An assessment of centralized and decentralized wastewater reclamation systems in Beijing

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1. Introduction

1.1 Background

Nowadays, water scarcity becomes an increasingly severe problem all over the world. 1.1 billion people have no access to a safe water supply and 2,6 billion have no access to basic sanitation, with the vast majority of these people living in developing countries. 1,6 million people die every year due to diseases related to poor sanitation and unsafe water supply(GTZ 2005). For the future, the situation will become more austere. Rapid economic growth and increasing urbanization will aggravate the uneven distribution of population, industries, and water in urban areas. With respect to these, water supplies and water pollution control are under unprecedented pressures. The major global challenges faced by then are the many people without sanitation, the health effects of poor water supply and sanitation, water shortage and water pollution and so on.

As one of the countries with limited water resources, China is confronted with the same problem. Despite the shortage of water, people use it profusely. Water is heavily used in farmfield irrigation, industrial production and in daily life. In addition, with economic development, water pollution has become more and more serious in recent years. Therefore, water resources are under pressure and the gap between water demand and water supply is becoming problematic. Relieving the bottleneck effect of water shortage to socio-economic development is taking on new urgency in China.

With these constraints in mind, several suitable reclamation processes related to water reuse have been created in China, which are helpful to improve the situation of water scarcity. Beijing, China's capital, the need to reuse of treated wastewater is discussed and applied for industrial and municipal purposes, and for scenic water reuse. The emergence of wastewater reclamation, recycling and reuse is becoming a vital component of sustainable water resources management in urban and rural area in and around Beijing. Moreover, the centralized reclamation system is becoming more and more popular than decentralized system. This thesis investigates the current practice of municipal wastewater reuse projects in Beijing and aims to analysis the performance of centralized and decentralized wastewater reuse systems. In order to do this, a number of cases studies have been investigated and evaluated based on technical, economical and social criteria and the comparison between centralized and decentralized reclamation system will be made.

1.2 Research Objective:

To investigate and assess the current performance of wastewater reclamation in Beijing and compare the centralized approach with the decentralized approach by doing three case studies (one centralized system and two decentralized systems) based on analyzing the technical, economic and social performance.

1.3 Central research questions and sub-questions:

- What is the current situation of water supply and wastewater treatment in Beijing?
  - What are the constraints in water supply and wastewater treatment in Beijing?
  - What is the current status wastewater reuse in Beijing?
- What are the features of the selected case sites, i.e. the centralized and the two decentralized systems for wastewater reclamation: in terms of:

  Technical aspects:

  1) What kinds of technologies are applied?
  2) What is the performance of the selected systems in terms of effluent quality?
  3) For what purposes is the reclaimed water used?
  4) What kind of problems occurred during the operation so far?

  Economical aspects:

  5) What are the costs and benefits of the systems?

Social aspects:

6) Who are the stakeholders involved with these systems (system owner, system operator, end users)?

7) Are the end users (the people whom wastewater is treated for) aware of and satisfied with the system?

Overall evaluation:

8) What are recommendations for future application in other parts of the city/region?

1.4 Definition of Concepts:

Centralized Wastewater Reclamation System: refers to the wastewater reuse systems that are applied on a large scale. In this context, the centralized wastewater reclamation system is mainly focused on municipal wastewater plants that have advanced treatment for water reclamation.

Decentralized Wastewater Reclamation System: refers to the wastewater reuse systems that are applied on a small scale. In this context, decentralized wastewater reclamation systems refer to specialized reuse projects for individual residential areas, hotels, universities, official buildings, etc.

2. Literature Review

In order to investigate wastewater reuse in Beijing, an integrity study for the wastewater reclamation, recycling and reuse was conducted. This chapter presents a full picture about the worldwide wastewater reuse and particularly, the history and the current status of wastewater reuse in Beijing.

2.1 Background

2.1.1 *The water cycle and wastewater recycling*

The engineered systems associated with wastewater reclamation, recycling and reuse play a major role in the natural hydrologic cycle. A conceptual overview of the cycling of water from surface and groundwater resources to water treatment facilities, irrigation, municipal, and industrial applications, and to wastewater reclamation and reuse facilities is shown in Figure 1. Water reuse may involve a completely controlled “pipe-to-pipe” system with an intermittent storage step, or it may include blending with non-reclaimed water either directly in an engineered system or indirectly through surface water supplies or groundwater recharge. The major pathways of water reuse are shown with broken lines in Figure 1 and include groundwater recharge, irrigation, industrial use, and surface water replenishment. Surface water replenishment and groundwater recharge also occur naturally through drainage via the hydrologic cycle and through infiltration of irrigation and stormwater runoff. The potential use of reclaimed wastewater for potable water treatment is also shown. The quantity of water transferred via each pathway depends on the watershed characteristics, climatic and geohydrological factors, the degree of water utilization for various purposes, and the degree of direct or indirect water reuse.

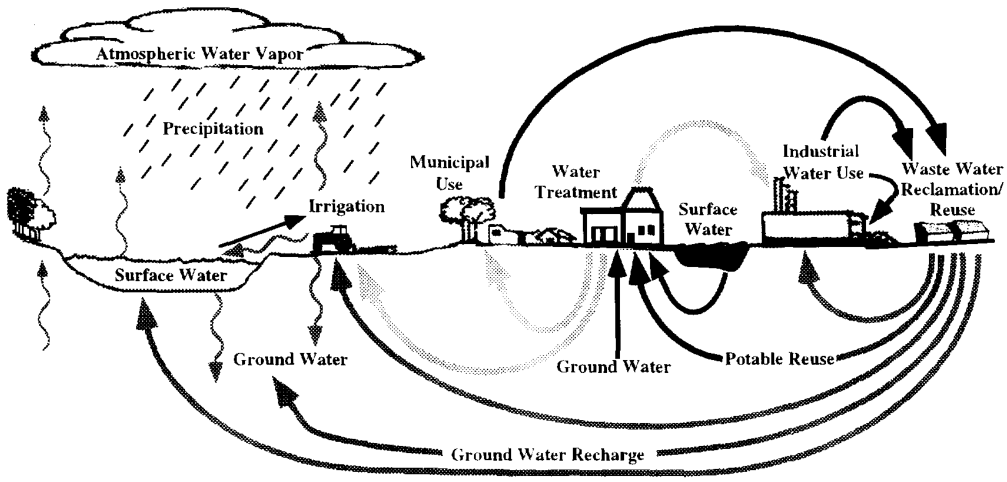

Figure 1**The Role of Engineered Treatment, Reclamation, and Reuse Facilities in the Cycling of Water Through the Hydrologic Cycle (Asano and Levine, 1996)**

2.1.2 The Evolution of water reuse

Wastewater reuse has a long and illustrious history as evidenced by the elaborate sewerage systems associated with ancient palaces and cities of the Minoan Civilization. Indications for utilization of wastewater for agricultural irrigation extend back approximately 5,000 years (Angelakis and Spyridakis,1996). A timeline for the development of sanitation systems is shown in Figure 2. In more recent history, during the nineteenth century, the unplanned and negative reuse, coupled with the lack of adequate water and wastewater treatment, resulted in catastrophic epidemics of waterborne diseases during the 1840s and 50s. (Young, 1985; Barty-King,1992).

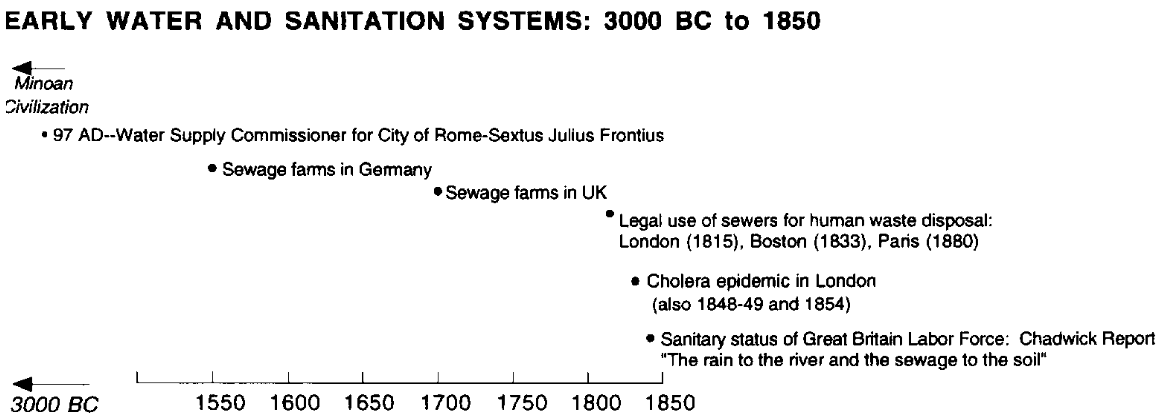

Figure 2. **Early water and sanitation systems (Asano and Levine,1996)**

The development of programs for planned reuse of wastewater within the U.S. began in the early part of the 20th century. The State of California pioneered efforts to promote water reclamation and reuse and the first reuse regulations were promulgated in 1918. During the last quarter of the 20th century, the concept of promoting wastewater reuse as a means of supplementing water resources have been spread to the European Union (Asano and Levine,1996). The European Communities Commission Directive declared that "treated wastewater shall be reused whenever appropriate. Disposal routes shall minimize the adverse effects on the environment" (EEC,1991).

Currently, there is an increased interest in wastewater reuse in many parts of the world in response to growing pressures for high quality, dependable water supplies for agriculture, industry, and the public. Today, technically proven wastewater treatment and purification processes exist to product water of almost any quality desired. Thus, water reuse has evolved to become an integral factor in fostering the optimal planning and efficient use of water resources. Milestone events that have been significant for the evolution of wastewater reclamation, recycling and reuse are itemized on the timeline in Figure 3 , (Asano and Levine,1996) which include the microbiological advances in the later 19th century (Fair and Geyer.1954), the advent of disinfection processes and the development of the activated sludge process in 1904,etc.

These technological advances in physical, chemical, and biological processing of water and wastewater during the early part of the 20th century led to the "*Era of Wastewater Reclamation, Recycling, and Reuse*". As shown in Figure 4, since the 1960s, Intensive research efforts, fueled by regulatory pressures and water shortages, have provided valuable insight into health risks and treatment system design concepts for water reuse engineering. There were some noteworthy events such as the Federal Water Pollution Control Act in US (1972) and the publication of "Guidelines for Water Reuse" by the US.EPA and Office for International Development (1992). (Asano and Levine,1996)

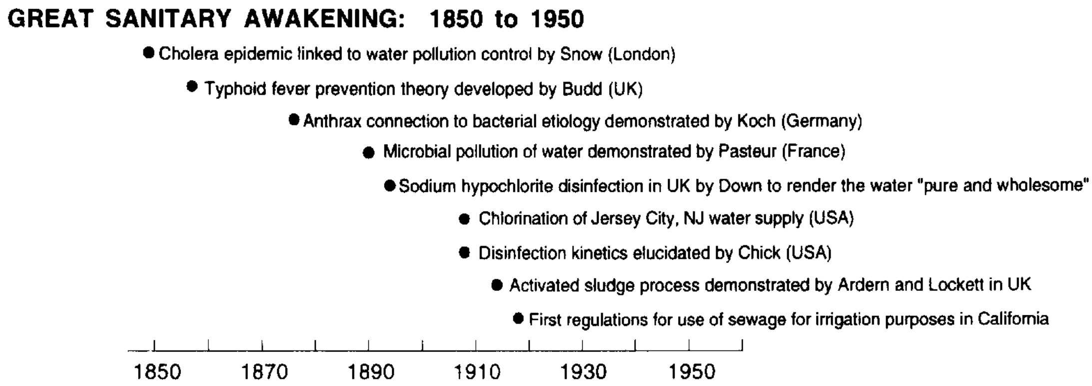

Figure 3. **Worldwide milestone events for the wastewater reclamation, recycling and reuse (Asano and Levine,1996)**

