gradually. In China, many new technological measures are adopted in the cities to solve water scarcity. Additionally, the governmental structure of the water sector is changing and new water policies are issued.

1.3.1 Technological measures

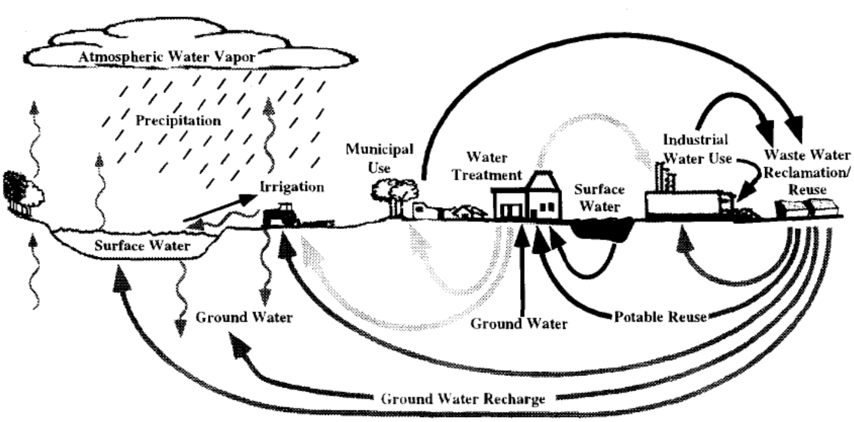
Recently considerable research and experiments related to sustainable urban water management have been funded by the governments and carried out by water engineering scientists for the purpose of solving the water crisis in cities (Asano 2005; Chu et al. 2004; Wilderer and Schreff 2000; Zuo et al. 2010). All of the technological measures for developing alternative water resources, such as wastewater reuse, rainwater harvesting or transferring water from another source to the city, have been applied in Chinese cities (Bao and Fang 2007; Deng and Chen 2003; Jia et al. 2005; Zuo et al. 2010). The following sections offer details of wastewater reuse and rainwater harvesting.

The largest and most well known project for transporting water from remote areas to cities is being constructed in the east of China, called the 'South-to-North Water Diversion' project. This project aims to transfer water from the Yangzi River (South) to the areas of the 3-H basins (Hai River, Huai River and Huang River) (North). Beijing and Tianjin are the important beneficiaries of this project. The 'South-to-North Water Diversion Project' was first proposed in the 1950s and is expected to be completed in 2014 (Source: interviews with officials at the Beijing Water Authority). Up to 2010, approximately 60 billion Yuan has been invested in the project. The detail of the 'South-to-North Water Diversion' project refers to the official website of the project: (www.nsbd.gov.cn). The project will make a large contribution to the water supply of Beijing. The project is expected to transfer 7m^3 per second of water if the project operates at full capacity. However, the financial feasibility of the project remains an open question. Since nine provinces and two provincial cities are involved in the project, there are complex issues concerning water rights, water allocation, water price and many others. Some NGOs (Non-Governmental Organizations) and researchers have criticized the project (Berkoff 2003; Liu 1998; Wang and Ma 1999).

Wastewater reuse

Wastewater reuse is the process of reclaiming grey water from industry and domestic sources and then reusing the water in industry as cooling water, domestically for toilet flushing and green irrigation, and in agriculture for irrigation. A conceptual cycling overview of urban water in Figure 1.9 illustrates the major pathways of water reuse and the potential use of reclaimed wastewater. The use of reclaimed water as an alternative water source can be perceived as an action of effective water management since fresh water is saved for other uses. It may prove sufficient flexibility to allow a water agency to respond to short-term needs as well as to increase long-term water supply reliability in urban areas (Asano 2001). Therefore wastewater reuse is a vital component of sustainable urban water management.

Figure 1.9
Roles of reclamation and reuse facilities in water recycling



Source: Asano and Levine (1996)

Several Chinese cities, such as Beijing, Nanjing and Wuhan have implemented wastewater reuse. Beijing is the first city in China to force decentralized wastewater reuse systems and is the first city to build large-scale centralized wastewater reuse systems.

