

Does Wastewater Reuse Present a New Future?

The Solution of Water Shortage in Beijing

School of Engineering Practice

Department of Engineering and Public Policy

Presented to: Dr. Gail Krantzberg

Prepared by: Chunbo Wang

Date: September 23, 2008

Table of Contents

Section 1	Purpose of the Inquiry.....	1
Section 2	Introduction.....	1
Section 3	Study of Water Supply.....	2
Section 4	Study of Water Consumption.....	5
Section 5	Wastewater Treatment and Reuse.....	9
Section 6	Wastewater Reuse Sources	11
Section 7	Current Institutional Framework of Water Management.....	13
Section 8	Thinking and Policy Recommendations	13
Section 8	Conclusion	24
References.....		27

Section 1 Purpose of the Inquiry

The purpose of this paper is to find solutions for the problem of water shortage in Beijing and find out whether wastewater reuse is a necessary and sustainable source of water supply. This is done by asking the following questions: What is the current situation of water supply and demand in Beijing? What are the reasons for water shortages? Are the engineering solutions which Beijing has preferred over the last decade sufficient and sustainable in the long run? If not, what is the prospect of wastewater reuse? What are the challenges of reuse and possible solutions?

Section 2 Introduction

For many years, Society has made tremendous efforts to find solutions to water shortages (Jia, Guo & Wang, 2005). This is because water is a very crucial resource in all aspects of a country' development. The reasons for water scarcity can be broken into two main categories: (i) natural lack of water resources; and (ii) poor water management arrangement.

Beijing, the capital of China, known for its long history and rich cultural heritage, has been experiencing water scarcity since 1990s (Atasoy, etc., 2007). But, in the distant past, Beijing was not short of water resources because of a smaller population and relatively abundant ground water resources. However, with the rapid economic growth and urbanization in Beijing, pressures on water supply have been steadily accumulating and have gradually evolved into a major constraint to further development. The remainder of this paper investigates into this problem and the plan is as follows: Section 3 studies the historical and current sources of water supply Beijing draws upon. Section 4 studies Beijing's water consumption pattern and points to possible places where wastewater could

be substituted for fresh water. Section 5 introduces the current situation and facilities of wastewater treatment in Beijing, analyzes its wastewater reuse potential and identifies the two sources of wastewater reuse: centralized and decentralized treatment systems. It then concludes that wastewater reuse is a reliable, practical and economical alternative water source. Section 6 presents the institutional challenges in the current water management framework. Section 7 summarizes the author's thinking and policy recommendations. The final section provides conclusions.

Section 3 Study of Water Supply

Beijing, the capital of China, is located in the middle reaches of Hai river basin and is the one of the most water-stressed cities in the country. It only has 1.5 per cent of China's water resources, but 10.1 per cent of China's population, 11.2 per cent of China's farmland, and 11.3 per cent of China's GDP. The per capita water resource is 350 cubic meters annually. Beijing has 8 million people in its core urban area and 6 million people residing in the rural periphery, respectively (Nickum & Lee, 2006). Beijing used to have abundant groundwater resource because it is located in the north-eastern of the alluvial North China Plain. According to the Beijing Municipal Water Resource Bureau in a median (P = 50 percent) year, Beijing receives 2.2 billion m³ in surface water and 2.5 billion m³ of groundwater inflow. Because part of the groundwater came from the surface, there was double counting on the above number and the average annual water resource is around 3.5 billion m³. Based on this information, Beijing should have abundant water resource, but the problem is that the amount of surface water is not stable and this directly leads to the insufficient inflow for groundwater. In the long run, the groundwater aquifer will keep declining; in 2004 the mean underground water table decline was around 0.5 meter and

some districts saw the water table dropping by even more than 4 meters (ER¹ 1). This is why the municipal government is now keeping a very strong control over the groundwater extraction.

Currently, there are two main reservoirs supplying surface water to Beijing, Guanting and Miyun reservoir. Guanting reservoir, built in 1954, is mainly in Hebei Province which is right adjacent to Beijing. Its inflow has dropped greatly because of the upstream construction of dams in order to meet all upstream water demands of Hebei itself and three other provinces. Also, the agricultural and industrial wastes from the upstream deteriorated the water stored in the reservoir so that the Beijing municipal government decided to stop drawing water from the reservoir for any use in 1997. The Miyun reservoir (as shown in figure 1) was built shortly after the Guanting reservoir and was originally not intended to provide water for the city of Beijing. However, Beijing's demand for water continued to increase; consequently, in 1980s the central government allowed the city to use water from the reservoir and now Miyun is supplying the most surface water to Beijing. It also provides drinking water for the city because overdrawing of groundwater was no longer allowed. Unfortunately, inflow into Miyun reservoir has also dropped because of recent drought years (1999, 2001 and 2003) (Nickum & Lee, 2006). Despite the decline in surface water supply, water demand keeps rising. Therefore, to fill the widening gap, Beijing intends to divert water from Yangtze River by 2010. The diversion project will not serve Beijing exclusively; it is intended to assuage the water shortage in the entire northern China. This diversion project is expected to be able to increase water supply in Beijing by 1 billion m³ annually. The challenges facing the water diversion project include how

¹ ER refers to electronic/website reference. See bibliography.

effectively it will work given its huge cost and whether the end-users are willing to and able to afford the charges. Furthermore, the project is not supposed to meet the precipitous increase of water demand.