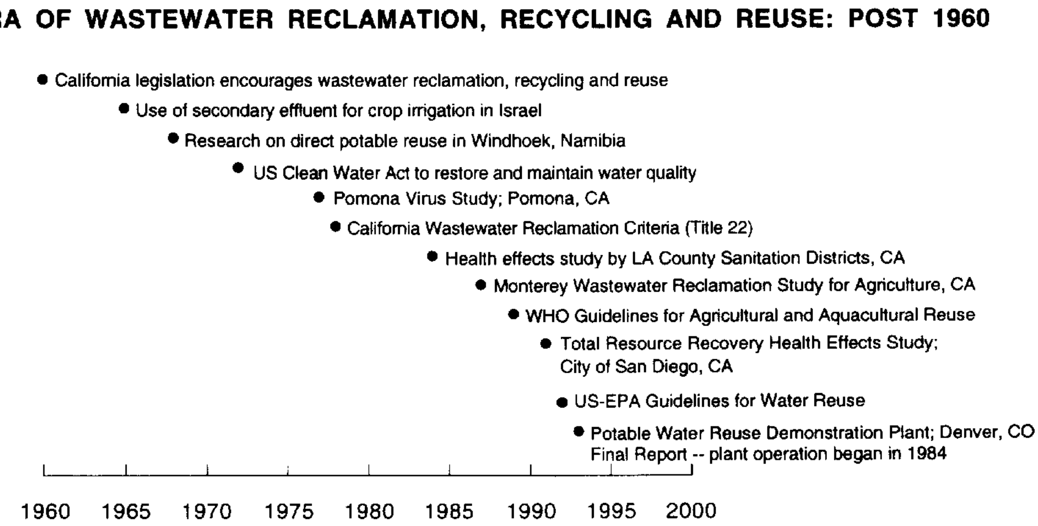

Figure 4. **The era of wastewater reclamation, recycling and resue (Asano and Levine,1996)**

2.1.3 Benefits of water reclamation and reuse

As illustrated above, the reclamation, recycling and reuse of the wastewater is more and more popular and encouraged all over the world. That's because, over the last few decades, the potential benefit for reclaiming water from wastewater instead of disposing it to the environment has been recognized in many industrialized countries. In fact, in many parts of the world, it is no longer practical or possible for water to be used only once. Thus, water reclamation and reuse has become one of the viable options in integrated water resources management in urban areas. Whether water reuse will be appropriate in a specific locale depends upon careful economic considerations, potential uses for the reclaimed water, and stringency of waste discharge requirements to the environment. In addition, public policy where in the desire to conserve and reuse rather than develop additional water resources via dams and reservoirs with considerable environmental expenditures may be an important consideration. Through integrated water resources planning, the use of reclaimed water may provide sufficient flexibility to allow a water agency to respond to short-term needs as well as increase long-term water supply reliability in urban areas. (Asano, 2004) Benefits of water reclamation and reuse and factors driving its future are summarized in Table 1.

Table 1 **Benefits of water reclamation and reuse and factors driving its future**[a]

Potential benefits of water reclamation and reuse

- Water recycling conserves water supplies:

  Water recycling increases the total available water supply. High- quality water supplies can be conserved by substituting reclaimed water where appropriate.

- Water recycling is environmentally responsible:

  Water recycling can preserve the health of waterways, wetlands, flora and fanua. It can reduce the level of nutrients and other pollutants entering waterways and sensitive marine environments by reducing effluent and storm water discharge.

- Water recycling makes economic sense:

  Reclaimed water is at the doorstep of the urban development where water supply reliability is most crucial and water is priced the highest.

- Water recycling can save resources:

  Recycled water originating form treated effluent contains nutrients; if this water is used to irrigate agricultural land, less fertilizer needs to be applied to the crops. By reducing pollution and nutrient flows into waterways, tourism and fishing industries are also helped.

Factors driving its further water reuse

- Increasing pressure on existing water resources due to population growth and increased agricultural demand.

- Growing recognition among water and wastewater managers and the public of the economic and environmental benefits of using recycled water.
- Recognition that reclaimed water can be a reliable source of water supply even in drought years.
- Increasing awareness of the environmental impacts associated with over-use or overdraft of water supplies.
- Greater recognition of the environmental and economic costs of water storage facilities such as dams and reservoirs.
- Preference to recycling over effluent disposal, coupled with tighter controls on the quality of any effluent discharged to the environment.
- Community enthusiasms for the concept of water reuse and water conservation.
- The growing numbers of successful water water reuse projects in the world.
- The introduction of new water charging arrangements that better reflect the full cost of delivering water to the consumers, and the widespread use of these charging arrangements.
- Increased costs associated with upgrading wastewater treatment facilities to meet higher water quality standards.

[a]Compiled from various sources including Asano (1998) and Queensland Water Recycling Strategy (2000)

Water reclamation and reuse make the best use of existing water resources by:

- ◆ Conserving high-quality water supplies by substituting reclaimed water for applications that do not require that quality,
- ◆ Augmenting potable water sources and providing an alternative source of supply to assist in meeting both present and future water needs,
- ◆ Protecting aquatic ecosystems by decreasing the diversion of freshwater, reducing the quantity of nutrients and other toxic contaminants entering waterways, and reducing the need for water control structures such as dams and reservoirs,
- ◆ Complying with environmental regulations and liability by better managing water consumption and wastewater discharges to meet regulatory limitations. Water reuse must be part of any program to conserve and utilize water where water must be used effectively and sustainable (Levine and Asano, 2004).

2.1.4 Categories of water reuse

In the planning and implementation of water reclamation and reuse, categories of reclaimed water application will usually govern the type of wastewater treatment needed to protect public health and the environment, and the degree of reliability required for each sequence of treatment processes and operations. From a global perspective, water reuse applications have been developed to replace or augment water resources for specific applications, depending on local water use patterns. In general, water reuse applications fall under one of seven categories: (Asano, 2004)

1) Agricultural irrigation, Agricultural irrigation represents the largest current use of reclaimed water throughout the world. This reuse category offers significant future opportunities for water reuse in both industrialized countries and developing countries.
2) Landscape irrigation, Landscape irrigation is the second largest user of reclaimed water in industrialized countries and it includes the irrigation of parks; playgrounds; golf courses; freeway medians; landscaped areas around commercial offices, and industrial developments; and landscaped areas around residences. Many landscape irrigation projects involve dual distribution systems, which consist of one distribution network for potable water and a separate pipeline to transport reclaimed water.
3) Industrial reuse, Industrial activities represent the third major use of reclaimed water, primarily for cooling and process needs. Cooling water creates the single largest industrial demand for water and as such is the predominant industrial water reuse either for cooling towers or cooling ponds. Industrial uses vary greatly and water quality requirements tend to be industry-specific. To provide adequate water quality, supplemental treatment may be required beyond conventional secondary wastewater treatment.
4) Groundwater recharge, Groundwater recharge is the fourth largest application for water reuse, either via spreading basins or direct injection to groundwater aquifers. Groundwater recharge includes groundwater replenishment by assimilation and storage of reclaimed water in groundwater aquifers, or establishing hydraulic barriers

against salt-water intrusion in coastal areas.

5) Environmental and recreational uses, This category involves non-potable uses related to land-based water features such as the development of recreational lakes, marsh enhancement, and stream flow augmentation. Reclaimed water impoundments can be incorporated into urban landscape developments. Man-made lakes, golf course storage ponds and water traps can be supplied with reclaimed water. Reclaimed water has been applied to wetlands for a variety of reasons including: habitat creation, restoration and/or enhancement, provision for additional treatment prior to discharge to receiving water, and provision for a wet weather disposal alternative for reclaimed water.
6) Non-potable urban uses, Non-potable urban uses include fire protection, air conditioning, toilet flushing, construction water, and flushing of sanitary sewers. Typically, for economic reasons, these uses are incidental and depend on the proximity of the wastewater reclamation plant to the point of use. In addition, the economic advantages of urban uses can be enhanced by coupling with other ongoing reuse applications such as landscape irrigation.
7) Indirect or direct potable reuse. Potable reuse is limited, but it is another water reuse opportunity, which could occur either by blending in water supply storage reservoirs or, in the extreme, by direct input of highly treated wastewater into the water distribution system.

The relative amount of water used in each category varies locally and regionally due to differences in specific water use requirements and geopolitical constraints.

2.2 Wastewater Reuse in Beijing

2.2.1 Water resource of Beijing

Beijing, also known as Peking, is the capital and the second largest city of China. It is a metropolis with more than 10 million people. Beijing's climate is defined as "continental monsoon." Annual rainfall averages nearly 700 mm, the per capita water allocation is only 300 m^3, 15 per cent of the national average and 4 per cent of the world's level.

With rapid social and economic development, Beijing is facing a shortage of water. Over the past ten years, the average water consumption of Beijing urban area was increasing step by step and the total water consumption was up to 1007 billion m^3 in 2000. In the capital’s 21st century water resources planning, it is predicted that the gap between water requirement and natural water supply would be 1.2–3.0 billion m^3 in 2010. (H. Jia et al, 2005)

Meanwhile, during the past century, Beijing’s urbanization outpaced the expansion of the wastewater treatment system. In 1998, the city had a sewer system of 2476 km length. The total amount of wastewater is 861 million m^3, only 14 % of which are treated in Beijing’s four treatment plants. (Spyra, W. 2004) This means that more than 70 % of the total wastewater are directly discharged into the rivers or groundwater or are spread onto fields. Untreated sewage usually contains large numbers of pathogenic micro-organisms such as schistosome ova, cercaria and ova of parasitic flukes and worms. The majority of urban river sections are also extremely polluted by chemicals and toxic compounds from industries. Although industries are moving out of the city the situation did not relax as not all of the remaining ones are equipped with an adequate wastewater treatment plant. In addition to the direct pollution of rivers and streams from sewer outlet or industrial discharge there is indirect pollution due to the enormous air pollution (which may be washed out by rain) and due to agricultural and urban runoff.

With the development of the urban-industrial sector, the volume of wastewater increased and its composition changed. In the 1950s, 80% of all wastewaters were household discharges and 20 % originated from industrial activities, but at the beginning of the 1960s industrial wastewater’s share increased to 50 % of the total wastewater discharge. Figure 5, as seen below, increase in the 1980s was only little, which is a result of both the change of the economic system and the natural water crisis.

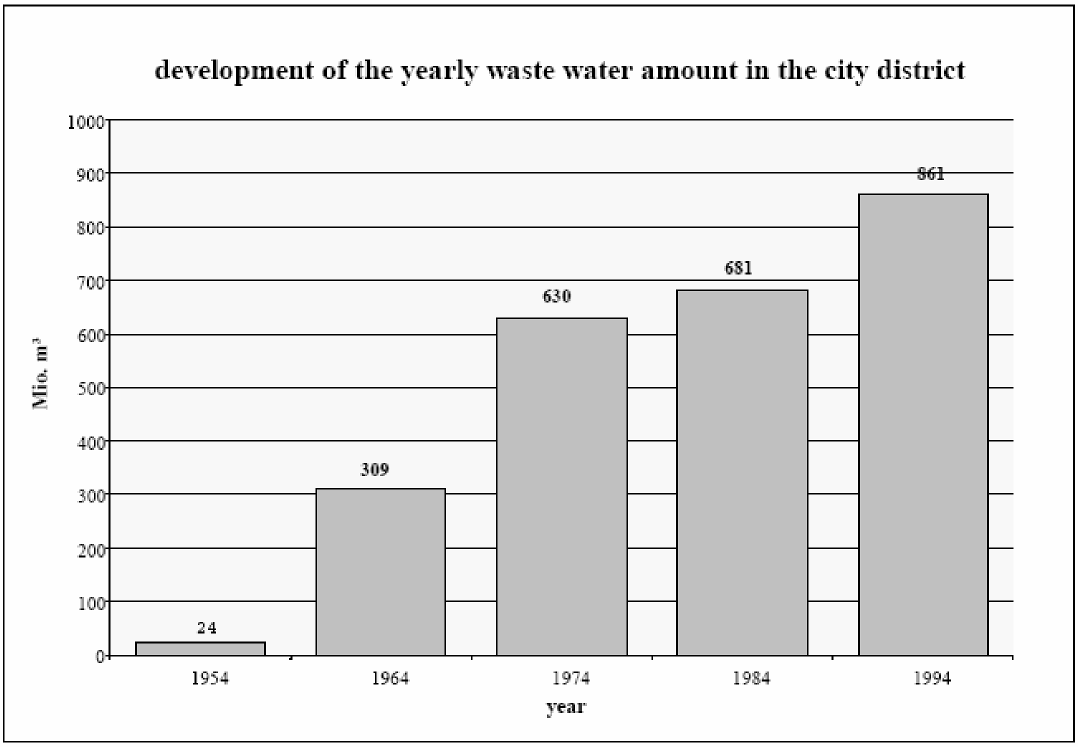

Figure 5. **Development of the yearly wastewater amount in Beijing**

Source: Sternfeld, Stadtentwicklung, 1997.

From 1989 until 1994, the wastewater discharge increased by 100 million m³ annually as the municipal water demand rose. Nowadays, with the further increase in municipal water demand, the amount of wastewater produced by households increases whereas the industrial wastewater production shrinks due to the growing number of on-site wastewater treatment plants and implementation of ISO standards.

