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A Study on Sustainable Urban Water Management in Small and Medium-sized Cities in China

by

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Abstract

Along with the implementation of national urbanization and modernization strategy in China, the urban scale and quantity are increasing systematically. In this process, the role of water is irreplaceable. Urban water system is a multipurpose and integrated system. Considering China's economic and social development requirements, there are many rigorous problems in exploitation, utilization, operation and management of urban water resources comparing with some developed cities in the world.

Currently, a number of cities, especially small and medium-sized cities (SMSCs), are on the serious condition of water shortage and water wasting in China. It is an important means for development of economy and society to achieve the sustainable utilization of water resources. Building a sustainable management and development system for urban water resources and water environment has conclusive sense for supporting the urban economic and social development. Moreover, the theory of water recycling and its operation models are put forward through the research of the complex system of water-society-economy-ecological environment. This dissertation will do a preliminary study and discussion on following aspects.

- Based on the analysis of the urbanization's impact on such water environmental factors as hydrology, water quantity, water quality, groundwater, and hydrophilicity, put forward the objective system, support system and evaluation system of sustainable development of urban water management in SMSCs.
- Based on the analysis of the relationship between flood control and urban socio-economic development, put forward the SD strategy for urban flood control as well as the construction of *Flood Prevention and Security City*. Urban flood control and management should coordinate with river basin flood control and construction of urban infrastructure, to guarantee and support urban socio-economic development, especially development of SMSCs.
- Based on the analysis of the economic instruments for water pollution prevention and control, put forward the SD strategy for prevention and control of urban water environment as well as the construction of *Eco-city*. Pollution charge, tradable water pollution right and evaluation of water resource value in national economic accounting are the important approaches to marketization and industrialization of wastewater treatment.

- Based on the analysis of the relationship between water supply and water demand, put forward the SD strategy for urban water resource utilization as well as the construction of *Water-saving City*. City construction and industrial distribution should consider the carrying capacity of urban water resources. Improvement of urban water saving depends on reform of water price system and market.
- Based on the analysis of the concept and contents of water culture, put forward the principles of construction and repair of urban water culture. Ecological restoration and water landscape restoration should coordinate with urban water culture.
- Based on the analysis of the regulation mechanism of water market and management, put forward the direction and contents of the reform of urban water market and management for the SD of SMSCs.
- Based on the integrated analysis of the SD of urban water management of SMSCs, put forward two models of circular economy – small and large scope recycling of urban water, and discussed the relevant practical case studies. MBR technology has been introduced in the case study of the wastewater treatment and recycling system of the DJD Hotel (small scope recycling of urban water); SBR technology has been introduced in case study of the wastewater treatment and recycling system of the Huludao City (large scope recycling of urban water).

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Chapter 1. Introduction

Water is a precious natural resource for survival and development of human; it is also a source for urban development and a root of cultural development. There is strategic significance for development of human society to protect water environment effectively and utilize water resources reasonably. Under the pressure of rapid economic development and endless inflation of population, it is the same challenge for most countries in the world to protect the quality of water and meet the needs of different functional requirements. Extensive economic growth and serious lack of urban environmental infrastructure have aggravated scarcity of water resources. The problems relating to global water resources and water environment have made a serious impact on survival and development of human life. More attention must be paid to solving the issues relating to water resources utilization and water environment protection.

With 1.3 billion population, China is the largest country in the world and it is estimated the population could reach 1.6 billion by the year 2050 (General Institute of Water Resources and Hydropower Planning and Design, 2006). China has become one of the major economic powers with the greatest potential in the world. The economy developed at an unprecedented rate since reform and opening-up in 1979. The Gross Domestic Product (GDP) for 2005 amounted to 18,308.48 billion Yuan (National Bureau of Statistics of China, 2006). During the process of the economical development, many environmental problems that have hindered developed countries have occurred in China all at the same time. The conflict between development and environment become ever more prominent. The critical problems of resources shortage, degraded eco-environment and insufficient environmental capacity are hindering China's development.

Along with the implementation of national urbanization and modernization strategy in China, the urban scale and quantity are increasing systematically. The problem of water resources, which guarantee the sustainable development of city, has drawn high attention of the government and public. It is necessary that building a modern urban water management system to guarantee the sustainable development of urban economy and society. Guided by the theory of Sustainable Development, integrating water management into the urbanization properly has been one of the important fields of the theory research.

1.1 Urban water management and sustainable development

The concentration of population and development of industry and commerce turn the city into the center of the politics and economy. It is a complicated structure consisted of natural, artificial and social factors. In addition, it is a highly artificial and intelligent open system (Li D, 1999). The urbanization and modernization of cities in China are implemented widely and fleetly. This strategy becomes more important in the national economic and social development. China is in a period of the rapid urbanization, the rate of the urbanization calculated by the population ratio will reach 70% in 2050 from 46.59% in 2009, and there will be 900 million people living in the cities (Pan and Wei, 2010). In the process of urbanization and modernization, the role of water is irreplaceable. Take a wide view the development history of the human society, water has a close relationship with the urban development. Along with the expansion of urban population and aggregating of fortune, city is becoming highly centralized field of water supply, water service and draining. Meanwhile, it is also confronted with challenge of flood control and water environmental protection. Therefore, the urban water management is playing an outstanding role. It is of significance to accelerate the research of theory and the practice innovation.

Urban water system is a multipurpose and integrated system. Considering China's economic and social development requirements, there are many rigorous problems in exploitation, utilization, operation and management of urban water resources comparing with some developed cities in the world.

- The standard of city flood control is out of date. There are 639 cities with flood control system accounting for 95% of the total among the 670 cities in the China. About 80 percent of those cities have a low level of flood control standard that is lower than the standard for once-in-fifty-years flood; some even cannot reach the standard for once-in-a-decade flood (Liu Y, 2007).
- The problem of urban water shortage is very serious. Around 400 cities face on water scarcity on different level, 110 of which are grievous shortage of water (Liu Y, 2007). Due to the water shortage, China loses Industrial Output Value with 230 billion RMB each year (Liang C, 2005). North China Plain has formed the largest underground composite funnel area in the world and the serious ground subsidence has arisen caused by excessive exploitation of groundwater. Seawater invasion occurred in Jiaodong Peninsula and Liaodong Peninsula, which cause serious destruction of the ecosystem.
- The pollution of urban water becomes increasingly prominent. The river pollution in 86 percent of China's cities is beyond standard, the groundwater of 50 percent of China’s cities is polluted to various extents (Wu H, 2005).
- The urban water management system is incomplete. At present, water management system in China still follows the traditional Planned Economy

System with the status of the unclear administration body and the inefficient policy system. The utilization and protection of water resources should be taken into consideration as a unity. Unfortunately, it has been separated. This not only has violated the law of nature of urban water cycle, but also has made it impossible to establish an appropriate price system and economic adjustment mechanism relating to water supply, drainage and wastewater treatment according to the principles of the market economy.

- The urban water-related investment is insufficient. Because of low investment, the level of flood control standard is low, which causes problem of water scarcity. The mechanism of investment also is unitary, which leads the water market irregular (Yuan and Zhong, 2007).
- The urban water management system lacks the support and regeneration mechanism, Due to the low price of water supply, the water management departments run at a loss and the project facility cannot be maintained timely. Because of these factors, the water conservancy projects cannot work effectively (Yuan and Zhong, 2007).

China has launched large-scale construction of water conservancy projects since 1949, and has improved the level of urban flood control. However, the pressure of flood is still serious. Along with the further fast process of industrialization, the urban water environment is more degradative. The relation among society, resources, environment and development should be adjusted through further thinking, methods and technologies. Currently, a number of cities are on the serious condition of water shortage and wasting in China. It is an important means for development of economy and society to achieve the sustainable utilization of water resources. Building a sustainable management and development system of urban water resources has conclusive sense for supporting the urban economic and social development. This dissertation will do a preliminary study and discussion.

1.2 Objectives, contents and methodology of the dissertation

1.2.1 Objectives

This dissertation proposes the sustainable directions, purposes, support systems and evaluation model of water management in Small and Medium-sized Cities (SMSCs) of China. The dissertation studies the strategies for urban water disaster prevention, environmental protection, water utilization and water culture building. Moreover, it analyzes the function of regulation and control of sustainable urban water management in SMSCs. Aimed at the sustainable utilization of urban water resources in SMSCs, the theory of water recycling and its operation models are put forward through the research of the complex system of water-society-economy-ecological environment. Meanwhile, this dissertation tentatively discusses the application of its technical support system.

1.2.2 Contents

Research of sustainable management of urban water relates to urban economic, social and cultural construction and so on, and it is a strategic issue combined with systematic, complexity and innovative ideas. In the complex systems of water resources-society-economy-ecologic environment, water recycling is an innovative idea and important method to solve the problems of water shortage and water pollution; it also has an important significance of the sustainable development of urban water management. The brief of contents is as follows:

- Sustainable development framework of urban water management in SMSCs: put forward the objective system, support system and evaluation system of sustainable development of urban water management in SMSCs by analyzing the dynamic changes of urbanization and environment.
- Strategic research of the construction of sustainable development of urban water management in SMSCs: study the integrated strategy for flood control and drainage, water environment management as well as water resources utilization, to study the optimal strategies for urban flood control; analyze the features of water utilization in SMSCs to propose water-saving measures and establish the evaluation indicator system in water-saving cities; analyze the meaning of urban water culture to build the cultural content.
- Control and regulation strategy for sustainable development of urban water management in SMSCs: propose the concept and contents of the reform for urban water management by the analysis of the two kinds of instruments from administration and market, to achieve the objectives of the control and regulation of sustainable management.
- New method of sustainable development of urban water management in SMSCs: propose the concept of water recycling, research its effect on different scopes in the complex system of water-society-economy-ecologic environment, and study its feasible composition and operation of support system.