Beijing Sustainable Use Plan (Nickum & Lee, 2006) has described in details

Beijing's water supply history:

“We made it (water shortage) through the urban water supply crisis of the mid-1960 by digging the Jing-Mi diversion that brought in Miyun Reservoir water [to the urban area]; we made it through the water supply crisis of the 1970s by drawing down the aquifer; and we made it through the water supply crisis of the early 1980s by relying on a Central Government policy shift to reserve the water of the Miyun exclusively for Beijing, cutting off Tianjin and Hebei (two coterminous cities of Beijing), as well as on developing planned water use and water saving.”

It is clear from the foregoing statement that the government has done a tremendous amount of work to maintain adequate water supply in Beijing and the programs implemented by the municipality did solve the problem during certain time periods. Also, it is manifest that merely digging in the ground for more water was not sustainable since the water table drops too rapidly. That was why Beijing had to cut off Tianjin and Hebei and reserve Miyun reservoir for Beijing exclusively. A salient feature of Beijing water management is that it is project-addicted and crisis-driven. To divert river from Yangtze will not be a panacea. A more sustainable way to solve the problem is to find a more long-run and less crisis-driven solution from within the city itself. For example, how to reasonably minimize the amount of water consumption and maximize the amount of reused water merit more attention and consideration than ever before. Engineering solutions are not boundless. The nation-wide water diversion project is a perfect example. It is true that the central government has the economic power and political right to use all resources across the whole country to support Capital Beijing, this will nevertheless hurt other parts of the country in the future, socially and economically. Moreover, this may give Beijing

citizens a false sense of water security and a disincentive to conserve water. Lately, there have been many discussions regarding whether or not the central government should continue to have centralized power of this magnitude and whether the power should be released to the local government, for instance to the provincial governments, and so on (Wang, 2007). This refers to the topic quickly taking off in China recently, “institutional reform”. Many sociological experts think that reforms can help the country to manage many social problems and make governments work even more effectively and efficiently (Nickum & Lee, 2006). There have been strident demands for institutional reform and more decentralized decision making process.



Figure 1 *Miyun Reservoir*

(<http://ditu.google.com/maps?gbv=2&ndsp=18&hl=zh-CN&q=%E5%AF%86%E4%BA%91%E6%B0%B4%E5%BA%93&ie=UTF-8&sa=N&tab=il>)

Section 4 Study of Water Consumption

With its large population, China has long been experiencing water shortages, low per capita water consumption as well as uneven distribution of water resources across time

and space. 667 cities in China have low levels of water supply and 27 per cent of China's surface water is of quality below the national water standard (Chu, etc., 2004). Beijing is one of the cities where the problem of water shortage looms large. Generally, there are three main consumptive uses: households/municipal, industry and agriculture (Abbaspour & Yang, 2007). According to *Beijing Water Resources Bulletin* (2005), domestic, environmental, industrial and agricultural water use account for 39%, 3%, 20% and 38% of total amount of water use, respectively (ER 2). Compared with 2003 and 2004, domestic and environmental water use increased and industrial use declined marginally.

As the capital of the China, Beijing has been experiencing rapid development in terms of economy and population, both of which accelerated the growth in water demand. According to a very recent prediction by the Ministry of Water Resources, the amount of water consumption in Beijing is going to reach 3.7 billion m³ in 2008, one sixth of which is expected to be supplied by reclaimed wastewater (ER 3). Different from long distance water transfer and exploitation of rare water resources, wastewater reuse can in many ways be considered as a reliable, practical and economic alternative water resource. Table 1 shows the general water use of different sectors, wastewater discharge and capacity of treatment plants in Beijing in the years of 1990, 1996, 2000 and 2003.

Water supply, wastewater discharge and wastewater treatment capacity in Beijing

	1990	1996	2000	2003
Total water supply (million m ³ /y)	4142	4094	4040	3800
municipal	704	930	1296	1163
industry	1234	1176	1052	954
agriculture	2204	1988	1692	1683
Wastewater discharge (million m ³ /y)	837	859	895	940
municipal	431	504	663	760
industry	406	390	232	180
Wastewater treatment capacity (1000 m ³ /d)	304	600	1050	1400
Ratio of treated wastewater to total wastewater discharge (%)	7	25	42	54

Table 1 (Abbaspour & Yang, 2007)

Domestic Water Consumption

In the predictable future, domestic water use will continue growing and may eventually dominate water usage in the city because more and more people prefer to move to and live in the capital of the country, especially after the 2008 Olympics hosted in Beijing. This is because the city's infrastructure will be improved greatly after the Olympics. Table 2 (ER 4) is the composition of domestic water use in Beijing. The number, 104.14 litres per person per day, is very low compared with many other cities in the world, but when the total population is considered, the volumes are large. Currently there are around 17 million (ER7) in Beijing and the total annual consumption of domestic water consumption is 646 million m³. According to one prediction, there will be 21.5 million (ER 8) people in Beijing by 2020 and this is equivalent to a total annual consumption of 800 million m³. This projection is calculated based on the current use of water in Beijing—104.14 litres per person per day. It is clear that Beijing has a huge potential gap to fill between the water demand of the present and that of the future. Table 2 indicates some potential areas to save water such as toilet flushing.