Because o the shortage of water, the concept of implementing wastewater reuse was created in Beijing. Several criteria and suitable reclamation processes related to water reuse have been set up, aiming to improve the situation of water scarcity.

2.2.2. The situation of wastewater reuse in Beijing urban area

2.2.2.1 The application for the wastewater

In Beijing, wastewater had been used for agricultural irrigation since 1950s, but in that time, the untreated wastewater was discharged into the river and then pumped to farm directly and so did some damages to the crops and the soils. As time went by, treated wastewater reuse applications have been expanding to other fields gradually with technical improvements. There are mainly four types of wastewater reuse in Beijing urban area now, including agricultural irrigation, industrial reuse, municipal reuse, and scenic water reuse. These applications indicated that the wastewater reuse should be considered as an important alternative for the water problem of semiarid Beijing:

- Agricultural irrigation. According to survey of 1997, the agricultural area irrigated by wastewater was about 10.96 million acres and the total wastewater consumption was about 0.22 billion m^3. Farmers pumped the reclaimed water from the discharge channels which had been treated by secondary treatment plants. In the future, with the adjustment of agricultural structure, the quantities of reclaimed water for agriculture in Beijing urban area may reduce. In the planning of wastewater reuse in Beijing central region, the agricultural irrigation was not considered.
- Industrial reuse. Some factories in Beijing urban area have built their own wastewater treatment facilities to treat the internal industrial wastewater. According to statistical data of 2000, 202 factories have built wastewater treatment facilities. Among these industries, 26 of them reuse treated wastewater and the total reuse quantity is 33,500m^3/d. Meanwhile, Beijing has built a large wastewater treatment plant, Gaobeidian Wastewater treat plant, which has a capacity of 1 millionm^3/d, from which the effluent is sent to the neighboring power plant and used as cooling water after certain additional treatment.
- Municipal reuse. Municipal reuse in Beijing began in the middle of 1980s, and the first wastewater reuse facility was built in a separate residential region. The main uses of reclaimed water are toilet flushing, street cleaning and grass irrigation. Up to 2002, in Beijing central region, more than 154 small wastewater reuse facilities have built and in which more than 120 small wastewater reuse facilities were in operation. These facilities were mainly built in hotels, universities, and office buildings.
- Scenic water reuse. Most rivers in urban area of Beijing run short of constant water supply and the main supply of some rivers were even wastewater. These urban rivers

might dry up after the cutting of wastewater. Using the reclaimed water to supply urban rivers would be a beneficial way to maintain the functions of urban rivers and keep the ecological balance. It should be mentioned that rivers for different functions need reclaimed water with different water quality.

With the scope of this thesis, the practice of municipal wastewater reuse will be studied. Both decentralized (small) and centralized (large) wastewater reuse systems will be investigated.

2.2.2.2 The Related Policy for Municipal Wastewater Reuse

The considerations described in the paragraph above show that the wastewater reuse is considered as an important solution for the water quantity problems of semi-arid Beijing. Therefore, more and more national and local standards deal with water reuse. "To prevent water pollution and to economize on water resources" has been declared as a national policy by the Chinese government. In 1986, the National EPA of China issued the Technical Policy of Water Pollution and Control (revised in 1996), that included recommendations:

- Strengthening management of water resource and water use, pricing of the water resource exploitation;
- Promoting the planned reuse of reclaimed municipal wastewater, especially in northern regions of China;
- Considering the reuse of reclaimed municipal wastewater during the planning and design stages of sewerage system and treatment works;
- Establishing stringent and systematic water quality standards for wastewater reuse.

In 1987, "The management regulation on the building of reclaimed water facility in Beijing (trial)" was enacted by Beijing Municipal Government. According to this regulation, all the hotels with construction areas exceeding 20,000m^2 and all other public buildings with construction areas exceed 30,000m^2 must have its reclaimed water facility. According to wastewater treatment planning in Beijing, 16 municipal wastewater treatment plants would be in operation and 90% wastewater in urban areas would be treated in 2008. In addition, Beijing plans that in the coming three years, the recycling rate for reclaimed water is 30%, 40%, 50%. In addition, for the residential areas, if they are in the areas of the pipe systems, they should use the reclaimed water transported by the pipe networks. If there are no pipe systems around the residential areas, the construction company should build the treatment and recycling facilities at residential level. The related regulations aim for non-potable uses of reclaimed water. Direct or indirect potable reuses are not recommended in China now. The relevant criteria are much more stringent than the related recommended guidelines for wastewater reuse published by the World Health Organization (WHO) in 1989 (WHO, 1989) but comparable to the related guidelines published by the U.S. Environmental Protection Agency (EPA) in 1992 (U.S. EPA, 1992).

Table 2 summarizes the typical reclaimed municipal wastewater quality standards for municipal uses (Zhou, 1996).

Table 2 **Recaimed water quality criteria for urban use.[(1)] (mg/L unless specified otherwise)**

Item	Min. of Construction(2) (1991)	
	Toilet flushing	Car washing and road flushing
Turbidity (NTU)	≤10	≤5
TDS	≤1200	≤1000
SS	≤10	≤5
Color (units)	≤30	≤30
PH	6.5-9.0	5.0-9.0
BOD_5	≤10	≤10
COD	≤50	≤50
NH_4-N	≤20	≤10
Hardness	≤450	≤450

Chloride	≤350	≤300
LAS	≤1.0	≤0.5
Fe	≤0.4	≤0.4
Mn	≤0.1	≤0.1
Chlorine residual	≤0.2	≤0.2
Total coliform (count/L)	≤3	≤3

(1) Urban green field, recreational waters, car $ street clean, etc

(2) Regulations issued by Ministry of Construction of China

In the wastewater reuse planning of Beijing central region, the user of the reclaimed water include industry, scenic water, street cleaning, grass irrigation, toilet flushing. Different water quality of reclaimed water should be met for different uses. The requirements to treatment degree were shown in Table 3 and the detailed indicators were determined by referring to the standard CJ25.1-89 which was enacted by Chinese Construction Ministry. However, with a view of the management, in the wastewater reuse planning of Beijing central region, all the reclaimed water from municipal reclaimed water factory would be secondary treatment plus flocculating settling. If higher water quality were needed, the appropriate treatment should be implemented by the corresponding major users.

Table 3. **The treatment degree of different reuse types**

Reuse types	**Agricultural irrigation**	**Industrial use**	**Scenic reuse**	**Municipal reuse**		
				Grass irrigation	Street cleaning	Toliet flushing
Treatment degree	Secondary	advanced	Secondary/ advanced	Secondary/ advanced	advanced	advanced

2.2.3 The selection of decentralized and centralized wastewater reuse systems

Both decentralized and centralized wastewater reuse systems have been used in Beijing regions, and they are very different in many aspects. Both of them have their own advantages and disadvantages. In the wastewater reuse planning in Beijing central region, the decision on the selection of decentralized wastewater reuse systems or the centralized systems should be made first. Here, the centralized wastewater reuse systems refer to that the wastewater were collected in a relatively large areas and was concentrative treated, then reuse separately. The decentralized wastewater reuse systems refer to that the wastewater were collected from a few buildings and then treated and reused locally.

This thesis will introduce and analysis both systems by means of considering three aspects: the technical, economic and social factors.

2.2.3.1 Technical factors of Wastewater reclamation systems

For the decentralized wastewater reuse systems, the influent water can be grey water and black water. The grey water refers to the wastewater collected from bathroom and washbowl, and the black water refers to the wastewater which includes the wastewater from toilets. For different wastewater, various treatment techniques can be adopted. In Beijing, according to the investigation in 2002, the 21 decentralized reuse systems which use grey water as supply mainly adopted the technique of contact oxidation plus physical and chemical treatment. And the 12 decentralized reuse systems which use black water as supply adopted several kinds of techniques, including contact oxidation plus physical and chemical treatment. As to the centralized reuse systems, it often uses the discharge of large secondary wastewater treatment plants as the water sources, and the additional treatment is mainly physical and chemical treatment. Therefore, centralized reuse systems are often based on the existing large wastewater treatment plants. In Beijing central areas, the planning of wastewater treatment plants was revised in 2002. The distribution of wastewater treatment plants in Beijing central areas is shown in Figure 6. (H.

Jia et al, 2005)

In general, the reclamation system is consisted by wastewater collection, conditioning, pre-treatment, secondary treatment, third treatment, storage unit and transportation unit. It is crucial to choose the right process to get the satisfied treatment effect. Normally, the pre-treatment unit includes bar screen, hair removal, pre-aeration and so on; the secondary treatment can be sorted by two types: the biological and physical treatment. The biological treatment has some methods such as biological contact oxidation, rotating biological disc process, biological aeration filter, etc. For physical treatment, the examples are coagulant sedimentation and flocculation. The third treatment has several methods such as filtration, active carbon adsorption, film separation and oxidized disinfection.

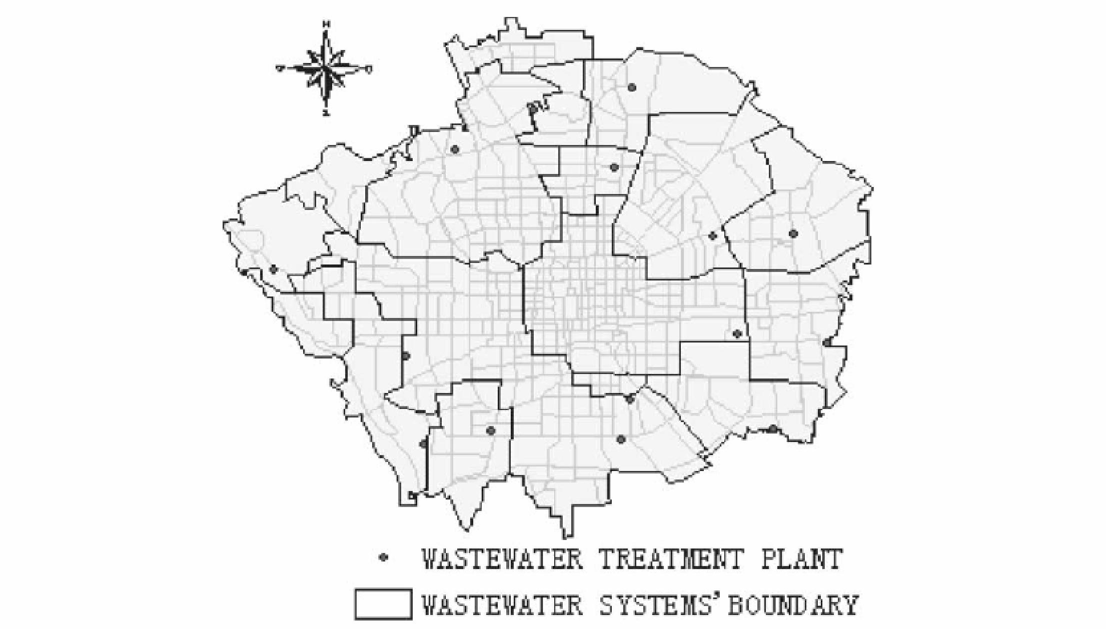

Figure 6**. The distribution of wastewater treatment plant and wastewater systems' boundary**

- Pre-treatment process. As same as all the wastewater treatment system, the first device for the reclamation system is bar screen with the aim to remove the big solid. Currently, most of the bar screens are manual cleaned, while some are cleaned by hydraulic screen or power bar screen. Most of the operators reflect that it is hard to clean the hair filter. With this in mind, the recent hair filter was developed with back wash function in order to solve this problem. For pre-aeration, in the current reclamation system, the retention basin can be divided by two forms: aeration and non- aeration. It is suggested to using aeration process because there are many advantages related to it:

a) It can keep the solid to be suspended. In this way, the solid would not settle at the bottom of the retention basin and can be cleaned easily

b) The existence of oxygen can avoid the bad smell due to the anaerobic activity by microorganism.

c) The performance of the indicators such as COD and BOD_5 can be improved.

◆ Biological treatment process. The aim of this process is to remove soluble organic matter and improve the indicator of COD, BOD and so on. The traditional biological treatment processes are biological contact oxidation and rotating biological disc process. In the early cases of reclamation projects, rotating biological disc process were used frequently, while the biological contact oxidation is more popular recently. This trend can be explained as follows:

a) The disc of the rotating biological disc process contacts with air, therefore there would be bad smell sometimes, for example, when the content of the wastewater is high. With this in mind, it would be limited in some kind of places, such as hotels, restaurants, etc.

b) The maintenance of the rotating biological disc is more difficult than other process because more appurtenances would be broken due to the friction, such as reduction gear, driving device and so on. So it would bring in more difficulty on daily operation.