1.2.3 Methodology

This dissertation synthetically studies the problems related to the sustainable development of urban water management in SMSCs by using the methods that combined with the theory study and practical application, systems analysis and individual analysis, as well as qualitative analysis and quantitative analysis. The main research methods are as follows:

Table 1-1: Main research methods in the dissertation

Study targets	Study method
Urban Water Management in SMSCs	Sustainable Development Theory
Directions and Targets of Sustainable Urban Water Management in SMSCs	Systems Analysis and Sustainable Development Theory
Support Systems of Sustainable Urban Water Management in SMSCs	Systems Analysis and Modeling
Evaluation System of Sustainable Urban Water Management in SMSCs	Utility Value Analysis and Analytical Hierarchy Process
Construction Strategies for Sustainable Urban Water Management in SMSCs	Data Analysis and Induction
Solution Mode: Water Recycling Economy	Systems Analysis and Comparison Method
Technological Application of Water Recycling Economy	Modeling, Proving by Examples and Case Studies

In this dissertation, the theoretical foundation for the research of urban water management in SMSCs in China is based on an analysis on concept and theory of Sustainable Development. Through the analysis on Sustainable Development Theory and System Theory, the SD framework of urban water management (Chapter 3) is formed and structured, which involves determining directions and targets (Section 3.2), constructing of support systems (Section 3.3), and organizing evaluation system (Section 3.4). Using the method of Systems Analysis and Modeling, the dissertation puts forward four support systems of sustainable urban water management based on analyzing the urban water circulation system and the relationship between urban water supply and demand. The methods of the Utility Value Analysis (UVA) and Analytic Hierarchy Process (AHP) are applied into the research on constructing and evaluating the evaluation system of sustainable urban water management, in order to structure and design an indicator system, determine weighting of each indicator and compare results.

Through an approach of documents induction and data analysis, this dissertation puts forward construction strategies for sustainable urban water management in SMSCs

(Chapter 4), which involve the strategy for urban water disaster prevention and control, the strategy for urban water pollution prevention and control, the strategy for water resources utilization and the strategy for construction of urban water culture.

Water policy regulation is one of four support systems of sustainable urban water management in SMSCs. Through an analysis on regulation and control of sustainable urban water management (Chapter 5) focused on the reform of water market management (Section 5.1) and urban water management (Section 5.2), this dissertation puts forward some suggestions within market and administration areas.

Through searching and analyzing the Water resource – Society – Economy – Eco-environment Composite System (WSEECS), this dissertation discuses the water recycling mode of circular economy in SMSCs (Chapter 6) and puts forward technical support systems of sewage treatment corresponding a large or small scale urban water cycling. Two case studies are described in this Chapter to prove the feasibility of technical application to different scales water recycling.

1.3 Research review on urban water management

1.3.1 Meaning of urban water management

Chinese Hydraulic Engineering Society (CHES) proposed that Urban Water Management involves the fields of urban flood control, water supply, water saving, soil and water conservation, protection of water environment, ecological environmental upgrading, water pollution control, wastewater reuse, utilization of flood and rainwater resources, water traffic and tourism, conservation and construction of water culture (Wu H, 2005). Modern urban water management was formed, under the guidance of the sustainable development theory, for the urban water-related problems. Urban water management is a result in the process of urbanization.

It can, based on the theory of rational water resources allocation, manage those water-related affairs among the urban economy and social activities, and achieve the coordination of nature and human targeting at sustainable development of ecological urban construction.

The basic content consists of reasonable allocation and utilization of groundwater and surface water; monitoring and control of water quality; managing, controlling, adjusting and protecting natural water resources; the allocation of water resources between different watersheds and/or regions through specific measures; meeting the water resources demand of the urban economic development in time and space. The purpose of implementation of modern urban water management is to achieve maximum economic and social benefits in urban area through reasonable utilization of water resources.

1.3.2 Urban water resources

Urban water resources mean all natural freshwater resources can be used by city, in a broad sense; it also includes seawater and reusable water (Wu J, 2002). According to the economic theory, the water resources can be divided into the proprietary water resources and non-proprietary water resources.

The research of value attribute of urban water resources began in1973, Nordhaus and Tobin proposed to modify GNP (Gross National Product) by “Measure of Economic Welfare”, which caused wide public concern for the environment measurement. In 1997, the transfer of water marketing and water rights of the Lower Rio Grande River Valley was accomplished in Texas, USA; this has opened up a new space for the realization of the value of urban water resources (Gao, 2003). The object of water market is to improve the efficiency of urban water supply and redistribute water resources; it is a new mode that the city purchases the water rights from farmer to increase urban water supply. In China, the research of water resources value began in 1965 (Zhao, 2011). The Water Law promulgated in 1988 stipulate: enterprise must pay for using of groundwater resources, the pricing standard system shall be formulated by the State Council. The proposition of the concept of water resources fees has promoted the study of water resources value.

The process of water utilization, protection, prevention and management is a process of recognization and acceptation for the water resources value. Along with the development of urban economy, the population growth and the enhancement of living standard, the situation of water shortage is getting more and more serious, and the value of water resources is increasing significantly. All of those force people to plan reasonably, dispose optimally, protect carefully, and manage scientifically for water-related affairs. In return, this driving force is promoting the integral development of sustainable utilization of water resources.

Water price is an important way to optimize the water resources disposition. In the situation of water shortage, user must pay the fees for water rights. That is opportunity cost for getting water rights. The cost includes the loss of decreasing water using for other water users and other water utilization categories. A completed water price system should involve the price of water resources, otherwise it cannot reflect all the opportunity costs of water, and water price cannot correctly guide the allocation of water resources. Unreasonable price policy and economic compensation cause the inefficient utilization of urban water resources. Many cities are exposed to the pressure of water shortage; unfortunately, their situations of water resource waste are getting more serious. Therefore, it becomes a realistic option to water demand control through the action or power of water price lever. John R. Teerink proposed that the charge from beneficiaries might be sufficient to meet the service costs of water supply (Teerink and Nakashima, 1993). Xiangchun Wang put forward the pricing principle of urban water supply (Wang X, 2002), which is the pricing according to the marginal cost and implementation of the two-step charging system. Yuguang Wang proposed four mechanisms to manage the urban water price (Wang Y, 2002), as follow: the cost restriction mechanism of water supply enterprise, the income supervising mechanism of water price adjustment, the inspecting mechanism of water pricing and the hearing mechanism of water price adjustment.

It depends on economic levers to allocate water resources by adjusting the price of water, which means adjusting the water quantity and structure consciously by adjusting the economic benefits relation, to achieve optimal allocation of water resources. Water price consists of three parts: the price of water resources, the price of water engineering and the price of water environment, among which the price of water engineering is relatively fixed and the price of water environment is relatively stable. As the opportunity cost of getting water right, the price of resources changes all the time because of the structure and quantity of water demands and supply as well as the efficiency and benefits of water utilization. Different water users require different water quantity from different sources in different areas in different time. Therefore, the water prices are different. The process that adjust the water resources price based on the status of water resources and development of economy and society can guide people to adjust the structure and quantity of water demand consciously, to achieve the optimal allocation of water resources.

Many practices of exploitation and utilization of water resources have proved that, according to different uses, choosing adaptive water quality is not only effective and economical, but also reduce the raising requirement of construction cost of new water sources. At present, China is facing the dilemma of urban water shortage. Development of water industry becomes a basic way to ease the water shortage (Zou and Zhou, 1999). Rainwater is an alternative source in developing or developed countries (Wang L, 2001). It also is one of the effective measures to solve the problem of water shortage. To study and develop the technologies of rainwater resources utilization and ecological compensation will bring social, economic and environmental benefits to improve the urban ecological environment, control flood and so on. Although the technologies of seawater or brackish water desalination are quite mature, the cost of desalination is very high, so it is impracticable in most areas of the world (Loaiciga and Renehn, 1997).

1.3.3 Urban water environment

Urban water environment refers to the urban water cycle system formed by the rain, surface water, groundwater and water supply and drainage, taking the city as a position and urban rivers as the center (Zhang, 2000). Water environment is the essential factor for survive and development of cities, it is the link of the urban life, industry social system, and customs. Scholars from China or other countries have studied the urban water environment from different views of the urbanization. The main ideas and method show as follow:

I. *Urban water environment improvement*

The object of urban water environment improvement is “multi-nature” or “re-naturalization” that emphasizes the ecological restoration of river; it was first proposed by the German scholar and accepted by Germany and neighboring countries such as Switzerland and Austria (Dong Z, 2004). With the enhancement of the urban economic strength and the promotion of water environment requirement, some developed countries take the lead in intensifying the management of urban water environment. Urban water environment improvement have been transferred from management of a single rive to management of the whole river basin (Wu H, 2004). In addition to maintaining the water quantity and purifying the water quality, it also included the protection of urban water ecosystem and effective utilization of water resources (Wang J and Nygard, 2003). Furthermore, it extended to “the visual effect and humanities effect” and launched the research of the negative influence of water environment caused by urbanization.

Chinese scholar Xiangrong Wang (2000), Shaoliang Zhang (2000) and Jinqiu Zhang (2000) proposed the construction connotation of multi-nature for China, namely three huge systems of space environment, biology environment and water environment. Space environment includes the functions of landscape, walking, hydrophile and entertainment; biology environment includes the functions of habitat, plant growing and natural environmental protection; water environment includes the functions of water purification and ensuring water quantity.

II. *Urban water pollution prevention and control*

To ensure the security of drinking water is a focal point of water pollution control. In China, drinking water sources in many cities have been contaminated. Organic matters in drinking water have the potential threat to cause cancer, malformation and mutation; heavy metals may make rapid poisoning and disease. At the same time, water pollution increases the quantity of microorganisms. The ultimate goal of the water pollution prevention and control is to ensure people’s health. Therefore, protection of drinking water safety should be as a focus of water pollution prevention and control. Jinxiang Fu (1998) analyzed and evaluated the current situation, main reasons and channel of secondary pollution of drinking water in China synthetically. He also presented methods and measures of prevention. Yuchuan Cui (1998) described the feature of micro-polluted drinking water resources and the organic pollutants in water and their damage.