Category of Consumption	Quantity (Litre/person day)	Percentage
Drinking	2.25	2.16
Self Cleaning (face, shower, etc.)	42.51	40.82
Cloth Cleaning	22.53	21.63
Cooking & Dish Washing	5.43	5.21
House Cleaning	4.25	4.08

Piscicultural and Floricultural Use	0.17	0.16
Toilet Flushing	27.00	25.93
Total	104.14	100.00

Table 2 (Household water consumption pattern in Beijing) (ER 4)

Industrial Water Consumption

Since the mid-1990s annual industrial water use (mainly manufacturing) in Beijing, on the whole, has decreased from 1.35 billion m³ and eventually stabilized at around 0.9 – 1 billion m³. One of the leading reasons for the decrease was that the manufacturing industry was no longer the primary contributor to the city's GDP and was superseded by the Service industry (Zuo & Chen, 2005). Other possible reasons include the recent technological development and the increase in the cost of water for certain industries that tend to use large amount of water (Zuo & Chen, 2005). Also, industrial use is expected to decline further more after the biggest industry in the city – Beijing Shougang Co., Ltd. is moved to Hebei province as planned. Ideally, industrial use could be eliminated from the city's water use because it is not necessary to keep a large amount of industry in the capital of a country. Two apt examples for illustration are Washington of the US and Ottawa of Canada. However, reallocation of manufacturing industries will engender shift of job opportunities from Beijing to other parts of the country. The possible large-scale unemployment is expected to have great bearing on social stability and welfare of citizens and therefore merits deliberate consideration by the municipality.

Agricultural Water Consumption

The agricultural use of water is not expected to decrease because on the one hand it is very important for the city's sustainable development and on the other hand it is almost impossible to reallocate all people, around 3.1 million in 2004 (ER 9), who are currently living on agriculture. Although the three gorges project involved large-scale reallocation, it is not likely to happen in Beijing since the city occupies 11.2 percent of the national farmland, which is a main source of food supply and is therefore very important in a country with a large population and great food demand.

Water consumption analysis shows that Beijing does consume a huge amount of water and this trend, no doubt, will last. This is something neither the central government nor the municipal government can easily control by administrative instrument since per capita water consumption is already at a rather low level. Additionally, according to the previous study on water supply it has become increasingly difficult and costly to rely on the unsustainable engineering solutions. In light of this, the government should look for sustainable solutions from within the city itself.

Section 5 Wastewater Treatment and Reuse

Different from long distance water transfer and draining of aquifers, wastewater reuse is a reliable, practical and economical alternative water resource. It is due to this reason that efficient wastewater reclamation and reuse should be key component of water policy making in China.

Wastewater Treatment

In China, “existing waste water treatment plants (WWTPs) are mostly money-losing enterprises and rely on public funds for operation” (Abbaspour & Yang, 2007). An official announcement in 2003 made it clear that the government would no longer monopolize the wastewater treatment market and would open the market to all interested parties because of financial pressure, low market participation rate and the resulting lack of efficiency (ER 10). Although the government realized the potential benefit of relinquish monopolizing power in wastewater management, it in fact continued controlling wastewater treatment through one primary enterprise, called Beijing Drainage Group which is responsible for wastewater treatment in Beijing. Beijing Drainage Group Co. Ltd (BDG) is a wholly state-owned wastewater utility established with the approval of the Beijing Municipal Government. Its registered capital is 1.8 billion RMB yuan and asset value has reached over 15 billion yuan (ER10). The principal activities of BDG are the collection and treatment of sewage as well as reclamation of treated wastewater, aiming at water pollution control and effective management of water resources. Now BDG boasts over ten subordinate professional companies engaged in activities that range from large capital programs delivery, operation and management of sewerage facilities, scientific research and development to technical consulting service (ER 11). On average, a new wastewater treatment plant and 100 km of high quality sewers are put in place each year. The fast expansion of wastewater facilities ensures that the treatment capacity grows at a rate of more than 10% annually. The facilities now possessed by BDG cover over 95% of those used in Beijing urban area. By 2008, over 90% of wastewater in Beijing will be properly treated (ER 12).

It is clear from the foregoing statement that Beijing now has adequate facilities to treat wastewater. However, there are controversies over the optimal scale of wastewater

reuse in Beijing. Also, despite the rapid expansion in the wastewater treatment capacity, the overall scale of wastewater reuse is small, less than 20% of the quantity of treated wastewater.

Reuse Potential

As estimated by Chu et al. (2004) using a Linear Programming (LP) optimization model, Beijing has the largest quantities of potential wastewater reuse, i.e. 0.31 BCM. However, the current quantities of wastewater reuse in Beijing are only 0.04 BCM, which only accounts for 12.8% of potential volumes estimated; whereas in progressive parts of China, reuse could account for as high as 38% of discharged urban wastewater. As a result, Beijing has a very large potential to reuse treated wastewater.

Section 6 Wastewater Reuse Sources

In General, wastewater can be reused through two main sources: central wastewater treatment plant and decentralized in house or on-site wastewater treatment facilities.

Centralized Wastewater Treatment Plant (WWTPs)

Chu et al. (2004) points out that centralized reclaimed wastewater is widely used for agricultural irrigation, landscape irrigation, ground water recharge, industrial uses and recreational impoundments, and currently it is the dominant wastewater reuse source in China and elsewhere.

Decentralized in-house or on-site Wastewater Treatment Facilities

The decentralized wastewater treatment is a process that wastewater is treated and discharged in the area where it is produced (Loudon, 2001). According to an Environmental

Protection Agency (EPA report, 1998), “decentralized on-site and cluster wastewater systems can be the most cost-effective option in areas where developing or extending centralized treatment is too expensive.”