As a result, the biological contact oxidation process becomes more popular than rotating biological disc process because of the good treatment effect, stable quality of effluent, easy operation and low operation expense. In addition, as the development of technology, a new type of process called biological membrane is paid attention to. Compared with other processes, the loading of the treatment is high, the devices are tight, and the separation unit for solid and liquid can be cut. So it is playing an important role in recent cases of reclamation project. The typical procedure of biological contact oxidation is shown as Figure 7 and the typical procedure of rotating biological disc is like Figure 8:

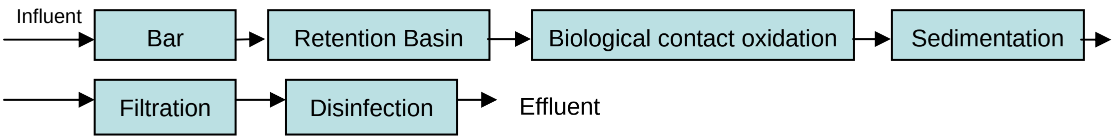

Figure 7**. The typical procedure of biological contact oxidation**

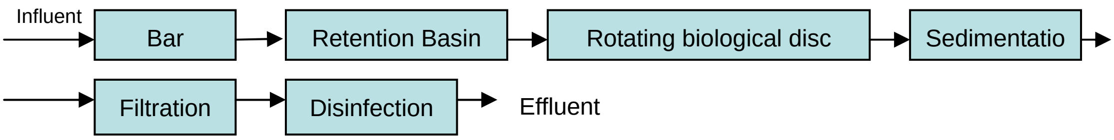

Figure 8**. The typical procedure of the typical procedure of rotating biological disc**

- Physical treatment process. The main unit of physical treatment is the coagulation process with the aim of removing the suspended and colloidal materials. It is proved that the type and amount of the coagulant play an important role on the treatment effect and the operation expanse. Take the Gaobeidian wastewater treatment plant for example, the best coagulant is polyaluminium chloride and the best dosing is 30mg/l, while in the case that the influent is the balneal water, both polyaluminium chloride and polyiron chloride can gain good effect, the amount of polyaluminium choride is about 5mg/l and the maximum is 10mg/l. After the coagulation reaction, the sedimentation and air flotation would be the effective separation method. The sedimentation device is simple but has big volume and the device for air flotation is opposite. Both methods are applied in Beijing, but the proportion of sedimentation is higher as a result of easy operation. As mentioned above, the purpose of coagulation process is suspended and colloidal materials, so it is not good at removing soluble pollutants which result in the bad performance on treating detergents. As far as the sedimentation is concerned, it can not remove anion detergent effectively. The air flotation, however, can treat it partly.
- Filtration Process. For the third treatment process, filtration is a vital unit which can ensure the transparency of water. There are many choices of filter medium and it is

important to choose the right one. Nowadays, the usual filter mediums are one-coat quartz sand filter and two-coat carbonaceous coal quartz sand filter. As the most popular method for the third treatment process, active carbon adsorption has good performance on adsorbing the decomposition products of detergent, the human secretion and faeces, etc. It can improve the quality of effluent but its price is expensive and the operation fee is high. So it is important to make different decision under different conditions. If the influent is the balneal water and the treatment process is biological, it is not necessary to use active carbon in that the biological treatment process can remove most of soluble organisms. But if the process is physical, as it is not effective to remove the soluble organisms, so sometimes the active carbon is used to improve the quality of effluent. Moreover, film separation method is developed fast in recent few years. It has excellent treatment effect, tight structure and small scale. However, because it belongs to physical method, the effect of removing COD, BOD_5 is not so significant.

2.2.3.2 Economical factor:

Although reusing water is not only environmental friendly, but also can mitigate water shortage, we should consider if it is affordable. The investment and operation expanse should be offset by its benefits. In addition, the price for using the reclamation water is better to be lower than using the tap water so that it can be accepted more easily.

2.2.3.4 Social factor:

It is important to recognize that public acceptance of reuse projects is vital to the future of wastewater reclamation, recycling, and reuse: the consequences of poor public perception could jeopardize future projects involving the use of reclaimed wastewater. In addition, in order to develop the reclamation system in whole society, the feeling of other stakeholders should be paid attention to as well, such as the system owner, Design Company, system operators, etc.

3. Materials and Methods:

The research was carried out by three means: Literature review, Case Studies and Data analysis.

3.1 Literature review:

To carry out the investigation for wastewater reuse situation in Beijing, the critical role of this strategy for Beijing should be understood firstly and the characteristics of reuse system. In addition, the related government policy and standards should be known as well in order to realize the background information for wastewater reuse in Beijing. The most important point is that the information and data used in this part is authorized.

3.2 Case study

In order to obtain more in-depth knowledge about the current reclamation situation of Beijing, case study is regarded as a powerful strategy. The aim of this thesis is to investigate the reclamation projects in urban areas. According to this, the scope was focused on the main central area of Beijing. In addition, the comparison between the decentralized and centralized system is fulfilled by means of choosing representative cases from each system. By the end of 2001, more than 100 reclamation systems were under using in total, meanwhile, another 100 reclamation projects were under construction. (The analysis of reclamation projects) With respect to this, there are many options can be chosen for the case study. However, due to large scale of Beijing, the cases are scattered all over the city. As a result, the time spent on the transportation will be huge due to the traffic jam so that only three demonstration projects were chosen in the end. The location can be found in Figure 9. One case is Gaobeidian Wastewater Treatment Plant which is an example for centralized system, and the other two cases are for decentralized system: Beiluchun Residential Areas and Beijing Jiaotong University. The research was based on the questionnaire mentioned in appendix A and B. At the beginning, each investigation includes interview and survey with different stakeholders involved in the cases, such as Design Company, operators, end users etc. Nevertheless, the questions were adjusted in order to fit the practical situation. An overview for these three cases is presented as follows:

- ***Gaobeidian Wastewater Treatment Plant:*** It is the largest municipal wastewater treatment plant in China which is located in Chaoyang district of Beijing. In 1996, the reclamation project for in-plant use was carried out as one of the reclamation demonstration case and the other reclamation process started from 1999 with the aim of reusing the water on municipal level. For this case, interviewing with the employees is the main strategy because they are specialized on technical issues, not only the background information related to reclamation, but also the daily operation. In addition, the data and information for economic issues can be collected from them as well. With respect to social issues, there are two aspects to be considered. On one hand, the employee's opinions can be seemed to represent the operator's feelings. On the other hand, surveys for end users (such as citizens who use the reclaimed water produced by Gaobeidian Wastewater Treatment Plant) can also be carried out to check whether the public awareness or/and public acceptance is good enough. The details are in Chapter 4.
- *Beijing Jiaotong University*: Established in 1993, as the first university to apply the reclamation process, Beijing Jiaotong University is regarded as a good example of decentralized system. It is located in Haidian District. For this case, unfortunately, it is not so easy to get connection with the Design Company named Beijing Municipal Research Institute of Environmental Protection because it is a government agency and is not to public visitors. In this way, the interviews with the operators and the survey for students play an important role to reach the research objectives. More details are in Chapter 5.

- ***Beiluchun Residential Areas:*** This case is a demonstration case of reclamation projects for residential areas which is located in Fanshan Distrcit. The research was focused on collecting information and opinions from its stakeholders. The main stakeholders are the Design Company, the operators and dwellers of this residential area. As it is located at the edge of central Beijing, getting the opinions from the operators and dwellers was not easy as expected due to transport limitation. Therefore, it addresses more emphasis on the interview with the Design Company. More details are in Chapter 6.

Figure 9. **The location of three cases**

3.3 Data Analysis:

In order to gain the insight of the reclamation process, the performance of the centralized and decentralized system should be analyzed. At certain point, the comparison of the reclamation quality on the same level can be made to see the difference between those two systems. This thesis will conclude the results of the case studies and compare from technical, economic and social aspects.

3.4 Research Planning:

The time schedule thesis is arranged as Table 4:

Table 4 **Research Planning**

Weeks	Months	Location	Tasks
Week 1-2	September	The Netherlands	Review Literature and finish the draft of proposal
Week 3-6	September- Mid October	China	Investigate local situation and change the direction of literature review and proposal
Week 7-12	Mid October- December	The Netherlands	Finish introduction and literature review parts and decide the site of case study
Week 13- 19	January- Mid February	China	Collect information and data related to cases
Week 20- 30	Mid February- May	The Netherlands	Finish the thesis and presentation

4 Gaobeidian Wastewater treatment plant:

4.1 Municipal Wastewater Treatment Systems in China

China's water infrastructures are state owned property regulated by government administrations. However, a few cases exist in which water and wastewater treatment plants were funded or owned by non-state-owned capital. Most municipal water and wastewater treatment systems are still managed by state-owned enterprises.

The pricing system reforms for water supply and wastewater treatment triggered and promoted the conversion of the water sector from a state planned to a market-driven sector. Under this system, the policy allows non-state-owned capital, such as foreign and private capital, into the public water infrastructure sectors. It also makes China's water market attractive to investors and private sector utility companies. The current water price in large cities is shown as Table 5.

Table 5. **Domestic water price in large cities**

City	Province	Total($)	Tap Water and Water Resource ($)	Wastewater Treatment ($)
Beijing		0.35	0.28	0.07
Jinnan	Shandong	0.31		
Tianjin		0.31		
Changchun	Jilin	0.30		
Chongqing		0.29	0.24	0.05
Shijiazhuang	Hebei	0.24	0.18	0.06
Nanjing	Jiangsu	0.23	0.11	0.12
Guangzhou	Guangdong	0.19	0.11	0.08
Shenyang	Liaoning	0.19	0.17	0.02
Wuhan	Hubei	0.18	0.13	0.05

Wulumuqi	Xinjiang	0.18	0.15	0.04
Yinchuan	Gansu	0.14		
Naning	Guangxi	0.13		

Note: The actual municipal water fee levied consists of three parts: the water resource fee, the tap water fee, and the wastewater treatment fee.

Source: China Resouce Conservation and Environmental Protection Network, www. Drccu.gov.cn

A municipal wastewater treatment fee is collected along with a water supply fee, which is based on the actual water consumed by users. All provinces in China levy wastewater treatment fees. Current prices range from $0.02 to $0.07 per cubic meter, which is lower than the actual costs of a secondary wastewater treatment plant at $0.07 to $0.1 per cubic meter. Water prices generally reflect the level of available water resources, as well as economic development. In the areas with water shortages and rapid economic development, such as Beijing and Tianjin, water prices are comparatively higher. The water price in Beijing is increasing to $0.48 per cubic meter because of water scarcities and continuous drought.

$1.94 billion will be invested in the construction of municipal wastewater treatment plants from 2001 to 2013, as shown in Table 6. The construction of municipal wastewater treatment plants started ahead of the main engineering schedule. The status of projects for 2001–2008 is shown in Table 7.

Table 6**. Construction plan for municipal wastewater treatment plants**

Year	**Budget ($ billion)**	**Number of Plants**	**Capacity (million m^3/day)**
2001-2008	1.17	78	3.785
2009-2013	0.77	57	2.905
Total	1.94	135	6.690

Source: PRC, State Environmental Protection Administration, " The Progress on the Wastewater Treatment on the Eastern Route of the South to North Water Diversion Project" (December 27,2002); Chinese text available at www.zhb.gov.cn /eic/ 652460104116862976/20030103 /1036571.shtml.

Table 7. **Current status of the municipal wastewater treatment projects**

Status	**Number of Plants**	**Treatment Capacity (billion m^3/ day)**	**Investment ($ billion)**
Completed	16	1.19	0.21
Under construction	15	1.01	0.18
Incomplete	47	1.58	0.75

Source: PRC, State Environmental Protection Administration, " The Progress on the Wastewater Treatment on the Eastern Route of the South to North Water Diversion Project" (December 27,2002); Chinese text available at www.zhb.gov.cn/ eic/ 652460104116862976/ 20030103/ 1036571.shtml

Urban Beijing has 11 wastewater treatment plants, with an existing capacity of 1.69 million cubic meters per day, and more plants with a combined capacity of 1.11 million cubic meters per day are planned. In this thesis, the Gaobeidian Wastewater treatment plant is chosen as one of the examples of case study.