Wastewater reuse was first promoted in 1987 in Beijing through issuing the *Regulation of Building Decentralized Wastewater Reclamation Systems in Beijing*, which states that all hotels and residence areas with construction areas that exceed 20,000 m^2 and all other buildings with construction areas that exceed 30,000 m^2 must build wastewater reuse systems. Decentralized wastewater reuse systems collect and treat grey water and reuse reclaimed water on site. Generally decentralized wastewater reuse systems have small capacity and scales. Until 2002, in the central region of Beijing, there were more than 154 small wastewater reuse systems (Jia et al. 2005). Although decentralized water treatment systems have developed in some cities, they are still at the early stage in developing areas. To date, around 1,000 decentralized wastewater reuse systems have been constructed in Beijing (Zuo et al. 2010). The number of decentralized systems in Beijing is increasing and will continue to grow in the future.

In addition to decentralized wastewater reuse systems, large centralized wastewater reuse systems operate in Beijing. Centralized wastewater reuse systems collect grey water from different organizations and households, reclaim the collected grey water in a large plant, and then distribute the reclaimed water to users. Normally centralized wastewater reuse systems are large-scale operations. The first centralized wastewater reuse system in Beijing began operating in 2000. There are five centralized wastewater reuse systems in Beijing: the Gaobeidian wastewater reclamation plant (designed treatment scale: 470,000 m^3/day); the Jiuxianqiao wastewater reclamation plant (designed treatment scale: 60,000 m^3/day); the Fangzhuang plant (designed treatment scale: 10,000 m^3/day); the Wujiacun plant (designed treatment scale: 40,000 m^3/day) and the Qinghe plant (designed treatment scale: 80,000 m^3/day). Only two systems, the Gaobeidian and the Jiuxianqiao plants are in operation, the others are still under construction.

Although wastewater reuse in Beijing started 20 years ago, the quantity of reclaimed and reused water is still very small. In 2008, in Beijing, 0.6 billion cubic metres of water was reclaimed, accounting for 17 per cent of total water supply in Beijing (Beijing Statistic Yearbook 2008). Reclaimed water in Beijing is mostly used for domestic uses (toilet flushing, car washing and green irrigation), industry (cooling water) and water supplementation of rivers and lakes. Very little reclaimed water is used for agricultural irrigation. Another technological measure, rainwater harvesting, which aims to supplement water for agricultural irrigation, appears in the next section.

Rainwater harvesting

Rainwater harvesting is to induce, collect and store runoff from various sources for various purposes. Researchers in many places, such as in Sub-Saharan Africa, the Middle East and Asia have made efforts to develop rainwater harvesting for irrigation. In China, people have harvested rainwater for thousands of years, especially in the rural areas of the western north of China. Yet the most efficient use of rainwater for agricultural irrigation remains a subject of debate (Li et al. 2000; Mushtaq et al. 2007; Tian et al. 2002).

In urban areas, rainwater harvesting is rare because of the challenges of collecting and reusing water of sufficient quality. Many industrial zones are constructed around the city and domestic consumption creates various wastes so that air pollution is unavoidable in the city. This leads to poor quality rainwater. Normally the process of rainwater harvesting is easy and cheap, including the process of collecting, depositing and reusing. Given the poor rainwater quality, it is necessary to add water treatment processes, which could raise the cost of using rainwater in the city. Therefore rainwater harvesting and reuse in urban areas is more complex and costly than in rural areas.

According to Zuo et al. (2010), rainwater harvesting in Beijing has gone through three stages: 1) initial study and exploration (1981-1999); 2) intensive research (2000-2005); 3) implementation of projects driven by the government (2006-present). A large number of rainwater harvesting projects have begun in Beijing since 2006, of which some are located in the urban areas of Beijing and others are in rural areas. In the rainwater harvesting projects in the urban areas, the collected rainwater is usually used for toilet flushing, car washing and green irrigation. In rural areas, the rainwater is mostly used for agricultural irrigation.