In the 21st century, urbanization is a clear trend in lower-income countries (Parkinson & Tayler, 2003). Obviously, Beijing is experiencing this situation and there are two groups of incoming people: the first group live around the peri-urban area and consist of a huge number of people who come from other provinces and work in Beijing; the second group are permanent immigrants who live in newly developed communities. In the peri-urban area, there are not comprehensive wastewater collection and disposal system so that people often discharge wastewater onto the ground or vacant areas. Clearly, this kind of disposal will not only cause environmental and sanitary problems but is certainly a waste of resource. Therefore, a decentralized system becomes practical in this situation. This requires the involvement of local departments to be responsible for managing the facilities. Parkinson & Tayler (2003) provide three options for decentralized treatment systems: anaerobic treatment, waste stabilization ponds and constructed wetlands. The anaerobic treatment is comparatively more applicable and important because it does not need much land area which Beijing lacks and it deals with “black water and faecal sludge from household latrines” which is the major contributor of household wastewater. It is also very easy to apply anaerobic treatment. According to Parkinson & Tayler (2003), the simplest form of septic tank “both settles suspended solids and achieves some anaerobic digestion of those settled solids”. One of weaknesses of the simplest septic tanks is that they are not very effective with pathogen reduction. Other anaerobic options include anaerobic waste stabilization ponds, anaerobic filters and upward-flow anaerobic sludge blanket reactors. There are more complicated forms of anaerobic treatment require more advanced

technology and higher cost but they are more safe and reliable and are suitable for wide application.

Section 7 Current Institutional Framework of Water Management

China's water supply is subject to segmented management problem where real powers are segmented and lie in the hands of quite different institutions. In terms of urban water cycle, "the water source does not manage water supply, water supply does not manage discharge, discharge does not manage pollution control, pollution control does not manage reuse" (Beijing Shi Renmin Zhengfu, 2001). For example, water (the most generic form) is managed by the Ministry of Water Resources (through the river basin commissions) in association with local governments. Water pollution problems, most of which could be traced to land-based sources, fall largely under the control of the State Environmental Protection Administration (SEPA). Soil erosion is a separate matter of concern to the Ministry of Agriculture and the State Forest Administration. The administration of hydropower stations is shared between the State Power Company and regional authorities (Gu, 2002). Urban water supply and sewerage has been the traditional domain of the Ministry of Construction. Water prices are set by separate pricing bureaux that are usually more concerned about social stability than cost recovery (Nickum and Lee, 2006). It is clear that the current institutional framework does not fit into either the hydrological cycle or the ecosystem. It is too complex and prone to rivalries and inefficiencies.

Section 8 Thinking and Policy Recommendations

One – Water Price Reform

The low fresh water prices in comparison to the reuse prices of treated wastewater in Beijing has discouraged reuse of wastewater and resulted in inefficiency in resource use.

Low prices have not encouraged water savings and source protection, and have forced all facilities to depend on the governmental subsidies in order to operate (Nickum & Lee, 2006). Beijing should raise water prices sufficiently to better reflect the value of water and encourage reuse of treated waste water.

As noted by Liu (2002), water is an economic good consisting of two components: the value and the cost. The value of water is the price consumers are willing to pay for using water. The cost of water includes supply cost, opportunity cost and externalities. Supply cost refers to operation and maintenance (O & M) cost, as well as capital cost. Opportunity cost refers to the fact that water consumed by one person is water deprived of another consumer. Externalities refer to such environmental cost as over-extraction from or contamination of water resources, as well as the impact of an upstream diversion of water or the release of pollution on downstream users.

It is crucial that Beijing considers the full cost of water as the combination of supply cost, opportunity cost and externalities. In thinking about sustainable development in economics term, “sustainable development can be understood so that sustainable development is development that pays its full cost during the process of development” (Panayotou, 1994). By charging full cost, the social cost of using water is also considered and therefore it can prevent overuse of invaluable water resources due to artificially low prices that ignore environmental concerns.

The Sustainable Use Plan mentioned that the city of Beijing had set a target which was to increase the water price up to 6 yuan/m³ on average and 4.5 yuan/m³ for household use, including sewerage and water supply. However, despite the efforts by the government to push through water price reform measures in recent years the water fees in Beijing were

only raised to an average level of 3.7 yuan/m³ (Xinhua she, 23 December 2004) due to political considerations. This is far from reaching the goal of sustainable development because even the target level remains too low (1-2 percent of disposable income) (Han 2004) to have a significant impact on household water use behaviour or to make operations attractive to private investors. Figure 2 exhibits the water price in Beijing since 1990s (Chen & Yang, 2007). Although it is evident from the figure that water price has increased rapidly since the 2000, it is only because the initial water price is too low, almost nothing. Another attempt by the municipal government to increase water price was a plan called “block pricing” in 2005 (Nickum & Lee, 2006) but this was again postponed due to the metering incompleteness among residents.

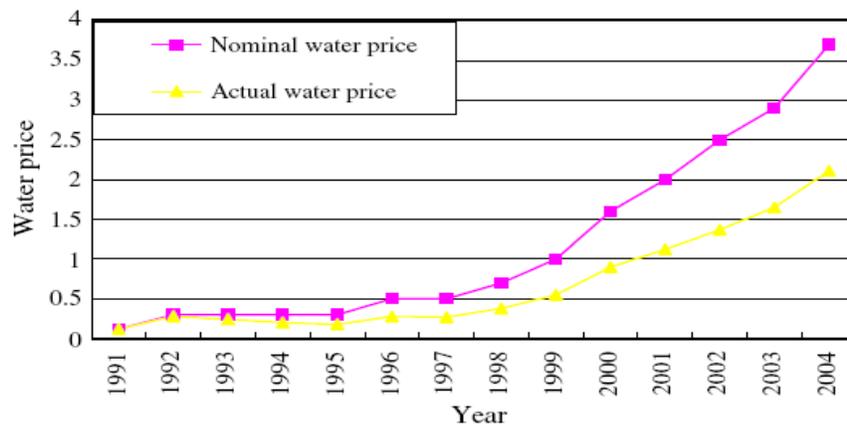


Figure 2 (Chen & Yang, 2007)

Although the above two attempts did not succeed, it does not by any means suggest that water price should not or cannot be raised to reflect social cost. The most common objection to increasing water price to its full cost is that the city’s per capita income is very low and this will hurt the poor and cause political instability. The author finds this argument not well-grounded under close scrutiny.