As the rapid urban economic development and irrational structure and extensive development mode of industry, the water pollution caused by industrial wastewater accounted for 50 percent of the total wastewater discharge in China (Zhao, 2011), and the most toxic and harmful substance have been discharged into water by industrial wastewater. In the long term, the control strategy of End-of-pipe and standards-based discharge has been proved that is of high cost, inefficiency and unsustainable development. Therefore, study on wastewater treatment became the focus of academic research. Enhai Zhao (2000) analyzed the development trend of China's wastewater treatment; Zhanpeng Jiang (1999) proposed to strengthen the primary treatment in process of sewage treatment; other scholars put forward the processing scheme of wastewater treatment evaluation and physical and chemical pretreatment (Han H, 2001). The control strategies which represented by cleaner production should be promoted. It includes eliminating those products and processes of high material, energy and water consumption, improving resource utilization in industrial processes and reducing pollution emissions (Qi J, 2010). Cleaner production, which can lead environmental and economic benefits, makes great sense to the economic development and environmental protection in China.

To strengthen the comprehensive management of non-point pollution is important. In the USA, non-point pollution becomes the first factor of environmental pollution, 60 percent water pollution originated in the non-point water pollution (Bertrand-Krajewski, 2002). In China, in addition to the drainage of industry and urban life caused the point source pollution, non-point pollution becomes more serious. Unbalanced rainfall causes uneven distribution of pollution, the serious effect of which has revealed in many cities. Jiashun Cao (1999) proposed the application of emissions trading to reduce non-point pollution problems. Yanming Zhu (2000) proposed the control countermeasures against non-point pollution in the source of water.

Prevention and control of groundwater pollution has not yet attracted enough attention. However, groundwater pollution is more complex, and Zhonghe Wang (1998) proposed the technology of groundwater control and health risk assessment caused by groundwater pollution.

1.3.4 Urban water-related disaster

Urban water-related disaster is a main natural disaster in city and mainly includes floods and waterlog. In China, economic losses caused by urban water disaster are about 5 percent of the National Gross Product every year (Li Y, 2000). Therefore, urban flood disaster is an important issue to study. Currently, the focal point of research on urban flood disaster is primarily related to non-engineering and engineering measures for urban flood control project.

The research of urban flood control with engineering measures mostly is that the construction of flood control project should convert into two aspects. On condition that meet the requirement of urban flood control, one aspect is how the urban flood control projects serve for the city. For example, Line Ren (2001) proposed that flood control levees should be combined with urban landscape construction; Houwen Huang (1999) proposed that we should create urban flood control mode assembled with flood control, transportation, and landscape and greenery coverage. The other is the construction of flood control project should converted into the ecological side.

The research on the non-engineering measures also is an important aspect for urban flood control. Flood dispatching with modern technology can reduce the losses caused by flood. The new measures of urban flood monitoring involved building and developing a remote monitoring system, a system of urban flood insurance and disaster reduction, and so on. According to the input and output principle, the research of flood control standard aimed to the quantitative analysis of urban flood disaster. American scholar S. J. Appelbaum (1985) proposed three methods to evaluate the pre-disaster value of affected assets, which are the original value method, the cost replacement method and the market evaluation method. Considering the calculating method of direct economic rate of flood, it is more common to use the parametric statistical model in the world presently: taking the characteristics like flood depth as the independent variable, loss rate as dependent variable, use parametric statistical method to determine the model parameters (Das and Lee, 1988).

Chapter 2. Background of China

2.1 Physical background

China is entirely located on the southeastern part of Eurasia. With a total land area of 9.60 million km^2, China ranks the third among all countries in the world. 14 other countries as well as the Pacific Ocean border it. China has a sea area of around 3 million km^2, and the total length of coastal lines is about 32,000 km (Ministry of Water Resources of the P.R. China, 2006).

I. *Topography of China*

The characteristic of topography is described as low east part and high west part. There are 5 homogeneous physical macro-regions, namely the northeast plain, north plain, southern hills, Xinqiang-Mongolia, and the Qinghai-Tibetan Plateau. The Qinghai-Tibetan Plateau is highest part of China. With an average elevation exceeding 4,000, the Tibetan Plateau is the world's highest and largest plateau and is called "the Roof of the World". The plains are distributed in the north to south direction, including Northeast Plain, North China Plain, Middle to Lower Yangtze Plain and Pearl River Delta Plain, being important industrial and agricultural bases and economic centers of China (Ministry of Water Resources of the P.R. China, 2006).

Land classified according to topographic types (Fig. 2-1):

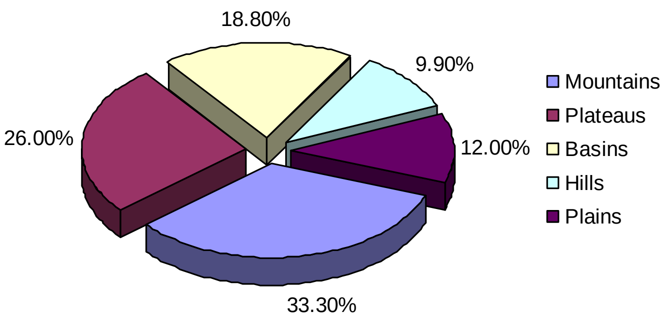

Figure 2-1: The types of topography in China
Data source: Ministry of Water Resources of the P.R. China, 2006

- Mountains account for 33.3% of the national land area;
- Hills account for 9.9%;
- Plateaus account for 26.0%;
- Basins account for 18.8%;
- Plains account for 12.0%

The mountainous areas (including Mountains, hills and rugged plateaus) totally account for 2/3 of the national land area.

II. General Climate

China's climate is particularly diverse with a feature of complex types. Monsoon winds dominate the climate and most of the areas are under the impacts of the southeastern and southwestern monsoons. Therefore, the southeastern China is wet and the northwestern China is dry caused by monsoon activity. Meanwhile, because of the influence by alternating seasonal air-mass movements and accompanying winds, most of the areas are moist in summer and dry in winter. Due to integrated affect by monsoon and topography, China becomes one of the countries facing the serious pressures of frequent drought, flood and water logging hazards in the world. .

III. Rivers and basins

With more than 50,000 rivers, China abounds in rivers and their total length is about 420,000 km. There are more than 1,500 rivers each with a drainage area of more than 1,000 km^2 or larger areas (MEP, 2006). Although China is rich in waterpower resources, the distribution of rivers in China is not evenly due to the affect of climate and topography. The rivers can be categorized as interior and exterior river systems in China. Most of the rivers, including the Yangtze, Yellow, Pearl, Heilong (also called Amur), Liaohe, Haihe and Huaihe, flow east and empty into the Pacific Ocean. The well-know Exterior River is Yarlung Zangbo River (also called Brahmaputra) that sources in Tibet and boasts the largest canyon in the world. It flows first east and then south, finally into the Indian Ocean. The Ertix River sourced in Xinjiang Uygur Autonomous Region flows north and empty into the Arctic Ocean (MEP, 2006).

There are nine major river basins in China, including Yangtze, Yellow, Pearl, Haihe, Huaihe, Songhua-Liaohe, Southeast Rivers, Southwest Rivers and Inland Rivers (Fig. 2-2). The Yangtze, Pearl, Southeast Rivers, Southwest Rivers are situated in the southern areas and the Yellow, Huaihe, Songhua-Liaohe, Haihe and Inland Rivers in the northern areas of China.

Figure 2-2: Major river basins in China

Source: China's River Systems Atlas (Daoqing Zhu, 2010)

2.2 Water resources and water pollution

2.2.1 Water resources

China has a large territory and numerous water systems. The volume of annual river runoff and annual groundwater resources are 2711.5 billion m^3 and 828.8 billion m^3, deducting 727.9 billion m^3 of overlapping volume between them, the total water resources in China is 2812.4 billion m^3 (MEP, 2006). The volume of annual total water resources in five northern river basins is 535.8 billion m^3, accounting for 19% of the national total water resources; the four southern river basins with 2276.6 billion m^3 account for 81% of the national total (MEP, 2006). The table 2-1 shows the annual total water resources by river basin.

Table 2-1: Annual total water resources by river basin

River basin	Surface water resources (10^9m^3)	Groundwater resources (10^9m^3)	Total water resources (10^9m^3)	Water yield module ($10^3m^3/km^3$)
China	2711.5	828.8	2812.4	294.6
Songhua-Liaohe	165.3	62.5	192.8	155.6
Haihe	28.8	26.5	42.1	132.4
Huaihe	74.1	39.3	96.1	289.5
Yellow	66.1	40.6	74.4	93
Yangtze	951.3	246.4	961.3	534.4
Pearl	468.5	111.6	470.8	816
Southeast Rivers	255.7	61.3	259.2	1080.8
Southwest Rivers	585.3	154.4	583.3	687.5
Inland Rivers	116.4	86.2	130.4	38.6

Data source: Ministry of Water Resources of P.R. China, 2006

The main features of water resources in China can be summarized as follows:

- Limited per capita water resources
  Around 2.8 trillion m^3 of the total annual average water resources volume is making China the fourth largest source for water in the world. However, because of China's large population, only 2,220 m^3 of the per capita water resource is 1/4 of the world average, ranking 88th in the world. Forecasted population will reach 1.6 billion by year 2050, thus the per capita water resources will be decreased to 1,760 m^3 (General Institute of Water Resources and Hydropower Planning and Design, 2006). In this respect, it presages serious water shortages in China.
- Unequal spatial distribution
  The water resource distribution is not in line with the layout of productivity in China. The water resource in the southern China amounts to 80.5% of the national total that service 46.5% of the national total population, 35.2% of arable land and 54.8% of GDP. In the north, water resource is only 19.5% of the national total, but it has to bear 53.5% of the national total population, 64.8% of arable land and 45.2% of GDP, and the per capita water is 10% of the world average (General Institute of Water Resources and Hydropower Planning and Design, 2006). Thus, the north China suffers from serious drought and water shortage.
- Unequal temporal distribution
  China's water resources are also subject to obvious seasonal changeability. During the flood season, the rainfall from June to September accounts for over 70% of annual rainfall (General Institute of Water Resources and Hydropower Planning and Design, 2006). In addition, there is a huge difference of annual precipitation between wet years and dry years.