4.2 Introduction of Gaobeidian Wastewater Treatment Plant

Figure 10. **Gaobeidian Treatment Plant**

The Gaobeidian Wastewater Treatment Plant built in 1961 and being the largest wastewater treatment plant in China, is located at the village of Gaobeidian in the east of Beijing. In 1999, with Swedish development aid, its treatment capacity was extended to one million m^3 per day; in summer, under rain conditions, it may even treat up to 1.2 million m^3 a day. Yet the full capacity has not been used as the sewer system was not extended and can therefore deliver at maximum only 800,000 m^3 per day (the situation is similar for all of Beijing's treatment plants). Today it receives and treats about 740,000 m^3 of wastewater every day. This can be compared to the amount of wastewater being treated in Beijing, 3,000,000 m^3 per day. Thus Gaobeidian treats about 25% of all the wastewater. About 80% of the wastewater comes from households and 20% from industry. The plant also receives stormwater due to the fact that the sewage system in this area is a combined system. The overall service area of the respective sewage collection system is 96.61 km^2. This includes residential areas (75.58 km^2) and industrial areas (10.85 km^2) mainly situated in the old urban centre and the eastern suburbs. The service population of this system is 2.4 million. After treatment the water will either be given to water plant number 6 or will be released onto fields of 400 ha in total. The sludge is dried and then used as fertilizer.

In 1996, as one of the demonstration project of Beijing, the reclamation process within Gaobeidian wastewater treatment plant was under construction which can be depicted shortly like this: After primary and secondary treatment for municipal wastewater, part of the effluent is under further treatment in order to reach the standards for reclaimed water. The water is for in-plant reuse afterwards, such as device washing, car washing and landscaping. The treatment capacity of this process is 10000m^3/d (420m^3/h).

In addition, another reclamation project for municipal level reuse was carried out in 1999. For this outside reclamation, the effluent from the secondary sewage treatment in Gaobeidian plant is lifted by the pump (Capacity: 470,000m^3/d) and then separated into two parts: one of them goes to Gaobeidian Lake (Capacity: 300,000m^3/d), on its way it will pass Huneng Power Plant and the water is further treated there which can be used as the cooling water; The rest part of water from Gaobeidian goes to No.6 Water Plant (Capacity:170,000m^3/d), It undergoes the advanced treatment in order to reach the standards for the urban reclamation water. Afterwards, part of this water is used as second municipal water resource and the other is for landscaping or agricultural irrigation.

Figure 11. **The allocation of the reclaimed water**

4.3 Technical Description

In Gaobeidian Wastewater Treatment plant, the water is treated firstly as normal wastewater treatment plant, and then part of the effluent undergoes advanced treatment in order to be reused for special purposes. Therefore, the context will start from the wastewater treatment and reclamation system afterwards. The information is mainly from the interview with Li yao, who is an employee of Gaobeidian technical training center and all the content is based on the questionnaire in Appendix A.

4.3.1 Treatment method for wastewater treatment

The centralized wastewater treatment plants in Beijing have different wastewater treatments but they are all based on a traditional combination of mechanical and biological treatment. The wastewater is first treated mechanically by a combination of a screen and an aerated sand filter. A primary sedimentation tank, where the primary sludge is removed, follows this treatment. In order to remove organic matter, nitrogen and phosphorus the wastewater is treated biologically. The biological treatment involves a series of anoxic and aerated zones. A secondary sedimentation tank follows where the secondary sludge is removed. Some of the treatment plants also have advanced treatment of the water so it can be reused as for example irrigation water.

There are different treatment methods for the sludge at the treatment plants. At Gaobeidian Sewage Treatment Plant, sludge is produced both in the primary and the secondary sedimentation tank and the sludge is treated separately. About 50% of the sludge comes from the primary sedimentation tank and 50% from the secondary. Sludge from the primary sedimentation tank is first thickened by gravity in a concentration tank. The sludge is then either treated in an anaerobic digestion chamber or dewatered directly by filter belts. The amount of sludge treated by digestion depends on the capacity of the digestion chambers and it is not known how much of the sludge that is digested each year. There are 16 digestion chambers and each have a volume of 7848 m^3. The sludge is digested in two steps. The first step includes digestion for 21 days and the second step for 7 days and both steps are operating at mesophilic temperatures. The biogas produced in the digestion chambers is used at the wastewater treatment plant to produce power used at the aeration process. Filter belts also dewater the sludge that has been digested. Figure 12 shows four digestion chambers at Gaobeidian Sewage Treatment Plant.

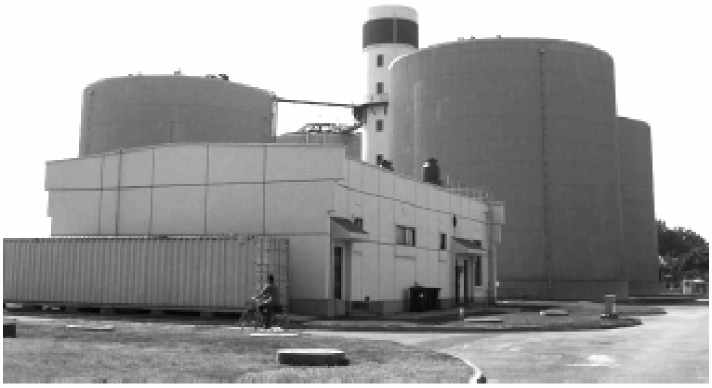

Figure 12**. Digestion chambers at Gaobeidian Sewage treatment plant**

Sludge from the secondary sedimentation tank is both thickened and dewatered in a combined process. The thickening of the sludge is carried out by the principle of gravity and filter belts treat the sludge in order to dewater it. Polymers are used in order to facilitate the dewatering of the sludge, from both the primary sedimentation tank and from the secondary. A schematic illustration of the sludge treatment is shown in Figure 13.

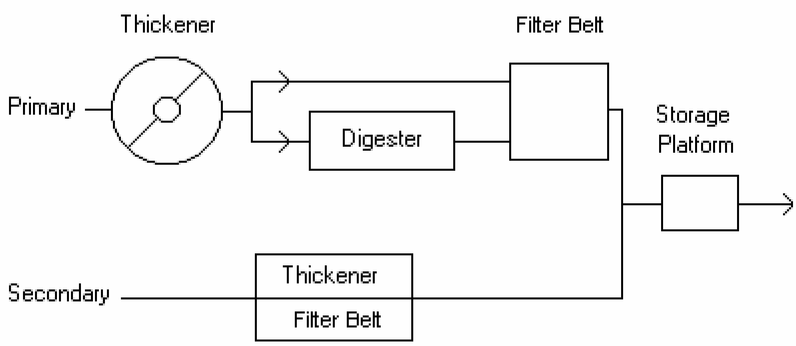

Figure 13. **The sludge treatment at Gaobeidian Sewage Treatment Plant**

All the sludge is mixed together when it comes out from the dewatering houses. The sludge is then gathered on a platform made of concrete with a sheltering roof. There is no intermediary storage in Beijing where treated sludge is collected. The sludge is kept at the different wastewater treatment plants until sufficient amounts of sludge have been produced. Then trucks transport it away for disposal. One of the trucks used for this transportation is shown in Figure 14. It is transported to Daxing Sludge Disposal Plant where the sludge is composted and sold as fertiliser or soil improver. (The distance to Daxing is 54km)

Figure 14**. Trucks that is used for transportation**

The total amount of sludge produced at Gaobeidian Sewage Treatment Plant after treatment is 110 m^3 of dry solids per day with water content less then 80%. Daxing Sludge Disposal Plant receives about 100 000 m^3 of sludge per year from Gaobeidian.

4.3.2 Quality of sludge

Monitoring the quality of the wastewater and the produced sludge is important in order to protect the recipient water and to control the performance of the wastewater treatment plant. The quality of the influent- and effluent water to all the wastewater treatment plants is analyzed every day. The amounts of Suspended Solids (SS), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), total nitrogen, total phosphorus and different heavy metals are measured. Wastewater treatment plants have discharge standards and have to keep records of the quality of the effluent water.

The quality of the sludge is also analyzed but this is done less frequently, only 4 times a year. Measures are taken for organic matter, total nitrogen, total phosphorus, total potassium, heavy metals, some organic pollutants and some bacteria. The quality is measured at different steps in the treatment process of the sludge. It is measured in the primary sedimentation tank, the secondary sedimentation tank, the digestion tank and in the sludge cake (sludge after treatment).

All the analyses in Beijing are performed by the Water Quality Analysis Centre. The Water Quality Analysis Centre is responsible for analyzing the water and the sludge and they have modern and advanced technology. The government has accredited this Analysis Centre. Wastewater discharge control and monitoring of water quality is handled by the State Environmental Protection Administration, while the Ministry of Construction administers the water supply to urban areas. This includes both domestic and industrial use of water. (Boon et al, 2000)

Gaobeidian has a high BOD removal efficiency: the incoming BOD_5 of 100 – 200 mg/L is almost the same to all plants, but the treated water from Gaobeidian Wastewater Treatment Plant exhibits as BOD_5 of 20 mg/L whereas the other treatment plants have an outlet value of 30 – 40 mg/L. The details are shown in Table 8.

Table 8**. Treatment efficiency of the Gaobeidian Wastewater Treatment Plant**

Indicator	**Influent values mg/L**	**Removal by Primary sedimentation**	**Final effluent quality mg/L**	**Removal Efficiency**
BOD_5	100 -200	25 -30%	< 20	> 90%
COD	500	30%	< 60	> 90%
SS	250	50- 60%	< 30	> 90%
Harmful microbes	present	uncertain	none	100%

Source: taken from the Gaobeidian Wastewater Treatment Plant's blackboard (2000)

4.3.3 Treatment method for wastewater reclamation

Based on the policy of government, Beijing planed to treat the wastewater in an appropriate way in order to reuse it as the second water resource and thus mitigate the crisis of water shortage. The project of Gaobeidian wastewater treatment plant is a demonstration of urban centralized wastewater reclamation. The planning and feasibility research was started in 1999 and it was finished around 2001. Beijing General Municipal Engineering Design & Research Institute took charge of the design and the operator is Gaobeidian wastewater treatment plant.

There are two reclamation processes related to Gaobeidian wastewater treatment plant: After treatment, part of the effluent is reused within the plant itself and the rest part is transport to other places to be used there.

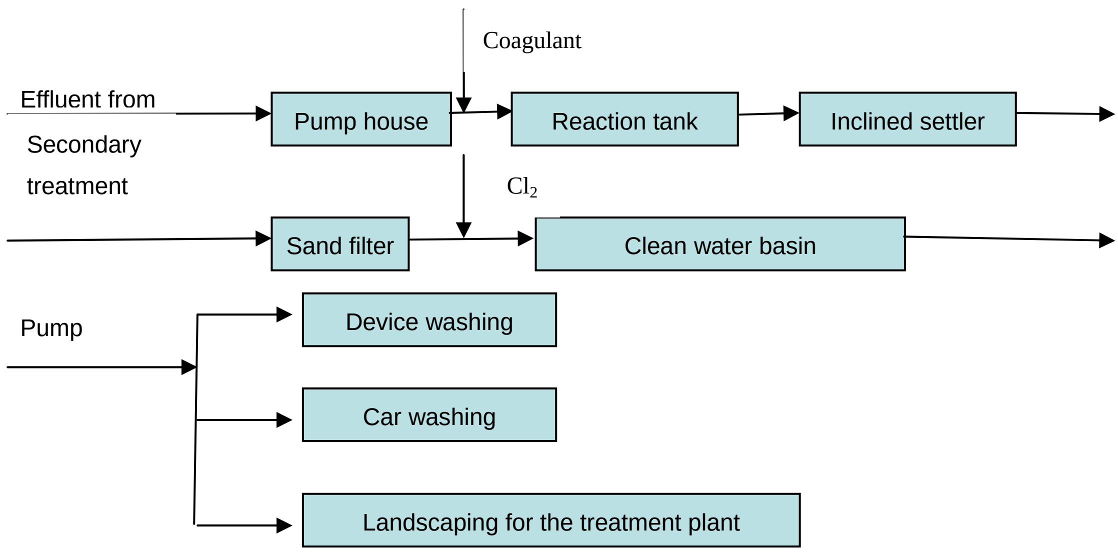

Figure 15. **The reclamation procedure for the reclamation at the plant itself**

For the first process which means the reclamation system in the plant itself, the flow chart is illustrated above as Figure 15. This reclamation system applies traditional treatment process which includes the coagulation, sedimentation, filtration and disinfection parts. The effluent from the secondary sewage treatment plant in Gaobeidian is lifted by the pump. After adding a coagulant, it goes to a static mixer and then goes into a high-rate reaction tank. The floc generated is settled in the inclined settler and the top clean water is sent to the sand filter of V-shape. Before going to the clean water basin, the water filtered is disinfected by adding the chlorine. The quality of the effluent is shown as Table 9. Seen from the table, the effect of the treatment was not so significant. It can be explained that the influent of this reclamation process is the wastewater after primary and secondary treatment. Therefore, a great deal of pollutants has been removed already which reduce the burden of reclamation process.