It is true that the city's per capita income is relatively low (Figure 3), according to the official report (ER 15), only around 20,000 yuan (equivalent to around 2920 US dollars). But the nominal amount says nothing about the current situation. Rather, it is the percentage of water fee to the disposable that really matters. According to Han (2004), this figure is very low-only 1 or 2 percent and still has large room for further increase.

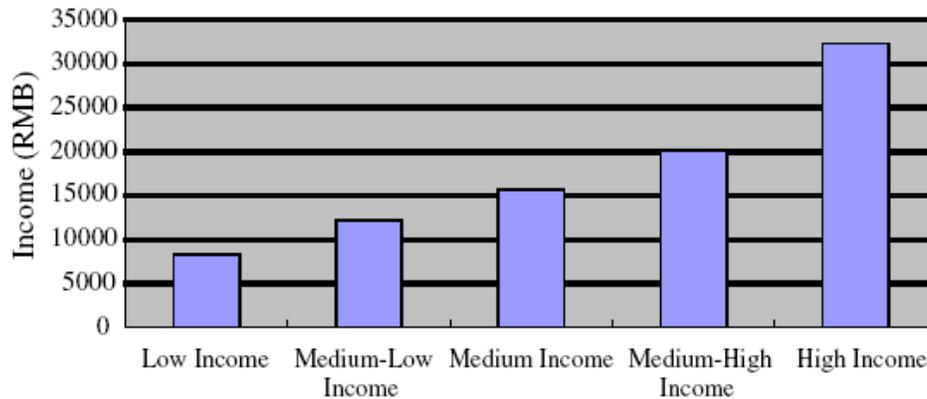


Figure 3 Income of five household groups in Beijing (Chen & Yang, 2007)

Despite low per capita income, it is equally important to note that income distribution is extremely uneven and gigantic gap exists between the rich and the poor. In this sense, the saying has some merit in that water is a necessity good and therefore its demand tends to be relatively inelastic. Increasing the price of inelastic goods will hurt the interests of the poor. However, the government could prevent the poor people's welfare from decreasing by tax levers or other practices enabling differential pricing. Three suggestions are proposed here (two of which being tax solutions), followed by a brief analysis of their relative advantages and disadvantages.

First, it is entirely possible that the government gives different tax reductions for water use to people belonging to different tax brackets so that people with different incomes can in effect be charged at different rates for water use. For example, if water is

charged at 6 yuan/m³, for every m³ of water used, the government can give tax reductions of 0.5 yuan, 1 yuan, 2 yuan to people in the income brackets of 40,000-60,000, 20,000-40,000 and below 20,000. In this case, the actual prices of water are 5.5 yuan/m³, 5 yuan/m³ and 4 yuan/m³ for the three groups of people with income ranking from high to low. In this way, the rate of water charged hinges upon people's ability to pay and can therefore avoid hurting the poor's interest with a flat rate for everyone.

Secondly, the city could also consider simply giving a fixed amount of cash rebates to people whose income is below a certain level regardless of how much water they use. For example, if 10,000 yuan is regarded as the critical standard, the city could give a 100-yuan cash back when people file their taxes. In this way, poor people are in fact partly reimbursed for the water they pay at flat rate.

The above two approaches are in fact subsidizing individuals directly. Alternatively, the city could choose to subsidize the water suppliers so that people below a certain income level could enjoy lower-than-average water rate. For example, the water company could charge water, which is normally 6 yuan/m³, at 5 yuan/m³ for people whose incomes are below a certain level. The profit loss of water supplier could be reimbursed by way of company tax reductions or credit.

Finally, the "block pricing" system where higher uses are charged at increasing rates is applicable if the city could spend money on metering infrastructures, such as making the metering devices complete and uniform. Or implementing and extending prepayment systems using IC (integrated circuit) cards.

Evaluation

The tax reduction approach is very flexible and equitable since it can best adjust prices to different income groups. It does not involve spending on metering infrastructures in case of block pricing, but it is complicated to implement since it requires differentiating different income groups and therefore higher budget to hire more staff. In addition, since it actually charges a lower rate at different income level, there is an incentive for low-income people to over-consume water at artificial-lower-than-full-cost price. This problem may be corrected by setting up a water consumption limit beyond which the tax reduction is no longer applicable.

The cash rebate approach is the easiest to implement and does not require a large budget as with block pricing. It can only benefit people below a certain income level, however, the determination of which is difficult and a bit arbitrary. A person with income just a little higher than the threshold income level is not much better off but cannot enjoy the benefit of cash rebate. In this sense it is less equitable.

The approach to subsidize water supplier has the most salient advantage of charging different nominal rate for water use by people with different ability to pay. For people who do not have an adequate education in taxation, they may consider this approach more equitable or fair because it is evident that they are getting water at lower rate whereas in the first two approaches, they are charged the same rate with everyone else.

The block pricing approach is the most complicated and requires enormous spending on metering infrastructure; however, once implemented Beijing citizens can be better off for years to come. This is because the improvement in metering infrastructure can save the city many future problems arising from metering complexities.