2.2.2 Water pollution

Water pollution is one of most critical environmental problems in China, although the natural status of China's rivers is correspondingly good in general. Due to the influence of human activities and rapidly increasing wastes discharge, most of China's lakes and rivers are polluted to some degree. In the river reaches of about 100,000 km for evaluation in the whole country, grade IV or worse account for 47%; and more than 75% of the lakes have been polluted. An investigation on drinking water of 118 cities indicates that groundwater has been polluted to a varying degree in 97% of the cities, 64% out of which have seriously polluted groundwater (MEP, 2006). China is still facing on a serious pressure of water pollution.

In 2004, a national survey of seven major rivers was carried out in China. According to *the national standard of surface water quality (GB3838-2002)*, water of grades Ⅰ-Ⅲ is suitable for drinking, grade Ⅳ is for industrial and recreational use, and grade Ⅴ is for agricultural use. Figure 2-3 shows the water quality of seven major rivers. The measure results of water quality of the Haihe and Liaohe rivers were below grade Ⅴ each with 57% and 38% (M Shao, 2006). That means the water supply is almost of no practical or functional use, even for agricultural irrigation.

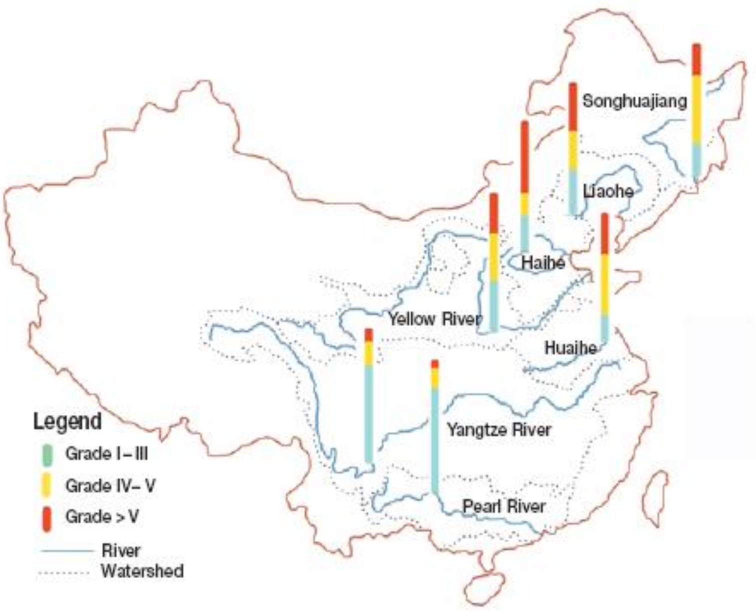

Figure 2-3: Water quality of seven major rivers in China

Source: M Shao et al. 2006

2.3 Urbanization in China

2.3.1 China's administrative classification

According to information selection from the official website of Chinese Government, China's administrative structure has been formed with a three-level system:

- The whole country is divided into provinces, autonomous regions, and municipalities directly under the Central Government.
- A province or an autonomous region is subdivided into autonomous prefectures, counties, autonomous counties, and/or cities.
- A county or an autonomous county is subdivided into townships, national minority townships, and/or towns.

Municipalities directly under the Central Government and large cities are subdivided into districts and counties; autonomous prefectures are subdivided into counties, autonomous counties, and cities. Autonomous regions, autonomous prefectures, and autonomous counties are all autonomous national minority areas. The Constitution specifically empowers the state to establish special administrative regions when necessary. A special administrative region is a local administrative area directly under the Central Government (GOV.cn).

China has 23 provinces, 5 autonomous regions, 4 municipalities directly under the Central Government, and 2 special administrative regions (GOV.cn). The total number of cities and towns are 655 and 19,522 respectively (NBS, 2005).

2.3.2 The rapid growth of urbanization

Since 1978, China has been experiencing the greatest rural-urban migration in the history of the world. The process of urbanization and the construction of new urban facilities have continued to accelerate. The number of small administrative towns in China has reached 19,000 up from 3,000 30 years ago, with an average annual increase to 0.63 percent. From 1992 to 2000, the populations in cities and towns in China increased by 132 million people and the rate of urbanization increased from 27.63% to 36.09% (MWR, 2003).

Many challenges have been brought in urbanization process. Cities and towns are influenced by employment crisis, overpopulation, environmental degradation, and insufficient housing infrastructure and services. Cities also contribute to problems regarding the environment and the social condition. The origin of many global environmental problems related to the pattern of production and consumption, waste, air and water pollution is cities (May Hald, 2009).

Urbanization is also taking its toll on China's environment, China is putting the concept of sustainable cities on its agenda and searching for novel ways to expand and develop urban areas while conserving natural resources and taking into consideration the socioeconomic implications of urban expansion (May Hald, 2009).

2.4 Sustainable development in China

2.4.1 Definition and principles of sustainable development

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs and does not imply in any way encroachment upon national sovereignty."

- The 15th Session of the Governing Council of the United Nations Environment Programme (UNEP)

Sustainable development was first explicitly discussed in the context of the UN Conference on the Human Environment at Stockholm in 1972. This was dominated by the environmental concerns of industrialized countries; the idea was put forward that concerns for the environment need not adversely affect development. There is a dominant "mainstream" to ideas of sustainable development. This "mainstream sustainable development" was formulated and elaborated in a series of documents drafted in the 1980s, the World Conservation Strategy (WCS) (IUCN 1980), Our Common Future (Brundtland 1987) and *Caring for the Earth* (IUCN 1991).

The Brundtland Commission reported directly to the United Nations General Assembly. In December 1989, the UN resolved to organize a conference on environment and development five years after the Brundtland Report, to report progress. This took place at Rio de Janeiro in Brazil in June 1992. Expectations of the United Nations Conference on Environment and Development were immense. Consensus was finally achieved through negotiations at ministerial level on 12th June, and Agenda 21 and the Statement of Principles on Forest Management were adopted on 14th June (Koh 1993). Rio Declaration on Environment and Development reaffirmed the Declaration of the United Nations Conference on the Human Environment, adopted at Stockholm on 16 June 1972, and sought to build upon it with the goal of establishing a new and equitable global partnership through the creation of new levels of cooperation among States and key sectors of societies and people. It also worked towards international agreements, which respect the interests of all, protect the integrity of the global environmental and developmental system, and recognized the integral and interdependent nature of the earth and our home. Alongside achievement of the Millennium Development Goals and other international agreements, The

Johannesburg Plan of Implementation (in Johannesburg, South Africa, in 2002) agreed at the World Summit on Sustainable Development affirmed UN commitment to “full implementation” of Agenda 21. Therefore, the Stockholm Conference, the Rio Conference and the Johannesburg Summit had significance in developing the concept of Sustainable Development.

Sustainable development is a right way of human survival and social development, and is the challenge and innovation of traditional model of economic development. Its definition includes three basic principles:

- Fairness principle

  It includes the fairness of time and space. The fairness of time, also known as intergenerational equity, means that it is necessary to consider the current development and future development, and to do not sacrifice the interests of future generations to meet the interests of contemporary. The fairness of space, also known as intra generational equity, means that people have the same rights of development and prosperous life.

- Sustainability principle

  The core of sustainable development is relating to development, but the development should not exceed the bearing capacity of environment and resources.

- Intercommunity principle

  Because the history and culture are different, it might be different on the target, policy and process of sustainable development in different countries. Nevertheless, human should be aware of the integrity and interdependence of common home - the earth. Sustainable development is the general objective of the overall global development.

2.4.2 China’s Agenda 21

“White Paper on China’s Population, Environment, and Development in the 21st Century (China’s Agenda 21) was completed in April 1994. China's Agenda 21 has been formulated so that it corresponds with Agenda 21 and reflects the Chinese situation” (ACCA21, 1994). At the same time, the Administrative Centre for China’s Agenda 21 was established jointly by the State Planning Commission and the State Science and Technology Commission to work on routine management affairs of China’s Agenda 21 (Klawitter, 2004). Its formulation process took into account the interests and plans of appropriate ministries, to make China's Agenda 21 comprehensive, workable and more authoritative (ACCA21, 1994).

Based on China's specific conditions and paying attention to population, environment, development and urbanization, China's Agenda 21 has set up a strategic goal of sustainable development that can promote harmonized development of society, economy, environment and resources. According to China's Agenda 21, some major directions of endeavor have been determined as follow:

- improve the quality of development and scientific and technological advancement while maintaining rapid economic development;
- promote overall social progress and establish a social basis for sustainable development;
- bring pollution of the environment under control so as to improve the ecosystem and rationally use natural resources;
- gradually incorporate into the legal system those mechanisms that promote overall coordination of decision-making for sustainable development.

Sustainable development is a complex strategically process, and the essence of which is to handle the coordination relationship among population, resource, environment and development. It is a comprehensive strategy for social development, economic development and ecological development.

Chapter 3. Sustainable Development Framework of Water Management in SMSCs

Through the analysis on Sustainable Development Theory and System Theory, the SD framework of urban water management will be formed and structured, which involves determining directions and targets, constructing of support systems, and organizing evaluation system for sustainable urban water management in SMSCs.