Table 9. **The performance of the reclamation process**

Indicators	The quality of the influent	The quality of the effluent
COD (mg/l)	46	22
BOD_5 (mg/l)	11	4.4
SS(mg/l)	15	4.8
PH	7.1	7.0

With respect to the reclamation process in Gaobeidian wastewater treatment plant, it is crucial to choose appropriate coagulant and its amount. In terms of the characteristics of the water from secondary sewage treatment plant in Gaobeidian, the relevant department carried out several trials to choose the coagulant. Based on the comparison among the Polyacrylamide(PAA), Polyaluminium chloride and Polyiron chloride, the result was that the best coagulant is Polyaluminium chloride and the best dosing rate is 30ppm. Moreover, The control system is operated automatically. For the sludge removal, the electric device is set to work every 2h. The operation period for the filter is 24 hours and the back flushing is 25min.

For the outside process, the main processes are accelerated clarification, sand filtration and disinfection, etc. The flow chart is shown below as Figure 16. The water is transported to related reclamation places by pipes and undergoes on-site advanced treatments there. So the whole process includes too many municipal facilities. Therefore, in this context especially in chapter7-Data Analysis, the in-plant reclamation process will be more focused on to make sure the comparison of three cases is on the same level.

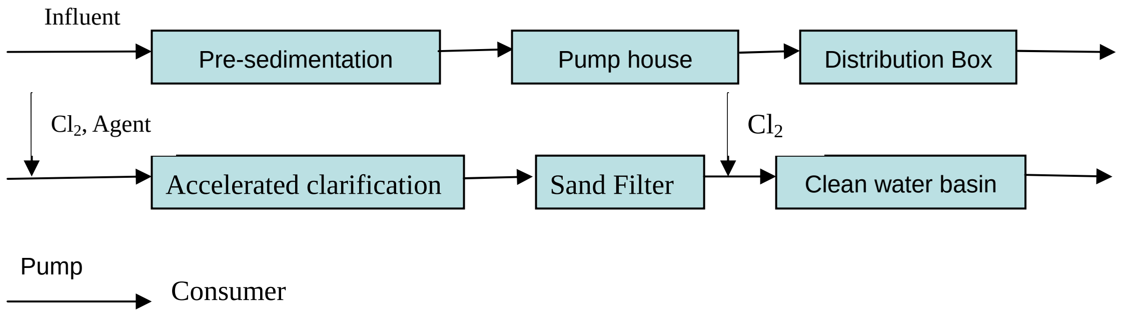

Figure 16. **The reclamation procedure for the outside process**

4.4 Economic issues

For the in-plant process, the occupied area is around 8500 m^2 and the total investment is 12,000,000 RMB, 9,000,000 of which is the construction fee and the rest is the device investment. In addition, the operation cost is 0.41RMB/m^3 and the details are shown as Table 10:

Table 10. **The details of operation cost for in-plant process**

Category	Electric cost	Agent cost	Hand-operated cost	Maintenance cost	Depreciation cost	Total
Expense (RMB/m^3)	0.12	0.10	0.07	0.03	0.09	0.41

With respect to the second process, the total investment is 3,600,000,000 RMB, the expanse for dismantling the inside devices is about 1,000,000,000RMB and the rest is the project expense. The project includes:

- The pump house in Gaobeidian wastewater treatment plant: 470,000m^3/d
- The improvement of Gaobeidian wastewater treatment plant. There were no standards to control the quantity of nitrogen and phosphorus at the moment of the establishment of Gaobeidian wastewater treatment plant. So the content of nitrogen and phosphorus is high and can not be used for reclamation. With these in mind, some technical adjustment is necessary to improve the quality of effluent.
- The flow pipe from Gaobeidian wastewater treatment plant to Gaobeidian

Lake:DN1800mm, length1480m

- The pipeline from Gaobeidian wastewater treatment plant to No.6 Water Plant: DN1400, length 4766m

The cost analysis of construction and operational of Gaobeidian wastewater reuse systems, was shown in Table 11. It should be mentioned that the construction and operational cost of Gaobeidian reuse systems included water supply cost and water treatment cost.

Table 11. **The details of operation cost for municipal process**

Design scale (10,000 m^3/d)	Construction (10,000 Yuan(RMB))			Construction Cost Yuan(RMB)/m^3	Operational Cost Yuan(RMB)/m^3		
	Permanent assets	Deferred assets	Total		Supply	Treatment	Total
47	29,814.58	2,537.41	32,351.98	688.34	0.16	0.62	0.78

As a result, the whole project can save 166,730,000m^3 of water which is as same as the production of one water plant with the scale of 100,000m^3/d. However, although this project has many economic benefits, it can not be extended so easily due to the shortage of distribution pipelines. The problem is that it is difficult to build the branch pipelines connected to every user (hotels, offices, residential areas, etc). As a result, the application of reclaimed water met some limitations. Moreover, due to the adjustment of Beijing Industry structure, the actual required water for supply from No.6 Water Plant is less than 50,000 m^3/d, so more than 120,000 m^3/d of reclaimed water are useless which make the economic benefits less than expectation.

4.5 Social issues:

4.5.1 Research strategy:

According to the research methods in Chapter 3, there are should be two ways to investigate the social response to this reclamation project. On one hand, interviewing with the employees plays an important role to collect exactly data and information about the daily operation. More important, it is a good way to understand the feeling and opinions from employees about the reclamation process. With this consideration in mind, the research was conducted by the interview with Li yao, one of the employees in the training center of Gaobeidian Wastewater treatment plant. She takes charge of giving introduction and training to public visitors so that she knows a lot about the basic situation of reclamation process. Moreover, she can provide her own opinions and other colleague's opinions for daily operation as well. The interview was based on the questionnaire in appendix A, especially the part for operators.

On the other hand, surveys for end users (the citizens who use the reclaimed water produced by Gaobeidian outside reclamation process) was also carried out to check whether the public awareness or/and public acceptance is good enough. Therefore, within the scope of the pipe system of Gaobeidian Wastewater Treatment plant, two groups of dwellers from two residential areas were chosen to generalize the result from all units in the operational population. The survey was carried out in the nearby residential areas which are using the reclaimed water generated by Gaobeidian Wastewater Treatment Plant: Gaobeidian residential area and Yi zhuang residential area. At the beginning, ten dwellers were picked up in both cases. The sample was picked up randomly since it can make sure all of the dwellers have an equal chance to give their opinions. Both of the conditions can make the result more reliable.

4.5.2 Research result:

Based on the interview with Liyao, the result can be concluded as bellows:

- As a mature system, Gaobeidian reclamation project has a good performance.

The treatment process is stable and reliable and the quality of the effluent achieves the national standards for reclaimed water.

- It hardly received complaints from citizens, especially in recent years.
- Furthermore, only a few of problems occurred during the operation. The main one was that the disinfection part was not good enough and has been taken into account to improve.
- The operators are working under safe environment. No accidents occurred during past years and there were no problems threaten to people's health.

While for the survey, the results are shown as Table 12.

Table 12. **the statistics for questionnaires**

Questions	**Gaobeidian Residential Area**		**Yizhuang Residential Area**	
	Yes	**No**	**Yes**	**No**
Do you know what the reclaimed water is	2	8	1	9
Do you know you are using the reclaimed water now	1	9	1	9

According to the table, among these ten dwellers, 8 of 10 and 9 of ten even do not know what the reclaimed water is. Moreover, the rest of them who know the definition of reclamation water can only express a few of opinions about their using experience. Therefore, the investigation for public acceptance met a big obstacle. This phenomenon can be explained by three possibilities:

- The citizens do not have right to choose the source of water. In other words, they just can use the water from pipe. So they do not care about the characteristics of water.
- Currently, the most popular usage of reclaimed water is for landscaping, people do not have direct contact with the water. Therefore, they are not aware of the existence of reclaimed water.
- The size of samples is too small. One hypothesis may be made that this sample can not represent the real situation. However, the sample was chosen randomly and it

can be regarded that everyone has equal chance. In addition, the situation in both residential areas was almost same. Therefore, although the data can not be seemed as statistically representative, but can be used to make inferences about the general situation.

5. Beijing Jiaotong University

5.1 Background

Beijing Jiaotong University, located in Haidian district of Beijing, is the precursor to implement the reclaimed water system among all the universities in Beijing. It uses the balneal water (the wastewater from the bathroom of the dormitory) as the reuse resource. The balneal water is one of the main elements of the domestic waste water. It has fewer pollutants compared with other kinds of waste water. As far as Beijing Jiaotong University is concerned, the daily balneal water is about 150-180m^3. It can be collected easily but it was not taken into account before. Meanwhile, there is a playground (as Figure 17) in this university which is about 16800m^2. Accordingly, 60-120m^3/h of water is needed for spraying system, but this system wasn't use for a long time due to water shortage. In order to solve this problem, Beijing Jiaotong University considered about the water reclamation. The balneal water treatment plant for reclamation was established in 1993. Beijing Municipal Research Institute of Environmental Protection took charge of the design and installation work, while the Beijing Jiaotong University is responsible for the construction and daily operation.

Figure 17**. The playground of Beijing Jiaotong University**

5.2 Technical description

As illustrated in Figure 18, the balneal water from the bathroom in University firstly goes to the bar screen to remove the solid pollutants. The function of retention basin is to adjust the flow quantity and average the quality of water. As a result of the high temperature, the water tends to have putrefactive odor, so there is an aeration jet for the wastewater. After that, the water was pumped to the treatment device. The first device is the hair filter to remove the hair and part of solid. The second one is the ZX-1 water reclamation device which is constituted by four parts: coagulant reaction, sedimentation, contact oxidation and filtration. The quality of the effluent can achieve the national standard for reclaimed water. The last step is the disinfection and the water can be reused afterwards.

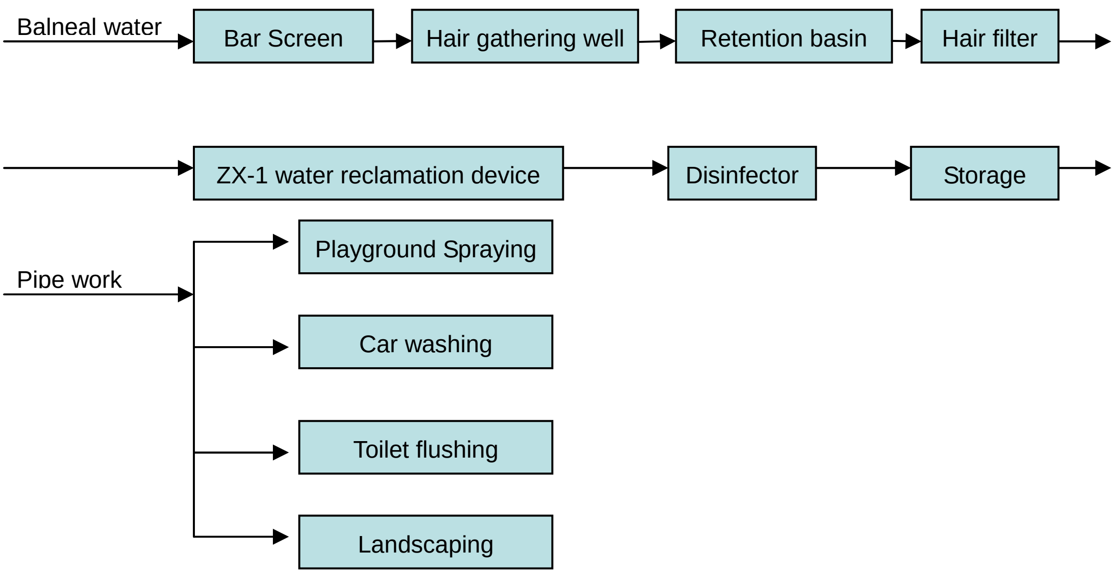

Figure 18**. The reclamation procedures for Beijing Jiaotong University**

Based on this, the designed capacity: 200m^3/d (10m^3/h) and the practical capacity: 150m^3/d or 10m^3/h. accordingly, the effect of the treatment is shown in Table 13. With regarding to this table, the performance of indicators has got obvious improvements.

Table 13. **The effect of the reclamation process**

Indicators	The quality of the influent	The quality of the effluent
COD (mg/l)	120-250	14
BOD_5 (mg/l)	60-140	3.5
SS(mg/l)	60-150	2
Pathogen(/l)	-	<3
PH	7.0	7.6
Residual chlorine (mg/l)	-	0.3

In addition, most of the devices are controlled by workers, such as the aeration device and filters. There are several issues which should be paid attention to in daily operation and management:

- The bar screen, the hair filter and the glass flow rotor in the ZX-1 should be cleaned regularly.
- Use aluminium sulphate as the coagulate agent for the coagulate part of ZX-1, the amount of which is 50-100 mg/l.
- Use inclined tub settler for the sedimentation part of ZX-1 and it should discharge the sludge twice per day.
- The rapid filter for the filtration part of ZX-1 is filled with non-bituminous medium. The rate of filtration is 6-9m/h.