To sum up, either one or a combination of these four approaches could be harnessed by the city depending on its own specific requirement and financial resources. If a tax approach should be used, it is important for the government to encourage tax education in community so that people understand how it works and feel assured that their welfare is being taken care of. If the block pricing system is to be adopted, it is important to realize that requiring neither the residents nor the water supplier to pay the entire expenditure of installing infrastructure is expected to meet with objections. It is more reasonable that the government pay part of, if not the majority, the expense as well. After all, large amount of tax payers' money has to be spent if the government chooses instead to continue building large projects, which will not be as sustainable.

Comparison across Jurisdictions

This part will compare water pricing across jurisdictions. Toronto is chosen as the object of comparison for several reasons. First, Canada is a developed country so information on water pricing tends to be more transparent, accessible and accurate. Second, Toronto is, like Beijing, a densely populated region; but unlike Beijing, it possesses abundant water resources and a much higher level of per capita water consumption. Although these two cities are not perfect analogies as a result of their own idiosyncrasies, it is through this direct comparison that similarities are identified and differences are explained.

A review of water rate and pricing structure (Toronto Water, ER17) shows that from 2004 till 2007, Toronto adopted a block pricing scheme that divided into seven different blocks according to annual water consumption in cubic metres (block 1 has the lowest annual water consumption). The first 2 blocks applied to residential water consumption and

the rest related to industrial water use. Block one water rate is lower than block two to encourage residential water use efficiency. It also shows that water prices increased by 6%, 9% and 10.8% in 2005, 2006 and 2007 respectively. These consistent high growth rate mirrors Toronto's full-cost-pricing approach.

Beginning 2008, Toronto adopted a new rate structure of pricing consisting of only two categories: general water rate of \$1.7352 / m³ for residential use and annual water use below 6000 cubic metres; industrial water rate of \$1.3881 / m³ for annual water use above 6000 cubic metres. Block pricing within the separation residential and industrial domains was revoked. The new residential water rate is higher than that of any block in 2007 and the new industrial water rate is lower than its counterpart in 2007. To make the change more equitable, the Toronto government will provide grant to low income families. It is worth noting that the lower price charged for large industrial consumers did not send the right signal when water efficiency is considered. However, Toronto did this because its policy goal was more to expand its industries than enhancing water efficiency, which it dealt with by charging a uniformly higher residential water rate.

It is clear from the foregoing statements that Toronto and Beijing are similar in the sense that both increased or needed to increase its water price to reflect the full cost of water and enhance water use efficiency; and in doing so, both used or could use tax levers (grant, rebate or reductions) to compensate for the welfare loss in the poor. Also, both cities need to fix metering problems as observed by Toronto Star (ER16) "the city is also working to get water meters into 80,000 houses in the old city of Toronto so if people conserve water they will see the payoff in their bills." They differ in the treatment of industrial water consumers. Beijing should not encourage industrial water consumption as Toronto did. This is because: first, Beijing has far less water resource and a much larger population and

therefore water efficiency should be enhanced in both industrial and residential uses; second, the policy priorities of Beijing and Toronto are different, the former being conserving water and the latter being expanding industries.

Two — Combining Centralized Reuse Systems with Decentralized Systems

Due to its rapid pace of economic growth and urbanization process, Beijing has seen a rapid expansion of its geographical boundaries. The densely populated and constructed old city core is now surrounded by a series of satellite districts less densely populated and having inadequate infrastructure. Based on this distinct feature of New Beijing, the author suggests building large centralized wastewater reuse systems in Beijing central region in the proximity of and making use of the existing central wastewater treatment plant (WWTPs) and supplementing small decentralized reuse system in the relatively new less-built satellite districts. The reasons are as follows:

First, the central region meets the infrastructure requirement. Jia, Guo & Wang, (2005) notes that large wastewater reuse systems refer to systems through which “wastewater are collected in large areas and was concentrative treated, then reuse separately”. They usually rely on the discharge of existing large wastewater treatment plants as the water sources. The expansion of WWTP capacity in recent years was concentrated in the central region. Large reuse systems could be readily built in these areas. The spatial distribution of reuse quantity of each block is exhibited in figure 3 and it shows that the blocks which had a large wastewater reuse quantity almost distributed near the planned wastewater plant (WWTPs). Therefore, it is suitable for Beijing to construct reclaimed water plant in vicinity to WWTPs.

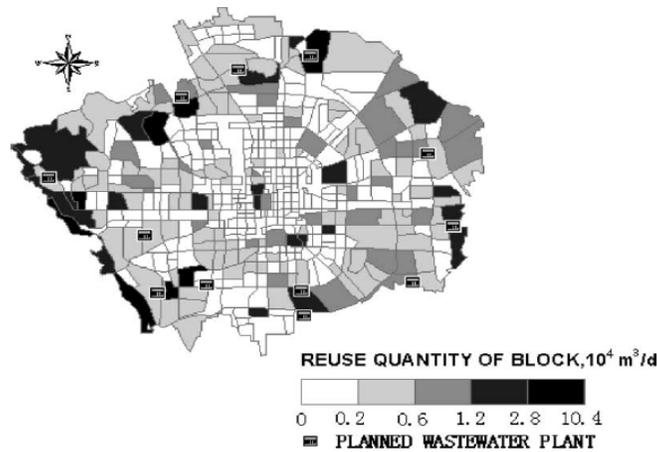


Figure 3 Spatial distribution of reuse quantity needed for each block (Jia, Guo & Wang, 2005)

Secondly, from the economic point of view, building large systems in the densely populated central region makes sense because large systems are cheaper than small systems as a result of economics of scale where wastewater is collected from several buildings and treated and reused locally (Jia Guo and Wang, 2005).