3.1 Urbanization and water environment changing

3.1.1 Type and role of city

I. City type

According to the development history of the city civilization, cities always originated in the transition period from primitive society to slave society. Cites share the same basic feature, which is the high concentration of population, economic activities and civilization in space.

There are many criteria for city classification. According to the urban geographical location, it can be divided in to coastal city, riverside city, and inland city, etc. According to urban topography, it can be divided in to plain city, mountain city, and river city, etc. According to the administrative area, it can be divided into the capital, provincial capital city and county, etc. Although the city classification has no uniform criterion at present, there are two kinds of prevailing criterion: dividing the city type according to the urban dominant function and city population size.

According to the urban dominant function, China’s cities can be divided into integrated city, mining city, traffic hub city, tourist city, and exhibition city, etc. Along with the development of market economy in China, the development of many cities with single function is gradually transferring to diversified and complex direction. According to urban population classification criterion and City Planning Law of the People's Republic of China (1989), China’s cities can be divided into metropolis, large city, medium-sized city with the population between 0.2 million and 0.5 million, and small city with the population under 0.2 million. SMSCs got great progress before 90s because China followed the urban development policy “strictly control the scale of city; reasonably develop small and medium-sized cities”. To end of 2000, there were 93 metropolis and large cities, 352 medium cities, and 20,312 small cities and towns (Lue, 2003).

II. Status and role of SMSCs

The rapid development of SMSCs becomes an important part of China's urbanization. From 1980 to 2000, the population of large cities increased 97 percent from 5.473 million to 11.323 million; the population of SMSCs increased 220 percent from 3.315 million to 10.611 million. By the end of 2000, the city population of china reached 4.32 billion, of which population of SMSCs accounted for 74 percent (Lue, 2003).

SMSCs can be divided into two categories, namely SMSCs around large cities and relative independent SMSCs away from large cities. The first type should be seen as an integral part of the metropolitan area, the other is the center of administration, service, logistics and economy in rural area.

- The role of SMSCs in metropolitan area

  Metropolis and large cities concentrated various industries and functions. On one side, they are more attractive. On the other side, overpopulated and over industrialized development resulted in many serious urban problems, such as traffic problem, air pollution and housing problem. To reduce the risks and damages, a part of housing function and industrial agglomeration have to be spread to the surrounding space of large city. Then they formed a metropolitan area with the cooperative and complementary functions. Therefore, SMSCs are an important part in metropolitan area.

- The role of relatively independent SMSCs

  Relatively independent SMSCs are far away from metropolis or large cities. They are the center of administration in local area, and provide education, health caring, and other service for themselves and their surrounding space. The development of these cities depends on whether competitive industries exist. The competitive industry may be the tourism, mining industry, or manufacturing industry, etc. Under the regulation and control of the China's traditional planning economic system, the development of most of these cities has been driven by single competitive industry, especially mining industry or manufacturing industry. The exhausted resource and the diminished activity of main industry have seriously hindered the development of the relatively independent SMSCs. Changing the singular industrial structure became an urgent problem, which need to be solved under the condition of the sustainable development of society, economy and environment. Another problem of these cities is about urban service functions. Usually, the situation of providing service is not satisfied for their surrounding area. It focuses on the social service, business service, and education service, as well as public health service.

Currently, the urbanization strategy of China has been made adjustments according to the requirements, which is “reasonably developing large cities, energetically developing small and medium-sized cities, and fully developing towns” (CSUE, 2011).

III. Sustainable development of SMSCs

As an important part of the system of city and town, SMSCs have their own features and development advantages compared with large cities and rural areas.

- Compared with large cities

  As the development of small cities started later, they can take lessons from the development experience of large cities to exploit their advantages and achieve the great-leap-forward development. Due to the constraints of a variety of factors, the extent of the damage to the environment is relatively smaller, and available resources are relatively more. Therefore, implementation of urban sustainable development can form relatively stable urban ecosystem, to achieve harmonic common development of the society, economy, environment and resources.

- Compared with rural area

  Medium and small cities provide much more comfortable living conditions (including water, electricity, sanitation, shops, health care, education and entertainment services, etc) and a wide range of employment opportunities. From the view of economy, value, taxes, consumer demand created by SMSCs are higher than by rural areas. Because of high employment density, the concentration of capital and technology, as well as sufficient floating population, SMSCs become the reliable power source of economic growth.

In the construction and development process of SMSCs, there still are many deficiencies. For example, urban planning is relatively lagging; urban construction cannot meet the needs of development; lack of general study of the integrated utilization of urban resources such as water, land, infrastructure, which however constrain the sustainable development of cities.

3.1.2 Influence of urbanization on water environment

Water is one of the most important factors of the urban environmental science. Urbanization causes an increase in the surface area of impervious land, water utilization of production, life and environment, as well as sewage emissions, which not only changes the normal water cycle and hydrological features of rive in urban area, but also brings a series of water environmental problems like water pollution.

I. The impact of urbanization on water cycle

In the process of urbanization, underlying surface is modified dramatically; the thermal radiation balance is broken; pollution of buildings, thermal and chemical pollution causes the urban heat island effect, which influence in the climate of the cities such as air temperature and composition, and wind speed. Expansion of impervious area reduces the infiltration of rainwater, which causes the reduction in the groundwater recharge. The surface evaporation and transpiration were relatively weakened and the hydrological cycle in urban area was obviously changed.

II. The impact of urbanization on the hydrological characteristics

Urbanization changes the hydrological characteristics, resulting in increasing the surface runoff velocity and volume, and peak flow. In Beijing city, the hydrological station of Yuejia Garden is one of the main control stations of urban runoff, where the catchment area is 98.8 square kilometers. The rainfall was 107.7mm on August 9, 1963, the peak flow is 193 m^3/s, and similar rainfall and rain type on August 4, 1983 was 97.3mm, peak flow 398 m^3/s, increasing 2.06 times (Ding Y and Zhang S, 2003).

III. The impact of urbanization on water consumption

Urban water consumption increases with the increasing of urban population and city scale, the contradiction between water supply and demand is becoming more prominent. By the end of 2000, the daily water supply capacity of cities in China is 218 million m^3. The daily water supply capacity during the eighth Five-Year Plan period (1991-1995) increased to 503.01 million m^3, and the average annual capacity of daily water supply is 10 million m^3. The total annual water supply capacity is 468.9 billion m^3, and average annual increase volume is 385.7 billion m^3 (Lue, 2003).

IV. The impact of urbanization on water quality

The impact of urbanization on water quality mainly refers to the water pollution of the environment caused by production, living, transportation, and other service industries discharge pollutants. By a survey of drinking water in 118 cities all of the country, only 3 % of the urban water is with good quality (Wang J and Nygard J, 2003).

V. The impact of urbanization on groundwater

Urbanization has led to an unbalanced status of the amount balance of groundwater. The groundwater exploitation is out of the groundwater recharge, resulting in groundwater funnel and land subsidence, which no longer cause ecological problems, but also lead to geological disasters. The water table in and around large areas of hardscape is usually very depleted because the amount of rainwater absorbed into the soil is insufficient to recharge the water table in that area.

VI. The impact of urbanization on hydrophobicity

Urbanization has led to the degradation of urban water environment. For example, water quality of urban river becomes worse, and both sides of the river are filled with construction, which reduce the opportunity of close contact to water, such as fishing, swimming and walking.

3.1.3 Urban size and changes of water environment

Generally, cities in upper basin are small, and cities in under basin are large in scale. The urban size and location influence water environment differently. Most small and medium-sized cities locate in the upper and middle basin, because of the constraints of terrain conditions and water supply capacity, urban development is restricted. It is dependent on the water retention capacity of internal forest and river basin, resulting in the easy occurrence of water shortage problem. Large cities are mostly in the river downstream with flat terrain, abundant water and convenient transportation. The residents' demand for living conditions is particularly high (Wu H, 2005). Accordingly, the construction of hydrophilic facilities in large cities is an important part of urban sustainable development

3.1.4 Changes of water environment in city center and surrounding area

The status of water environment in city center area and surrounding area are different; the human activity in center area has a great impact on the water environment and in surrounding area has a small impact on it. Details shows in table3-1:

Table 3-1: Water environment changes in city center and surrounding area

		City center area	**City surrounding area**
Water resources	Water conservation	Reduction of groundwater seepage, decline of groundwater level	Reduction in water retention ability with the increasing of hardscape
	Water demand	Increase in water consumption	Increasing water consumption due to the increase of use of tap water, living standard and population growth; Increasing industrial water consumption due to the establishment of industrial parks
	Water resources exploitation	Drain of shallow wells; Expansion of underground funnel zone by deep wells	Reduction in the well water utilization; Transfer of surface water sources
	Water shortage	insufficient water supply during the utilization peak in summer	Insufficient industrial water supply
Water environment	Land utilization	Increase in municipal roads; Reduction in green land; Increase in impervious surfaces	Reduction in agriculture land and forestry land; Increase in homesteads and roads; Increase in impervious surfaces
	Waterside environment	Reduction in watersides; Landfill of river; Increase of Garbage and floats	Landfill of pool
	Water quality	Urban river pollution; Groundwater pollution	Deterioration of water quality; Groundwater pollution; Eutrophication in lakes and wetland
	Water disaster	Land subsidence; Increase in water environmental disasters	Higher peak of flood

3.2 Analysis of sustainable development targets of water management in SMSCs

3.2.1 Review and prospect of urban water management in China

The development history of human society experienced three stages: adapting nature to live, costing environment to develop, and coordinating nature to develop (Wu, 2005). Water conservancy is an important part of the infrastructure of city. In the process of China's urban development, its development also experienced three stages - with water-engineering project as the dominant factor, with environment as the dominant factor, and with eco-environment as the dominant factor.