Figure 1.10 illustrates the distribution of urban and rural areas of Beijing. Beijing occupies an area of 16,410 square kilometres, of which 8 per cent is urban areas and 92 per cent rural areas. According to the statistics, the number of rainwater harvesting projects in rural areas is greater than in the urban areas of Beijing (Zuo et al. 2010). Thus rainwater harvesting in Beijing is currently concentrated in rural areas for agricultural irrigation. Rainwater is the alternative water resource to replace ground water for supplementing the supply of irrigation water in rural areas of Beijing.

Figure 1.10
Distribution of Beijing's urban and rural areas

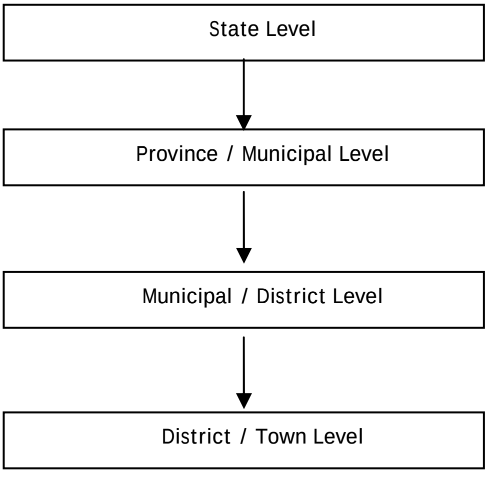
1.3.2 Water governance structures

Water governance in China

The water governance structure in China is a multi-layered hierarchy. The various agencies within the structure are divided by territory, function and rank. Figure 1.11 shows the hierarchy in terms of territory. The arrows lead from the order-giving body to order–receiving body.

Some agencies have specific functions. They are always headed by a ministry at state level and have corresponding agencies or bureaus at provincial, municipal, county and district levels. For example, there are the State Environmental Protection Agency (SEPA), provincial environmental protection agency and urban environmental protection bureaus. SEPA owns the provincial environmental protection agencies, which in turn owns the urban environmental protection bureaus. The head of SEPA appoints the heads of the provincial environmental protection agencies. The functional agencies exist within the different territorial ranks. So in different provinces or cities, the functional agencies concerned with water service and resource governance are almost the same.

Figure 1.11
Hierarchy of territorial rank



Every agency or bureau within the governance structure has a rank. Agencies and bureaus with the same rank cannot issue orders to each other. Only higher-ranking agencies can issue authoritative orders to lower-ranking agencies. For example, the Ministry of Construction has the same ranking as the Beijing municipal government. So the Beijing government could not issue a command to the Ministry of Construction. The communication should flow up and down level by level. It is rare that the provincial government issues commands to the town level skipping the municipal level.

The hierarchical governance structure creates a complex system of ministries, agencies and bureaus. It leads to an unclear policymaking process. Finding out how policies are made in China is much like tracing the movement of a single blood cell through the entire human body: the journey is time consuming and involves a network of organs and the specific route depends on the situation (Hou 2000). Figure 1.12 shows the old water governance structure of Beijing. It reflects the hierarchical order in the water sector and shows all kinds of agencies involved in water management in Beijing. In spite of the rigid structure, organization and cooperation between the agencies is poor.