Thirdly, it is not suitable to build centralized reuse system in the suburbs because the suburbs do not have the infrastructures needed and it will be too costly to build and run small individual reuse systems where economics of scale is not possible. Although the technology of decentralized wastewater system is not as mature as that of the large systems, Beijing can patronize research in its various large universities in conjunction with the water supplying companies to get a safe and reliable system.

Three — Institutional Reform

Sustainable management of water resources requires considering the water source, pollution, soil erosion, flood control, water prices and regulations together to bring about optimal development. Therefore, the ideal water management arrangement should be one with a sound conflict management mechanism to perform multi-objective planning. Due to the highly fragmented nature of the current water management framework in China, many

institutions and local authorities are ill-coordinated and tend to ignore the benefits of other regions and sectors when making unilateral decisions. From this perspective, the management should transform into an integrated system where the multi-facet aspects of an entire region are considered holistically. One single institution, perhaps the Ministry of Water Resources, should be relegated the legislature and enforcement power and be in charge of all areas of water management so that by assembling the demands of all parties to balance their rights and interest, mitigating conflicts through negotiations and mediation, an overall plan that attempts to satisfy all parties is developed. On the other hand, with the expanding complexity of water and the degree to which its management is complementary to other activities, it is not reasonable to expect this single institution to deal with everything.

Under these circumstances, a new model could be introduced here. Integrated Management of Water Resources in River Basins (IMWRRB) is a uniform management mode for the entire river basin with an emphasis on long-term sustainable utilization of water resources. According to Zeng (2006), the targets of IMWRRB involve not only supply of water resources and flood control, but also problems including wetland protection, agriculture development, sustainable development of water resources, and global environmental protection. IMWRRB emphasizes long-term and sustainable utilization, rather than unilateral decision making to meet certain water resources demands. The objectives of IMWRRB are: 1) to maintain high quality of water resources in order to achieve long-term, sustainable and stable developing objectives; 2) to properly allocate water resources so as to mitigate the conflicts in the process of water resources exploitation from aspects of water quality and quantity; 3) to reduce cost on water resources utilization that are either competitive or incompatible; and 4) to improve the potential of multi-object

utilization. It is a process of negotiation, in which the proper allocation of limited water resources among conflict sectors is gained by conflict analysis (Zeng, 2006).

Under IMWRRB, the government should develop a framework of “concentration-separation”. Concentration refers to “the constitution of policies, acts and standards formulated by one uniform management institution of water resources and the coordination among sectors or districts involved in the exploitation of resources” (Zeng, 2006). Separation refers to “separated management on water resources of different sectors or districts in accordance with their respective functions and limits of power” (Zeng, 2006). In this way, “the autonomy of sectors and districts are initiated without neglecting the overall consideration and comprehensive management of the entire river basin” (Zeng, 2006).

Section 8 Conclusion

In this paper, I examine the history and current situation of water supply and demand in Beijing. This study shows that Beijing has been experiencing water shortage since the 1980s, which it survived by either drawing ground water or building large projects to transfer water from other regions. The persisting trend of rapid economic growth and urbanization predicts an ever enlarging gap between future supply and demand.

The increasing scarcity of freshwater resources and the temporary nature of engineering solutions make it imperative to seek sustainable solutions from within Beijing itself. In light of this, wastewater reuse is proposed here. Beijing has recently expanded its central wastewater treatment (WWPTs) capacity in the central region and now 90% of wastewater is now properly treated.

Despite this high ratio of wastewater treatment, Beijing currently reuses only 12.8% (0.04 BCM) of its potential wastewater reuse quantity 0.31BCM (the proportion of treated

wastewater that is suitable for reuse, such as for toilet flushing, irrigation, industrial use, etc). This shows that Beijing has a large potential to reuse and reclaimed wastewater merits serious consideration as an important accessory water source.

Currently, wastewater can be reused through two main sources: the central wastewater treatment plant and the decentralized in-house or on-site wastewater treatment facilities. The former has the advantage of mature technology and proven effects, and is the dominant source of reuse. However, it relies on existing WWPTs for discharged wastewater and its systems are built in the proximity of WWPTs. Also, the large reuse systems are usually expensive to build and enjoy benefits from economics of scale. Therefore, the author suggest that Beijing build centralized reuse systems in its densely populated central region where WWTPs are located to meet the infrastructure requirements and benefit from economies of scale. As for the suburbs where infrastructures are inadequate, decentralized systems of treatment and reuse are mostly applicable since it will be too costly to build and run small individual facilities. This is possible to do because Beijing can draw on its abundant university talents and come out with safe and reliable decentralized treatment and reuse systems.

The current low wastewater reuse ration was largely due to the relatively low price of fresh water in comparison with that of treated wastewater. This low price of fresh water does not reflect the full cost of using water and results in lack of incentive to use wastewater and conserve water resources. Given the urgent need to increase fresh water price to a sustainable level and encourage reuse to achieve greater efficiency in water resource distribution, as well as the politically sensitive nature of price increase, the author suggests that water price be increased by different proportions for people with different ability to pay. The government can subsidize the poor directly via tax reductions or cash

rebates, or it can subsidize them indirectly by giving water suppliers tax reductions/credits if they agree to charge the poor a discounted rate. The “block pricing” system is also applicable if the city is resolved to fix the problem of metering complexities.