In general, several points can be addressed:

- The ZX-1 device has small scale and can be operated simply.
- Not only the putrefactive odor can be prevented by the aeration jet in the retention basin, but also organic matters can be degraded partly by the aerobic bacteria. As a result, the indictor of COD is reduced by 25% from retention basin.
- Because of the pre- coagulant sedimentation process of ZX-1 device, the organic matter is reduced by 50%. Therefore, the retention time for the contact organic tank is decreased which is only around 1.2h.
- In the practice, the effluent of this reclamation process is only applied for spraying the playground and landscaping. As the weather condition of Beijing, the reclaimed water

can not be used in winter and the water will be discharged to the surface water. So this project has seasonal limitation.

- This reclamation process is an open system and sometimes it has bad smell which gives the workers some troubles.
- Beijing Jiaotong University is responsible for daily inspection of the residual chlorine, the other indicators are under controlled by Beijing Environmental Protection Bureau or other governmental agency.

5.3 Economic Factor

The whole process occupied 40 m^2 of area. The total investment is 300,000 RMB and 180,000 of which is the construction fee and the rest is the device investment. The operation cost is 0.75RMB/m^3, the details are shown as below in Table 14:

Table 14. **The details of operation cost of Beijing Jiaotong University**

Category	**Electric cost**	**Agent cost**	**Hand-operated cost**	**Maintenance cost**	**Depreciation cost**	**Total**
Expense (RMB/m^3)	0.30	0.17	0.13	0.02	0.13	0.75

5.4 Social Factor

5.4.1 Research strategy

In the first place, the research was carried out by means of interviewing Mr. Wu Guohuang who is a professor of Beijing Jiaotong University. He also takes charge of supervising reclamation projects among all the universities in Beijing. As a result, not only the information related to Beijing Jiaotong University, but also the information for other universities can be gained. More important, he can present the overview of reclamation cases for universities. The interview was based on the questionnaire in appendix B, especially the part for operators.

On the other hand, according to the research method, the social aspect of reclamation system should be measured by the survey among students of Beijing Jiaotong University. With respect to the experience of the residential areas near Gaobeidian Wastewater Treatment Plant, the frame of the sample was designed more carefully. The students were chosen based on their majors. Four majors related to reclamation process were the options: Environmental engineering, Chemical Engineering, Biological department and Physical department. The size of the sample is 40 students, in another word, there were 10 students of each departed selected as the sample. These 10 students were chosen randomly so that all students of the four departments have equal chance to participate survey.

5.4.2 Research result

Based on the content of the interview with Mr. Wu Guhuang, it can be concluded that as far as it were concerned, the whole process is easily controlled, small scale, less expense, and environmental friendly. Nevertheless, just like each coin has two sides, there are several disadvantages in this case. The operator said sometimes the smell was not so good due to bad ventilation. In addition, the system has no usage in winter because it was so cold that there is no grass on the playground. Meanwhile, he pointed out that some new technologies can solve the smell problems, more and more university are using the developed methods and have got the significant effect. In general, as the first university to implement the reclamation project, Beijing Jiaotong University gave others a good example. Based on its experience, other university carried out the reclamation project as well and applied new technologies.

The results of the survey were concluded and shown in Table 15. Seen from this table, it is obvious that the concept of reclamation did not get enough public awareness. Similar as the situation of Gaobeidian case, 90% of students didn't know about the definition of "reclamation". Just one of the students who major in environmental engineering knows it, but unfortunately, he had now ideas about the situation of reclamation system in Beijing Jiaotong University. This phenomenon can be explained like this:

- There was no channel for students to realize the existence of this reclamation project. The university doesn't have special tendentious activities.
- Students are not care about the reclamation project since the source of the system is the water from the public bathroom so that it doesn't have causal relationship with normal life of students.
- There is a possibility that the sample was not the exactly sample which can reflect the truth. However, as the students from these four departments were chosen randomly, so everyone had same chance to be the options. As a result, although the data can not be seemed as statistically representative, but can be used to make inferences about the general situation.

Table 15. **the statistics for questionnaires**

Questions	**Department**							
	Environmental		**Chemical**		**Biological**		**Physical**	
	Yes	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
Do you know what the reclaimed water is	**2**	**8**	**1**	**9**	**0**	**10**	**0**	**10**
Do you know you are using the reclaimed water now	**1**	**9**	**0**	**10**	**0**	**10**	**0**	**10**

6. Beiluchun Residential Area

6.1 Background

Beiluchun Residential Area located in Fangshan district. It occupies 94 ha totally. The construction area is about 700,000m^2 and can accommodate 3000 dwellers. It has gained the certification of ISO 9002 and is regards as one of the demonstrations of eco-residential areas in Beijing. It has on-site treatment for solid waste and reclaimed water. As far as the reclamation is concerned, the designer and the construction company is Beijing Tsinghua Novel Ltd. Beijing Fanshan Real Estate Company is responsible for the operation.

6.2 Technical description

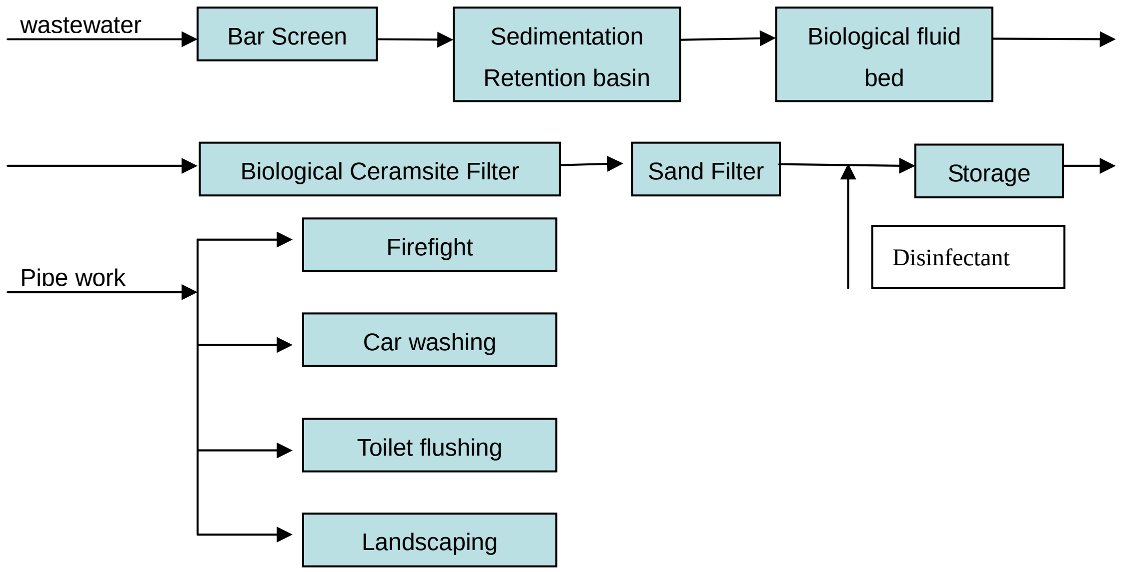

Figure 19 **The reclamation procedures for Beiluchun residential area**

Figure 20. **The overview of the reclamation project**

As shown above, the wastewater which includes the black water (the wastewater from the toilet) and yellow water (the water from kitchen and bathroom) goes to the bar screen by pipe system. After removing some big particulate matter, the steam goes to the sedimentation retention basin and then pumped to the three-phase biological fluid bed （Figure 21）. The effluent from the Biological Cereamsite Filter can reach the standards for discharge and it can be reused after the sand filtration and disinfection.

Figure 21**. The feature of the three-phase biological fluid bed**

The residual sludge in the fluid bed is sent to the retention basin regularly which makes it stable. The refuse of the basin is taken out by Environmental Hygiene Agency periodically and the refuse on the bar screen is regarded as the solid waste which is get rid of with other waste produced by this residential area.

The reclaimed water is stored in the firefighting water tank. The water in this tank keeps circulation, the water table is stable and the overfall of residue reclaimed water goes to the artificial lake.

According to this, the designed capacity is 640 m^3/d (26.7 m^3/h) and the practical capacity: 600 m^3/d (25 m^3/h) and the effect of treatment are shown as Table 16. As illustrated in this table, most of the indicators have got better performance. The treatment efficiency achieved at high level(all the main indicators have exceed 90%), which ensures it can meet the standards of national reclaimed water.

Table 16. **The effect of the reclamation process**

Indicators	**The quality of influent**	**The quality of effluent from fluid bed**	**The quality of effluent from ceramsite filter**	**The quality of the reclaimed water**	**Treatment Efficiency**
COD (mg/l)	350	67.6	34.5	34.5	90.1%
BOD_5 (mg/l)	180	18.5	6.3	6.3	96.5%
SS(mg/l)	197	19	8.07	8.07	95.9%
Pathogen(/l)	-	-	-	3	-
PH	8.22	-	-	7.8	-
Residual chlorine (mg/l)	-	-	-	0.35	-

1 2 3

Figure 22. **the usage of the reclaimed water**

1. For landscaping 2. For firefighting 3. For car washing

6.3 Economic Factor

The whole process occupied 1097 m^2 of area. The total investment is 1400,000 RMB, 250,000 of which is the construction fee and the 1150,000 RMB is for the device. The operation cost is 1.08 RMB/m^3, the details is shown as below:

Table 17**. The details of operation cost of Bailuchun residential area**

Category	**Electric cost**	**Agent cost**	**Hand-operated cost**	**Maintenance cost**	**Depreciation cost**	**Total**
Expense (RMB/m^3)	0.43	0.05	0.09	0.03	0.48	1.08

6.4 Social Factor

Because this residential area is far from the central area, it is difficult to contact the local citizens. However, some useful information is got from the design company. The manager of Beijing Tsinghua Novel Ltd said this case is an inchoate project for reclamation. From then on, many new technologies were developed and improved such as the membrane method. But the problem is that the Real Estate Developers do not want to investment enough money on these reclamation projects. They just care about the sales of the houses. In addition, for the daily operation and management, there are not enough technical workers. The training is a tough task for the designer.

Although this interview was just one side of story, it can reflect the truth more or less. Currently, the reclamation policy only regulate that estate developers should investment some money on building reclamation facilities. However, it did not mention to which extend the investment should be. Some developers follow the policy but they did not contribute sufficient efforts so that the design company met tough problems. The cooperation between two parties can not be satisfied. As a result, the obligations for each party should be clearer in future.

7. Data Analysis

This chapter presents an evaluation of the performance of the investigated centralized and decentralized reclamation systems. The systems are compared based on technical performance, costs and social aspects..

7.1 Technical performance

As described in Chapter 4, 5 and 6, the technical performance was investigated from several aspects: the wastewater treatment technology and of the reclamation system, the performance of various indicators, the applications of the system and the operation and management. Table 14 concludes the technical performance of the three cases.

Table 18. **technical performance of the three cases**

Indicator	Gaobeidian Wastewater Treatment Plant	Beijing Jiaotong University	Beiluchun Residential area
Main process	Physical[1]	Biological & Physical	Biological
Design Capacity	-	$200m^3/d$	$640m^3/d$
Practical Capacity	$10000m^3/d$	$150m^3/d$	$600m^3/d$
Occupied area	$8500m^2$	$40m^2$	$1097m^2$
Efficiency of removing COD	52.2%	>89%	90.1%
Efficiency of removing BOD_5	60%	>95%	96.5%
Efficiency of removing SS	68%	>97%	95.9%
The application of the effluent	Car washing Landscaping Cooling water	Spraying the playground	Firefighting Landscaping

	Device washing		

[1] This process only refers to the reclamation system, i.e. after the wastewater treatment

After comparing different issues, some results can be found as follows:

Firstly, In general, all these three cases are using a similar process which is constituted by three main parts: Pre-treatment unit, Treatment unit and advanced unit. The function of pre-treatment unit is to remove big solid pollutants and hair. The bar screen was designed in all the three cases as the devices for pre-treatment. The next step is the treatment unit which is for reducing the indicators of COD, BOD and so on. The three sites apply a different treatment unit. For Gaobeidian Wastewater Treatment Plant, it mainly uses physical treatment technology, while both physical and biological treatment technologies are included in the reclamation process of Beijing Jiaotong University and Beiluchun Residential area uses biological treatment system. Although they are using different technologies, all of them show good results. Seen from the table, the decentralized system has a good performance with respect to removal of COD, BOD_5 and SS. For the centralized system, the efficiency is lower. But it can be explained that the influent was from the advanced treatment and it has got high quality already, so the treatment effect was not so significant.