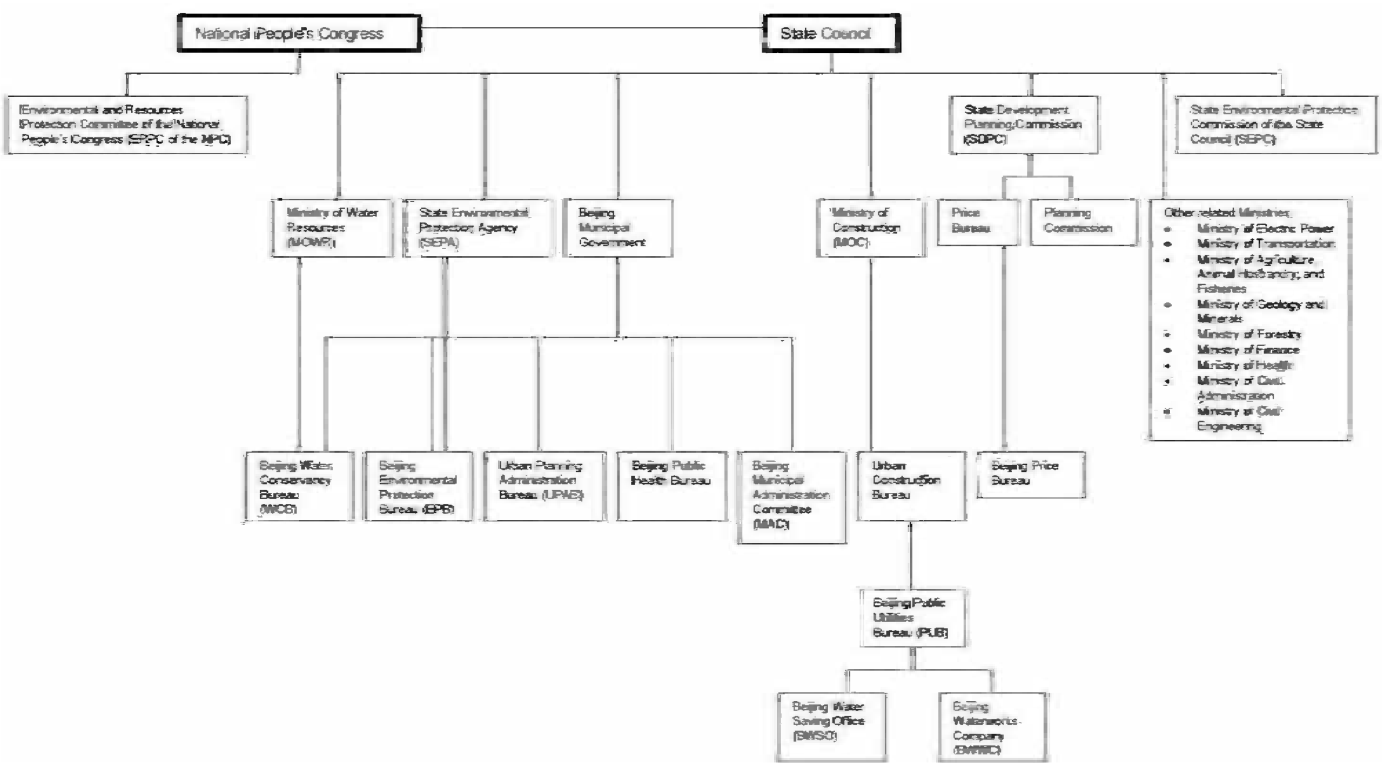
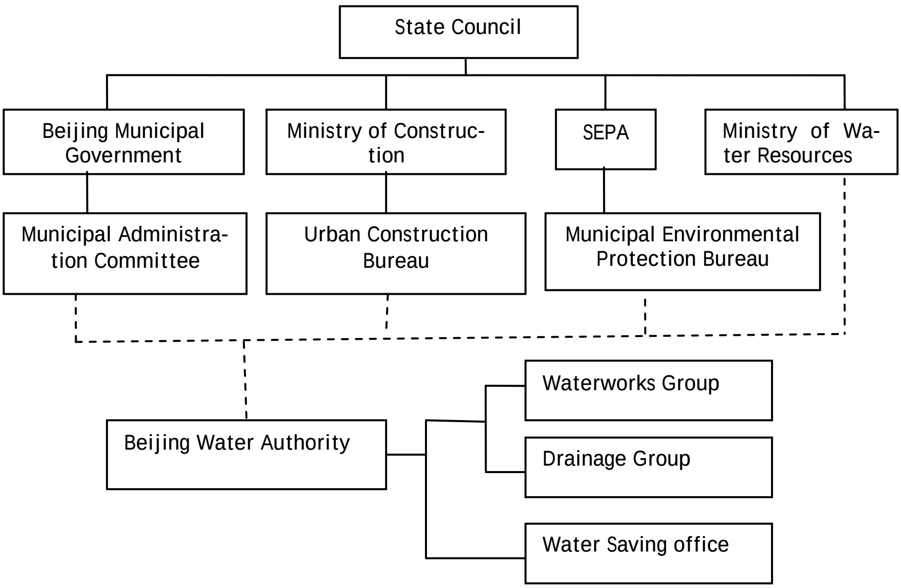