Despite the above challenges, the fragmented water management arrangement adds to the difficulty of sustainable development by disassembling the multiple conflicting objectives in water management and fuelling ill-coordination and functional overlapping across institutions. To correct this problem, the concept of Integrated Management of Water Resources in River Basins (IMWRRB) is proposed with an emphasis of long-term planning and sustainable development. Based on this concept, the author suggests that, on the one hand, China should relegate to the Ministry of Water Resources the power of constituting policies, acts and standards, and of coordinating different sectors and districts that may have potential conflicts in using water resources. On the other hand, it should separate water management of different sectors and define their respective functions and power limits more reasonably to avoid overlapping of functions.

References

- Abbaspour, K. C. & Yang, H. 2007. Analysis of Wastewater Reuse Potential in Beijing. *Desalination*, 212 (2007): 238 – 250.
- Atasoy, E., Murat, S., Baban, A. & Tiris, M. 2007. Membrane Bioreactor (MBR) Treatment of Segregated Household Wastewater for Reuse. *Clean*, Vol. 35, No. 5, pp. 465 – 472.
- Chen, H. & Yang, Z.F. 2007. Residential Water Demand Model Under Block Rate Pricing: a Case Study of Beijing ,China. *Commun Nonlinear Sci Number Simul* (2008), doi: 10.1016/j.cnsns.2007.12.013.
- Chu, J.Y., Chen, J.N., Wang, C. & Fu, P. 2004. Wastewater Reuse Potential Analysis: Implications for China's Water Resources Management. *Water Research*, 38 (2004):2746 – 2756.
- Environmental Protection Agency (EPA) Report. 1998. *Journal of Environmental Health*, Vol. 60, No. 10: pp40 (2).
- Gu, J. H. 2002. Guangdong Shen Shui Zi Yuan Gon Xu Mao Dun Tu Chu de Yuan Yin ji Dui Ce: *Causes of and strategies to resolve the intensification of contradictions between supply and demand of water resources in Guangdong Province. Renmin Zhujiang (People's Pear River)*, 1: 17 – 20.
- Han, X. Y. 2004. Beijing Shi Shui Jia Gai Ge Yuan Yin ji Xiao Ying Fen Xi. *Zhongguo Shuili*, 20: 48 –49.
- Jia, H., Guo, R. & Wang, J. 2005. Research on Wastewater Reuse Planning in Beijing Central Region. *Water Science & Technology* Vol. 51, No. 10, pp. 195 – 202.
- Liu, S. 2002. Water Pricing Towards Sustainability of Water Resources: a Case Study in Beijing. *Journal of Environmental Science*, Vol. 14, No. 4, pp. 518 – 523.
- Loudon, T. L. 2001. Decentralized Treatment and Recycling Domestic Wastewater. *BioCycle*, 42.9.
- Nickum, J. E. & Lee, Y. S. F. 2006. Same Longitude, Different Latitudes: Institutional Change in Urban Water in China, North and South. *Environmental Politics*, Vol. 15, No. 2, 231—247.
- Panayotou, T. 1994. Economic Instruments for Environmental Management and Sustainability Development. The United Nations Environment Programme's Consultative Expert Group Meeting. Naimbi.
- Parkinson, J & Tayler, K. 2003. Decentralized Wastewater Management in Peri-Urban Areas in Low-Income Countries. *Environment & Urbanization*, Vol. 15, No. 1, 75-90.
- Wang, Y. H. 2007. An Evaluation on the Institutional Reforms of Water Pricing. *Water Right and Water Market in China*, Vol. 5, No 30.

Zeng, W. H., Yang, Zh. F. & Jia, G. S. 2006. Integrated Management of Water Resources in River Basin in China. *Aquatic Ecosystem Health & Management*, 9:3, 327 – 332.

Zuo, J. B. & Chen, Y. S. 2005. Analysis and Countermeasures on Industrial Water Use in Beijing. *Geography and Geo-Information Science*, Vol. 21, No. 2. (in Chinese)

Electronic Resources (ER)

1. <http://www.bjgtj.gov.cn/tabid/201/InfoID/2209/Default.aspx>
2. <http://www.bjwater.gov.cn/Portals/flfg/files/szygb.pdf>
3. http://www.gov.cn/gzdt/2008-06/16/content_1017529.htm
4. <http://report.drc.gov.cn/drcnet/corpus.nsf/ead71405477efdd4825683500054e56/ab21db56814d49a648256f0a000826c6?OpenDocument>
5. <http://www.toronto.ca/watereff/home.htm>
6. <http://www.google.com/search?client=opera&rls=zh-cn&q=how+many+people+in+toronto&sourceid=opera&ie=utf-8&oe=utf-8>
7. <http://news.sina.com.cn/c/2007-12-04/014213013606s.shtml>
8. http://news.xinhuanet.com/fortune/2007-12/09/content_7219620.htm
9. http://www.cctn.org/news_view.asp?newsid=320
10. http://news.xinhuanet.com/newscenter/2003-08/06/content_1012753.htm
11. http://www.bdc.cn/cenweb/portal/user/anon/page/BDC_Brief.page
12. http://www.bdc.cn/cenweb/portal/media-type/html/user/anon/page/BDC_Chief.page
13. http://www.gov.cn/jrzg/2006-06/29/content_322482.htm
14. <http://www.bjwater.gov.cn/tabid/40/default.aspx>
15. http://news.xinhuanet.com/newscenter/2008-01/21/content_7465074.htm
16. <http://www.ontariotenants.ca/water/articles/2004/sun04k03.phtml>
17. <http://www.toronto.ca/water/index.htm>