The consideration for choosing different technologies is based on the practical situation which refers to the scale of the sites, the quality of the influent, the investment costs and so on. The design companies are in charge of the technology selection or, in another words, these companies choose the reclamation process. The system owner is only in charge of daily operation and management. As far as Gaobeidian Wastewater Treat Plant was concerned, the workers were well trained and the system was managed in a proper way. However, for the decentralized system such as Beijing Jiaotong University and Beiluchun Residential Area, the operators lack specialized technical knowledge and the design company usually can not afford sufficient training for them, so in most cases the reclamation system for decentralized cases are running automatically and do not need too much manual work. The systems of the three cases were under loaded for years. Therefore, no big problems have occurred so far.

Compared with the centralized system, the capacity of the decentralized systems is much smaller. But on the other hand, decentralized systems are more flexible and can be implemented on small scale. Moreover, for the decentralized system, the actual production/sales are much lower than design capacity. This phenomenon is probably because there are not enough specialized technical workers to operate and maintain this system so that it can not perform as expectations.

All the cases have many applications which were concluded in the table, but none of them reuse the waste water for toilet flushing. It can be explained that the reconstruction work for new pipe line settlement would take a long time and huge expense. As a result, nowadays the main usage for reclaimed water is landscaping and car washing.

7.2 Investment and operational costs

The economic performance was assessed based on the investment and operation expanse of three cases which is illustrated as Table 14. With respect to the difference of scale, the indicator of "investment" is considered with occupied area and practical capacity in order to address the comparison on the same level. In addition, since the municipal reclamation process of Gaobeidian Wastewater Treatment Plant is connected with other municipal plants or facilities, so it is not easy to distinguish the exact investment specialized for Gaobeidian. With this consideration in mind, the comparison is made up of the in-plant process of Gaobeidian Wastewater Treatment Plant, Beijing Jiaotong University and Beiluchun Residential area.

Table 19. **Economic comparison of the three cases**

Indicator	**Gaobeidian Wastewater Treatment Plant (in-plant)**	**Beijing Jiaotong University**	**Beiluchun Residential area**
Investment (RMB)	12,000,000	300,000	1400,000
Investment/ occupied area (RMB/m^2)	1411.76	7500.00	1276.21

Investment/ practical capacity (RMB•d/m^3)	1200.00	2000.00	2333.33
Operation expense (RMB/m^3)	0.41	0.75	1.08

Taking the economic factors of centralized and decentralized system into account, it can be found that the investment of the centralized system is much higher than decentralized system due to vast scale and required devices. When the reclamation scale and capacity are considered, the difference between three cases is not so obviously. The investment of in-plant reclamation process of Gaobeidian Wastewater Treatment Plant is even cheaper than that of Beijing Jiaotong University and Beiluchun Residential Area when practical capacity were took into account(1200 to 2000 and 1200 to 2333.33). Beiluchun Residential area was the cheapest when thinking about the factor of investment and occupied area. However, its operation expanse is higher than the other two cases. Gaobeidian Wastewater Treatment Plant took much advantage from operation, the expense is only 0.41 RMB/m^3 which is much lower than the two cases of decentralized reclamation system. However, in any of the cases, the cost of the reclaimed water is much lower than the price of tap water (as shown in Table 5, the tap water of Beijing is 0.35$/$m^3$ which is about 3RMB/m^3).

7.3 Social Factors:

As a whole, all these three cases have similar components of stakeholders: Design Company, system owner/operator and end users. The design companies were responsible for selecting the technology, they are the decision maker. System owner invested in the whole system and took charge for the operation and management. The end users usually refer to those citizens who use the reclaimed water directly or indirectly.

In all the three cases, the citizens who were interviewed use the reclaimed water indirectly. For example, the application of reclaimed water for Beiluchun Residential area is landscaping and firefighter. Therefore, the dwellers do not have direct relationship with it which result in insufficient public awareness. Based on the results of interviews and surveys for the cases of Gaobeidian Wastewater Treatment Plant and Beiluchun Residential area, over 80% of interviewees did not know the definition of reclaimed water and can not express their opinion about it. As a result, the research depth for the social factors was limited.

For the design companies, they are more willing to do the centralized projects and some decentralized projects for official buildings and hotels. The reason is that for these kinds of projects, the cooperation between the design companies and system owners is easier than that in residential areas. The construction companies and project developers that establish the residential areas usually do not want to invest a lot of money on reclamation systems. So in many cases, the design companies are limited by funds and sometimes they have to choose unsatisfactory technology and devices.

Due to these limitations, the centralized system seems more and more favored by the design companies and the system owners. One argument against centralized systems is that Beijing has piping systems in place for sewage removal and tap water supply. To install new pipes for reclaimed water requires a lot of construction work and investment. But the municipality is reserving budget for it. One argument in favor of centralized systems is that, although the initial investment is huge at the beginning, the operation cost are lower compared to decentralized systems, so it is meaningful for long-term.

8. Conclusions and Recommendations

8.1 Conclusions

Based on this study, conclusions are drawn concerning performance, economic aspects and social aspects.

For the technical performance, due to the use of mature technologies, both the centralized and decentralized reclamation system are effective in achieving the quality requirements. All the quality indicators comply with the national standards for reclaimed water. The performance difference between centralized and decentralized systems was not significant.

With respect to economic factors, the chosen cases demonstrated that it is beneficial to use reclaimed water. The price of the reclaimed water is lower than that of tap water. The cost difference is bigger for the centralized system. The interviews with design companies reveal that the cooperation between design companies and real estate companies is not always good. Real estate companies tend to save on the investment costs for decentralized reclamation systems and as a consequence the installed systems and devices are sometimes unsatisfactory.

The study also reveals that wastewater reclamation system does not get much public awareness. Most of the Beijing residents that were interviewed were not aware of it.

With respect to the investigated evaluation factors, the centralized reclamation system is more favorable.

8.2 Recommendations

As the reclamation projects have economical advantages and reduce water scarcity, they should be popularized in the future. Insufficient public awareness could be an obstacle to it. Therefore, it is suggested that the awareness is raised. Through the media, the importance of water reuse could be explained and the reliability and good quality of reclaimed water put forward. More attention should be paid to demonstration projects and the general public could be invited to visit urban water reuse facilities. With respect to decentralized applications, the responsibilities of the construction companies and design companies should be made clearer so that each party could know its obligation and the cooperation between different parties would become better in future. In addition, the government could make more compulsory rules or standards to regulate activities of the parties.

I

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Appendix A: Questionnaire for Gaobeidian Wastewater Treatment plant

<u>Part Ⅰ: Technical issues</u>

1. Which technology do you choose for wastewater treatment?

   ....

2. Which technology do you choose for reclamation part?

   …………………………………..

3. What is the process for this system (flow-charts)?

   …………………….

4. What is the function of each part?

   …………………….

5. What is the performance of this system?

   The designed capacity (m^3/d) ……………….

   The occupied area (m^2): …………….

Indicators	The quality of the influent wastewater	The quality of the effluent reclaimed water
COD (mg/l)		
BOD_5 (mg/l)		
SS (mg/L)		
PH		
Pathogen		

6. What kind of standards does the effluent reclaimed water comply with?

   …………………………….

7. What is the reclaimed water used for? (Multiple choice)

a) Toilet water

b) Landscaping

c) Fire-fighting water

d) Car-washing water

e) Industry cooling water

f) Agriculture irrigation

g) Others……………………………..

8. What's the scope of the pipe system of the effluent reclaimed water?

....

9. How to operate this system?

a) Automatic and just need periodically maintenance

b) Need technical operators and periodically maintenance

c) Can be operated by normal workers and need periodically maintenance

10. How often do you maintain the system?

…………………………………………………..

11. How many times per year does a system failure occur?

……………………failures/year

12. Which parts of the wastewater management system failed/was out of order? What was the problem? When and how often does it happen? How did you solve it and who did it?

Part of the system	Problem	When? (Date)	often? (t/m /y)	Solution	Solved

13. When the sanitation system fails, what is the average down time in hours?

…………hours/failure

Part ll: Economic issues

1. What about the cost?

The investment: ……………….

The operation expense: …………………

2. Do you think there are any opportunities to extend the market?

a) Yes (go to question 3)

b) No (the end)

3. Which kind of difficulty will be encountered?

....

4. How to solve it?

....

Part lll: Social issues:

For the operators:

1. What do you think about the working condition of this system?

…………………………………………………………….

2. Did you get any complaints from the customers?

a) Yes (go to question 3)

b) No (go to question 4)

3. What are the complaints about? (Multiple choices)

a) Odors of the reclaimed water

b) Colors of the reclaimed water

c) Safety of the reclaimed water

d) Price of the reclaimed water

e) Others……………………….

4. What is the chance that you could come into direct contact with untreated or partially treated water (in percentages)?

……………….%

5. Have you suffered some kind of illness due to the wastewater management system?

a) Yes,

It's about: ………………………………………………………………………..

....

b) No

5. What kind of benefits of the waste water management system do you experience?

………………………………………………………………………………………

……………………………………………………………………………………….

6. What kind of drawbacks of the waste water management system do you experience?

………………………………………………………………………………………

………………………………………………………………………………………

7. Do you have any recommendation for this system?

a) Yes.

………………………………………..

b. No

For the end users:

1. Do you know what the reclaimed water is?

a) Yes. (go to question 2)

b) No

2. Do you know you are using the reclaimed water now?

a) Yes

b) No

3. How do you think about the reclamation system you are using?

a) good enough

b) acceptable

c) no opinions

d) not satisfied

Because…………………………………………………………………..

……………………………………………………………………………..

4. Do you have any recommendations for future improvements?

a) Yes

……………………………………………………………………………..

……………………………………………………………………………..

b) No

Appendix B: Questionnaire for Beijing Jiaotong University

A. For the operators:

Technical issues:

1. Which technology do you use for this university?
   …………………………………..
2. What is the process for this system (flow-charts)?
   …………………….

3. What is the function of each part?
   …………………….

4. What is the performance of this system?
   The designed capacity (m^3/d) ……………….
   The occupied area (m^2): …………….

Indicators	The quality of the influent wastewater	The quality of the effluent reclaimed water
COD (mg/l)		
BOD (mg/l)		

5. What kind of standards does the effluent reclaimed water comply with?
   …………………………….

6. What is the reclaimed water used for? (Multiple choice)
   a. Toilet water
   b. Scenic water
   c. Fire-fighting water
   d. Car-washing water
   e. Others……………………………..

7. How to operate this system?
   a. Automatic and just need periodically maintenance
   b. Need technical operators and periodically maintenance
   c. Can be operated by normal workers and need periodically maintenance

8. Are there any technical problems occurred during the construction and operational period?
   a. Yes
      It is about: ………………………………
   b. No

9. How did you solve it?

…………………………….

10. Is the sanitation system being monitored?
    a. Yes (go to question 2)
    b. No (go to question 3)

11. What kind of indicators do you monitor?

…………………………………………………..

12. How often do you maintain the system?

……………………………………………….

13. How many times per year does a system failure occur?

……………………failures/year

14. Which parts of the wastewater management system failed/was out of order? What was the problem? When and how often does it happen? How did you solve it and who did it?

Part of the system	Problem	When ? (Date)	often? (t/m /y)	Solution	Solved

15. When the sanitation system fails, what is the average down time in hours?

…………hours/failure

Economic issues:

1. What about the cost and benefits?

   The investment: ……………….

   The price for households: …………………

Social issues:

1. What do you think about the working condition of this system?

   ………………………………………………………….

2. Did you get any complaints from the households?

   a) Yes (go to question 2)

   b) No

3 What are the complaints about? (Multiple choices)

   c) Odors of the reclaimed water

   d) Colors of the reclaimed water

   e) Safety of the reclaimed water

   f) Price of the reclaimed water

   g) Others……………………..…..

4. What is the chance that you could come into direct contact with untreated or partially treated water (in percentages)?

   ……………….%

5. Have you suffered some kind of illness due to the wastewater management system?

   a. No

   b. Yes,

   It's about: ………………………………………………………………………..

   ……………………………………………………………………………………………

B. For the students (Social issues)

1. Do you know what the reclaimed water is?

   a) Yes. (go to question 2)

   b) No

2. Do you know you are using the reclaimed water now?

   a) Yes

b) No

3. How do you think about the reclamation system you are using?

a) good enough

b) acceptable

c) no opinions

d) not satisfied

Because…………………………………………………………………..

……………………………………………………………………………..

4. Do you have any recommendations for future improvements?

a) Yes

……………………………………………………………………………..

……………………………………………………………………………..

b) No