Figure 1.12

Organization of water relative governance in Beijing (Source: Hou, 2000)

Figure 1.13
New water-relative organizations of Beijing



China is experiencing reform in water governance structures and institutions. The purpose of the reform is to reduce the number of agencies and bureaus involved in water management. The new water governance structure of Beijing, which could be an example for other Chinese cities and provinces, is shown in Figure 1.13. It reveals that in the new governmental structure there are four most relevant agencies: the Ministry of Water Resources, the State Environmental Protection Agency, the Ministry of Construction and the Beijing Municipal Government, involved in urban water management within Beijing. Beijing Water Authority is a new organization for water services and management, which was established in 2004 and is owned by the Beijing municipal government. It is in charge of water services and management at the different ranking territories. It is being established in many cities and provinces. There are two main functional organizations in the Beijing Water Authority: the Waterworks Group and the Drainage Group. The waterworks group is responsible for municipal water supply and the drainage group is responsible for municipal sewage treatment. Additionally the Water Saving Office (shown in Figure 1.13) is an important organization in the Beijing Water

Authority, in charge of promoting policy or project performance related to water saving.

According to the hierarchical structure, there will be provincial water authorities, urban water authorities and district/county water authorities. In Beijing, the Beijing Water Authority faces three layers of government from the municipal to the town levels (Table 1.1). Beijing has 16 districts and two counties, each district has sub-districts or, each county has towns.

Table 1.1
Three layers for water management of Beijing

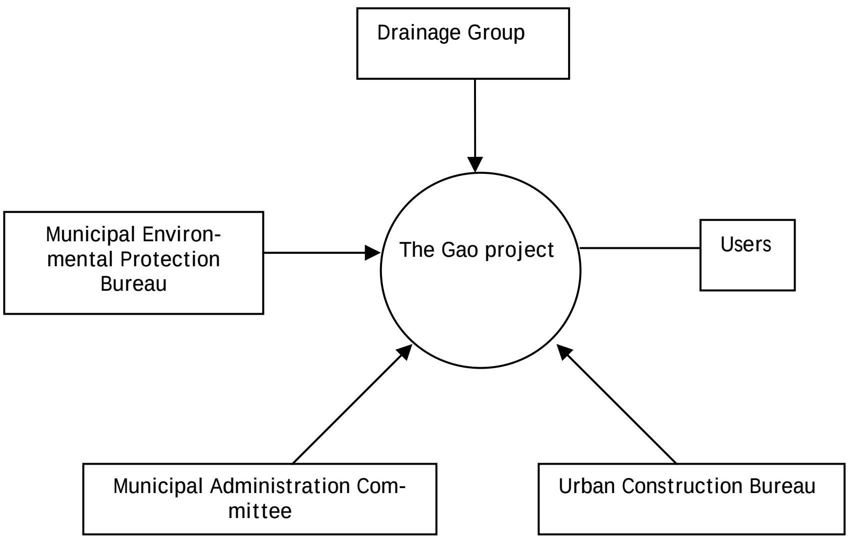
Municipal Level	Beijing Water Authority	**Responsibilities**: Water resources, water supply and water pollution management etc. within the municipality. Coordinates among districts/counties.
District/ County Level	District/County Water Authority	**Responsibilities**: Water resources, water supply and water pollution management etc. within the district/county. Coordinates among sub-districts/towns.
Sub-district/ Town Level	Sub-district/Town Water Management Station	**Responsibilities**: Water resources, water supply and water pollution management etc. within the region.