I. *The development stage with water-engineering project as the dominant factor*

Water is indispensable substance and condition of the human survival, economic and social development. After a long-term practice and exploration, people gradually found the methods to prevent and alleviate water disasters, to develop and utilize water resources by the construction of various water-engineering projects. Therefore, people continue to study how to build, manage project as well as improve project, which forms the traditional water conservancy. In this stage, the urban social and economic development was staying at the initial level, agriculture was the locomotive that drives the urban development, and the urban water management research was focused on the water quantity.

II. *The development stage with environment as the dominant factor*

The "Water - human - nature" mode was rapidly extended and applied for the development of human society. The nature was comprehensively humanized, and human fully intervened to the nature. At the same time, the impacts of human activities on the nature have been used as a geological force, which were involved in the evolution process of the earth. Since the industrial revolution, human has changed the evolutionary trajectory and rate of the earth by using of knowledge, science and technology. However, the industrial revolution not only has caused the air pollution, but also has resulted in the serious degradation of water environment. In that period, the problem of water pollution appeared in succession in Britain, France, Germany and other developed industrial countries (Wang J, 2003). As the largest developing country, water-related issues have frequently occurred in China. With the huge population, inefficient management and weak environmental awareness, China paid a heavy price for its environment while keeping continual development of economy. In 1972, the Club of Rome, which was organized by the Western countries, raised considerable public attention with its report “Limits to Growth” (Donella H et al., 1972).

It also contributed to the Rio de Janeiro Conference on environment and development, which alarmed the world about the environmental problems for the first time. In this stage, the urban economic and social development is on a relatively developed level, and the industrialization was dominating the urban development. The research of urban water management was focused on water quality.

III. The development stage with eco-environment as the dominant factor

Human history has gone through collection and hunt civilization, agricultural civilization and industrial civilization. Agriculture gave birth to the classical civilizations. The industrial revolution gave birth to the modern globalized civilization. Now ecological consciousness is giving rise to ecological civilization. A new civilization - ecological civilization is pursued by China, which was proposed by Hu Jintao, general secretary of the Central Committee of the Communist Party of China (CPC), in his report to the just concluded 17th National Congress of the CPC. The term “ecological civilization” has become official state policy in the country. “This concept reflects an important change in the Party's understanding of development …, the Party authorities have come to realize that development…, must entail a list of elements including the right relationship between man and nature” (China Daily, 2007).

The industrial civilization, in the base of the predatory exploitation of natural resources, got the wealth as the main value orientation for the society, which has led to a series of global environmental issues, obstructing the survival and development of variety of life on earth. The transition of industrial civilization to ecological civilization of human society shows that human settlements will be oriented a new human settlement model - ecological city. The eco-city development needs ecological water conservancy to be fundamental support.

In this stage, urban economy and society will achieve the developed level, and the research of urban water management will be focused on water environment and space.

3.2.2 Urban water management features

Urban water management features is as follows:

- Urban Water Management is operating with an obvious regional characteristic. Because a city is usually located in a catchment node, and its influence or radiation range is limited in a region or area, regional feature of urban water management is obvious in the range.
- Urban water management focuses on the research of artificial water cycle system. Urban water management studies the artificial water circulation system and the natural water circulation system. Because the urbanization process is accelerated,

the urban natural water circulation system is destroyed seriously, so the urban water management focuses on the strengthening of the construction of artificial water circulation system and recovery of natural water circulation system.

- Urban water management has a close relationship with urban industry. Industry is the foundation for the economic development of city. Between industrial water demand and urban water supply capacity, there is a certain gap usually. In China, based on the water resources condition, the industry development model of deciding requirements and production according to supply was suggested. On one hand, industry needs to save water and compress need. On the other hand, it is necessary to moderately control urban industry scale and adjust the industries with high water consumption, in order to realize the balance of supply and demand of water.
- Urban water management is coordinating with construction planning. Urban planning reflects the urban overall function including the urban landscape characteristic. With respect to the urban water management, it should not only reflect the urban overall functional requirements for water resources, but also ensure the urban landscape requirements, which means that the urban water management should not only have engineering features, but also embody the water culture characteristics consistent with the urban landscape planning.

3.2.3 Sustainable development targets of water management in SMSCs

Based on the traditional development and utilization of rural water resources, urban water management is a new field, which gradually develops within the increasing urbanization process, including the urban flood control, water supply, drainage, water environment protection, wastewater treatment and reuse, groundwater protection and many other aspects of the work. The urban water management, which is the product of the urbanization, manages the urban water affairs uniformly with the theory of sustainable development as the core and regional water resources allocation as the guidance, ultimately realizing the harmonious coexistence of "man and nature". Combining with the status of China, the sustainable development targets of urban water management can be roughly expressed as follows.

- Guarantee for the sustainable urban development by the effective supply of water resources. Urban water management should guarantee fresh water supply to satisfy the water demands of people's life, industrial production and eco-environment. With the implementation of combined approach of the resource-development, water saving and water allocation, the urban water management should transform from demand-decided model to supply-decided model, in order to provide the reliable water resources for the sustainable urban development.

- Guarantee for the safety of city by improving the comprehensive and perfect system of flood control. To construct the necessary flood control facilities prevents and reduces loss of life and property caused by the urban flood, and to construct and rebuild the urban drainage network improves the drainage capacity, in order to ensure the water security for the sustainable development of society and economy.
- Guarantee for the good urban water environment by integrated pollution control based on the pollution source control. It is necessary to promote the buffering capacity, resistance capacity and self-purification capacity of the urban water environment, to strengthen the integrated control of water pollution, in order to provide a superior water environment for city.
- Guarantee for the efficient operation of urban water management by policy adjustment and market regulation. It is necessary to work by law, reform the traditional management system, strengthen the development and utilization, saving and protection, and management and control of urban water resources, and establish a water market which is adapted to the market economy, in order to meet the needs of urban development.

Sustainable urban water management is a complex and orderly open system. It should develop towards four directions, namely: the economics direction with basic content of the productivity distribution and balance of supply and demand of water resources; the sociology direction with the main content of water resources allocation and balanced sharing of benefits; ecology direction with the main content of water environment protection and ecological balance of water; systematics direction with the main target of coordinating the urban and rural development, regional development, economic and social development, harmonious development of man and nature.

3.3 Support systems of sustainable urban water management in SMSCs

3.3.1 Urban water circulation system

I. *Composition of the urban water circulation system*

The natural water cycle describes the continuous storage and circulation of water on Earth over time and space through the processes of evaporation, condensation, precipitation, infiltration, run-off and transpiration. Embedded within the natural water cycle is the Urban Water Cycle, which describes the collection of water for use within urban areas and its return to the natural water cycle. The urban water circulation system is composed of artificial circulation system and a part of the natural circulation system (see Figure 3-1). In the natural circulation system, water is contacted by evaporation, precipitation, and atmospheric circulation, which can be analyzed by storm runoff model; storm runoff impacts on urban water quality and quantity; urban water and ground water contact with each other through the water infiltration and groundwater recharge campaign within water cycle, which can be analyzed by soil infiltration model and groundwater movement model.

Urban artificial circulation system is composed of urban water supply, drainage and their treatment. In fact, on the process of the system operation, in addition to that some are absorbed and consumed by human, plant and products, most are discharged to the urban drainage network, and the quantitative changes is small while the main change is quality.

II. Characteristics of the urban water circulation system

- City construction and artificial surface expand the waterproof area, which greatly reduces the land surface retention and infiltration capacity, increases the transformation from precipitation to surface runoff, and hinders the groundwater recharge in shallow region slow.
- Construction of urban drainage network and regulation of drainage ditches enhance the capacity of flood releasing and draining in city. Runoff created by rainstorm discharges into the nearest water-body, which results in the speedy convergence, short retention time and short draining process in city area. The risk of the flood peak that moves forward will be increased greatly. All of which increase the possibility to occur swift and violent flood disaster.
- Discharge standard and sewage treatment system play a decisive role in the artificial water circulation system, and have a significant impact on the reuse of urban water resources. After the sewage treatment reaches a certain quality, sewage can turn into resources through the waterway system, which is an important factor to solve the urban water shortage.
- Urban water cycle is a complex, dynamic, open system.

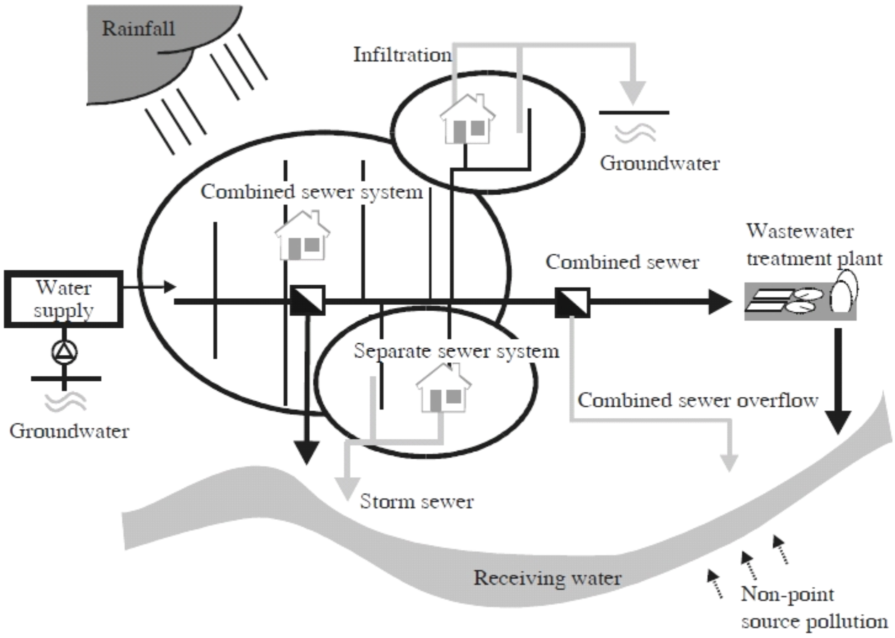

Figure 3-1: Urban water circulation system

Source: Siedlungswasserwirtschaft (W. Gujer, 1999, P195)

Base on urban water circulation system, a corresponding management mode is to be introduced in chapter 6.