Source: Pan (2006)

Water governance structures in Beijing to deal with water scarcity

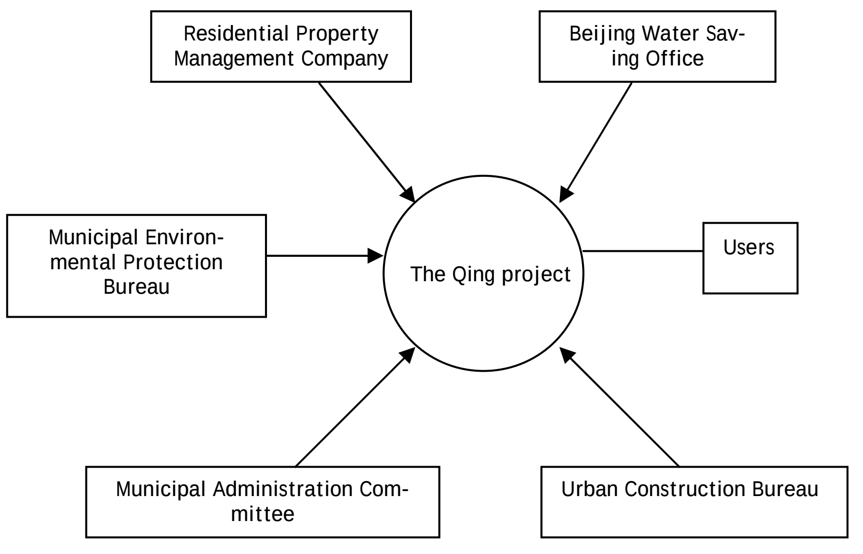
Since the mid-1980s, continuous droughts and increasing population have worsened water scarcity in Beijing. Many projects concerned with water saving have been constructed and are promoted by the Beijing government. Because of the reform in the water governance structure, the number of organizations involved in the management of these newly constructed projects decreased. Meanwhile, to deal with water scarcity efficiently, many new organizations were established for the management of the projects related to water saving.

Figure 1.14
Gao plant main stakeholders



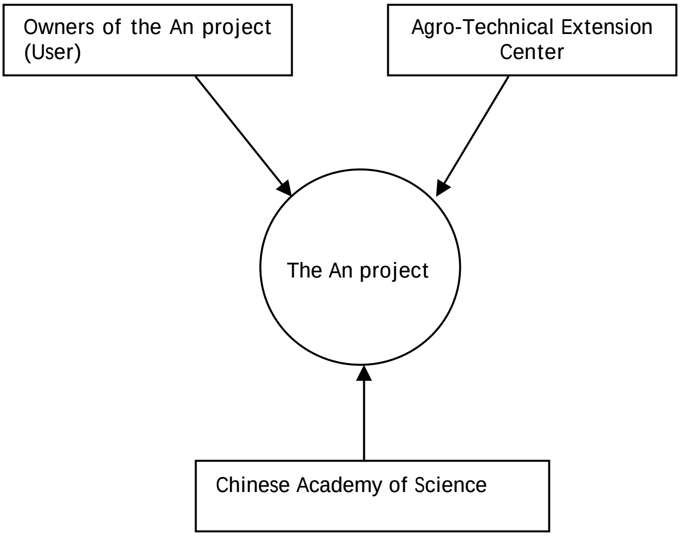
For the large water treatment plant, previously there were many organizations involved in management because it has a critical influence on society's health. This leads to problems in management of the large plants, which are often inefficient and sometimes ineffective. The reform of the water governance structure decreased the number of involved organizations, which may lead to improved management efficiency. The Gao Bei Dian wastewater reuse plant (Gao plant) in Beijing started in 2000 and is an example of the management of a large plant in the new governance structure. The Gao plant is owned by the Beijing Drainage Group, which belongs to the Beijing Water Authority. As shown in Figure 1.14, there are four main stakeholders in the Gao plant: the Drainage Group, the Municipal Environmental Protection Bureau, the Municipal Administration Committee and the Urban Construction Bureau. Under the 'old' structure of water governance in Beijing, there would have been eight organizations involved in the management of the Gao plant, while in the 'new' structure, the Beijing Drainage Group, as the owner of the Gao plant, is the key manager of the Gao plant. The functioning of the Gao plant is analysed in Chapter 3.

Figure 1.15
Qing plant main stakeholders



For decentralized treatment projects related to water saving, the Beijing Water Saving Office plays an important role. The Beijing Water Saving Office was established in 1981. Before the reform in water governance in Beijing, it was a small institute belonging to the Beijing Public Utilities Bureau. Previously the Water Saving Office was below the bureau level. However, after the reform in water governance structures in Beijing, the rank of the Beijing Water Saving Office increased to the bureau level. Due to serious water scarcity in Beijing, the promotion of water saving became more important. Consequently the responsibility of the Water Saving Office was enhanced. An example of the management of a decentralized water saving project is Qing plant (Figure 1.15). There are five main stakeholders involved in the management of the Qing plant. The Municipal Administration Committee and the Urban Construction Bureau (in charge of operation supervision), as well as the project manager and the Water Saving Office play important roles in managing the plant. In Chapter 2, an economic and financial analysis of the Qing project will assess its feasibility.

Figure 1.16
An plant main stakeholders



Many rainwater harvesting projects have been constructed in rural areas of Beijing to diminish water scarcity. The Beijing Water Saving Office supports some of these projects, and the Beijing Agro-Technical Extension Center supports others. Generally the owners of projects and the Beijing Agro-Technical Extension Center/ Beijing Water Saving Office are the main stakeholders of these projects. In some cases, academic institutions are involved in the management of the experiment. Figure 1.16 illustrates the main stakeholders of a rainwater harvesting project in rural areas of Beijing, the An plant. At the An plant, in addition to the owner and the Beijing Agro-Technical Extension Center, the Chinese Academy of Science is an important stakeholder. The detailed analysis of rainwater harvesting appears in Chapters 4, 5 and 6.

The Beijing government has promoted water saving in various sectors such as industry and agriculture. To extend water saving effectively, organizations in different sectors join in project management. For example, the Beijing Agro-Technical Extension Center is responsible for training farmers in new agricultural technologies and for technical support. The Agro-Technical Extension Center is not a professional organization in the water sector, but it joins the management of rainwater harvesting systems. Other academic institutions such as the Chinese Academy of Science are also involved in the management of these projects.

1.3.3 New policies

There are several crucial laws concerning water resource management in China. The *Water Law*, issued in 1988 and revised in 2002, aims to undertake the rational development, utilization, saving and protection of water resources. Additionally there are the *Water Pollution Prevention Law*, the *Water and Soil Conservation Law*, the *Environmental Protection Law* and other relevant laws and regulations. The *Water Pollution Prevention Law*, issued in 1984 and amended in 1996, plays an important role in preventing water pollution. The *Water and Soil Conservation Law* issued in 1991, emphasizes protection and conservation of water and soil recourses. The *Environmental Protection Law* issued in 1989 aims to protect and conserve national environmental resources.

In response to legal institutions established at the national level, the provincial and municipal governments are able to establish their own legal systems appropriate to local circumstance. For example, due to the rapid development of urbanization and industrialization, wastewater discharges into rivers, lakes and trenches without serious treatment. This means that a number of Chinese cities have experienced serious water pollution. The State issued the national level *Water Pollution Prevention Law* to help prevent water pollution in urban areas. Accordingly different regulations were issued at the regional level. For example, in Beijing, there are the *Quality Standard of Wastewater Discharge in Beijing* and the *Guan Ting Dam Water Conservation*.

As water scarcity is a serious problem in Chinese cities, many regulations concerning water saving were issued in some Chinese provinces or cities. For example, in Beijing, there is the *Regulation of Reward on Water*