3.3.2 Characteristic of supply and demand change of urban water resources

China's urbanization is entering an accelerating period according to the newly published 2009 City Development Report of China, an annual report conducted by China's Association of Mayors, the Xinhua News Agency reported. In 2009, the total urban population is around 621.86 million. Meanwhile, according to forecasting by the report, almost 50 percent of the Chinese population will live in cities by 2020, and the percentage would reach 75 percent by 2050. The report also mentions that the urbanization rate of China has accelerated rapidly during the past 60 years, from 10.6 % in 1949 to 46.59% in 2009; the quantity of cities grew from 132 by 1949 to 655 by 2009 (Jian Xu, 2010).

Before 1980, Chinese cities as a whole were in the initial period, presenting the primary characteristic of industrial civilization; a term from 1980 to 1990 was the development period; after 1990, Chinese cities stepped into high-speed development period, the modern industrial civilization syndrome were significantly, and the urbanization rate was expected from 18 percent in 1990 to 50 percent in 2020. By

2050, China's urbanization rate will reach 75 percent, and the urbanization of China will enter a stable growth period (see Figure 3-2).

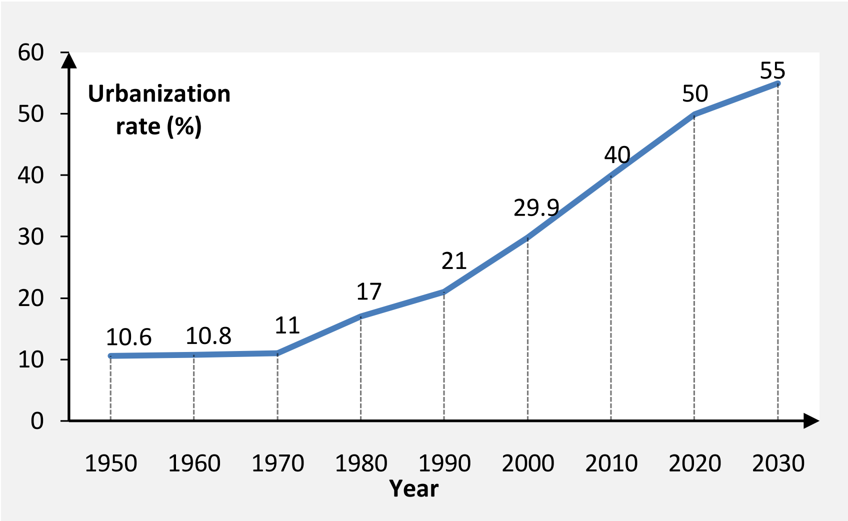

Figure 3-2: Development curve of China's urbanization rate

Data source: Official web of National Bureau of Statistics of China and Kun Huang, 2011

The development process of urban water management is associated with the development process of city. With the development of city, the urban water demand increased dramatically. In the initial period and early period of high-speed development of urbanization, the urban water supply exceeded the urban water demand, and the water sources mostly come from the urban area. The characteristics included low price, extensive management and serious waste. After turning into the late period of high-speed development, the water supply in urban area has been unable to meet the water needs of urban development, water shortage frequently occurred in cities. The cities, where is rich in water resources, over-exploited and over-utilized the water resources for industrial production, which caused water pollution and water environment degradation. The large amount of sewage discharged by cities exceeded the receiving ability and self-purification ability of water bodies, and changed the water quality, which led to pollution-induced water shortage. In the stage of stable development, urban economic development will be limited by urban water supply. Through the measures of policies and economic adjustment, broadening sources, controlling pollution and restraining demand, water supply and demand will gradually achieve a harmonious balance. When urbanization enters into a period of steady growth, ecological city with water-saving society pattern will be formed; the urban water management will be working efficiently, based on the dynamic balance of urban water supply and demand.

3.3.3 Support systems of sustainable urban water management

Based on analyzing the urban water circulation system and the relationship of urban water supply and demand, four support systems of sustainable urban water management are proposed according to the goals and directions of sustainable development of urban water management, which are for the water supply, water environment protection, water disaster prevention and water policy regulation (see Figure 3-3, 3-4, 3-5 and 3-6).

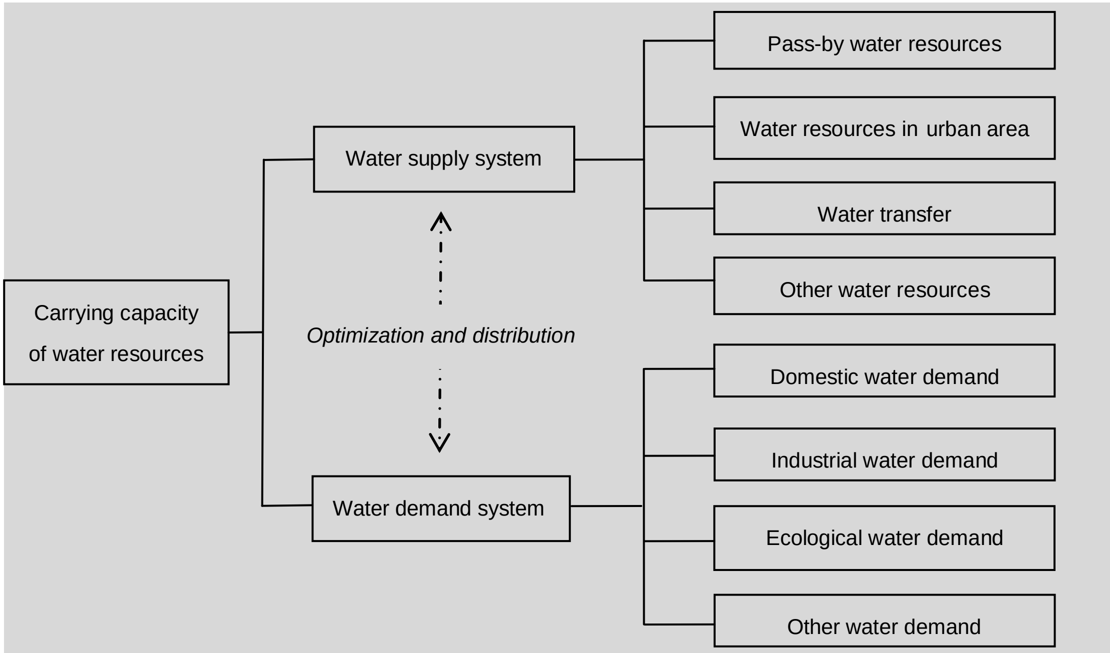

Figure 3-3: Urban water supply system

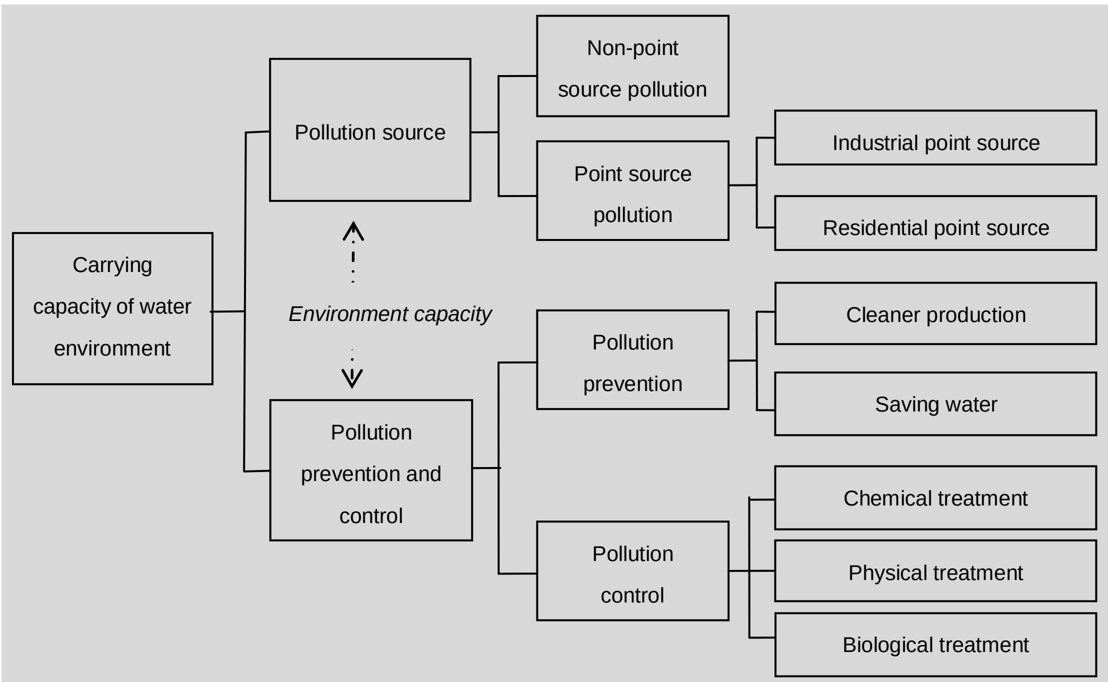

Figure 3-4: System of urban water environment protection

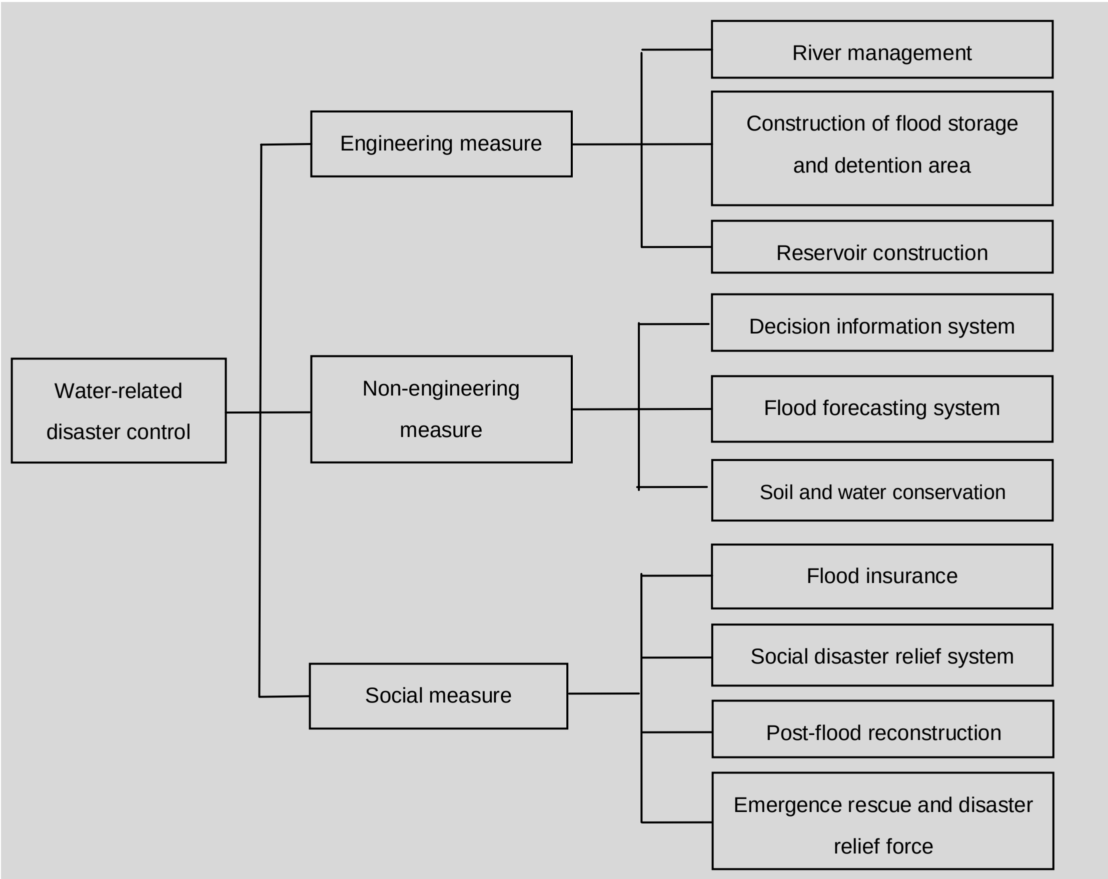

Figure 3-5: System of water disaster control

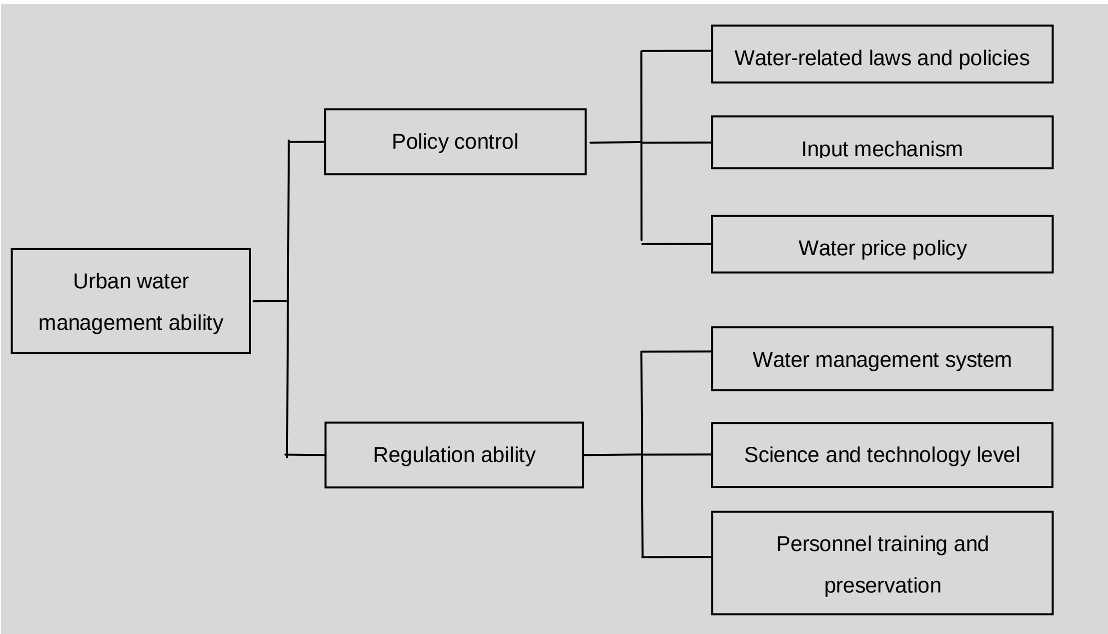

Figure 3-6: Policy regulation system

Urban water supply system expresses the carrying capacity of urban water resources through the balance of water supply and demand; water environment protection system describes the carrying capacity of urban water environment through the pollution prevention and control; water disaster control system expresses the disaster control ability through engineering measures, non-engineering measures and social measures; water policy system describes the urban water management ability through the policy control and regulation ability. The division of four support systems is the analysis of the structure of urban water management system. It reveals the essential characteristics of urban water management, and clarifies the research thinking and contents of urban water management.

3.4 Evaluation system of sustainable urban water management in SMSCs

3.4.1 Evaluation indicator

In this section, the research methodology for construction of an evaluation system of sustainable urban water management is based on the Utility Value Analysis (UVA) method. The UVA is an analytic approach for evaluating and comparing a number of different or complex alternatives, with the aim of ordering them according to the preferences of the decision-maker in a multi-dimensional target system (Siedentop, 2010 and Goetze et al, 2008).

I. *Concept and connotation*

Evaluation of sustainable development of urban water management is a reflective activity of valuator on the value relationship between properties of urban water management system and needs of sustainable development, namely process of defining value. The evaluation of the sustainable development of urban water management is based on the analysis of the system structure of urban water management to find out problems of development process. Thus, it is able to help decision makers to take measures to ensure the sustainable development of urban water management.

II. *Indicator system*

Indicator is the specific value and quantitative meaning to reflect the system elements or phenomena, and it includes the name and numerical value of indicator. Evaluation indicators of sustainable development of urban water management are a collection of development conditions of urban water management. It is an organic series composing of some indicators with hierarchy and structure, which interconnect and complement with each other. The evaluation indicator system include the basic indicators that directly come from the original data and reflect the features of subsystem, and the comprehensive indicators that are abstract and summary based on the basic indicators. The comprehensive indicators present the connection among subsystems, and reflect the natural features of urban water system, such as "ratio" and "degree”. Urban water system is a complex system; it is composed of many function groups with the same or different level, different effects and characteristics. According to targets of sustainable development evaluation, the indicators of function group with hierarchical structure are used to describe different development characteristics of the system. In the evaluation system, based on the support system of sustainable urban water management, there are six parts to be presented, namely water-saving, urban water environment, flood control and drainage, urban water resources, urban water management and science input.

The indicator system is composed of a set of interrelated function groups with hierarchical structure, and function group consists of a set of system parameters and factors. Therefore, the choice of indicator of function group is the key to success, determining the system framework. In order to choose the comprehensive and concise function group indicators of sustainable development evaluation, it is necessary to understand the structure, function and characteristics of the system of urban water management. Based on the system science theory of sustainable development, this dissertation designs a set of sustainable development indicator system with "superimposed three-layers, successive convergence, standard weight, unified scheduling". The indicator system is divided into the target layer, criterion layer and indicator layer. The structure is shown in the table 3-2.

Table 3-2: Structure of evaluation system of sustainable urban water management

Target layer	Criterion layer		Indicator layer
Sustainable development ability of urban water management	A: Water disaster prevention and control	1	Flood control standard
		2	Drainage standard
		3	Integrity ratio of flood decision information system
		4	Flood insurance ratio
		5	Hardscape ratio
	B: Utilization of water resources	6	Amount of water resources per capita
		7	Adjustable water amount per capita
		8	Degree of supply-demand balance
		9	Water supply guarantee ratio
		10	Utilization ratio of water resources
	C: Water environmental protection	11	Surface water quality
		12	Groundwater quality
		13	Drinking water quality
		14	Integrity ratio of monitoring system
		15	Integrity ratio of water pollution prevention and control system
		16	Green coverage ratio
		17	Sewage treatment ratio
	D: Water saving	18	Water intake of industrial output of ten thousand Yuan
		19	Recycle ratio of industrial water
		20	Water intake of city's residential use per capita per day
		21	Reuse rate of treated sewage
		22	Water saving ratio
	E: Science and technology	23	Investment mechanism
		24	Investment to GDP ratio
		25	Level of scientific and technical personnel
		26	Utilization ratio of water culture
	F: Urban water administration	27	Integrity ratio of management system
		28	Integrity ratio of management mechanism
		29	Integrity ratio of management policy
		30	Integrity ratio of control measures

The target layer is the ability coefficient of the sustainable development of urban water management; it comprehensively expresses the general ability of sustainable urban water management, representing the overall situation of sustainable urban water management and overall effect of strategy implementation.

The criterion layer deciphers the sustainable development system of urban water management into six subsystems with internal logical relationship: the water disaster prevention and control, water resources utilization, protection of urban water environment, water saving, science and technology, and urban water administration.

The indicator layer directly measure the quantity, strength, and speed of the system, subsystems and layers by measurable, comparable, obtainable indicators and indicator groups. The evaluation system of sustainable development of urban water management adopts 30 indicators, which quantitatively present the status of sustainable development of urban water management through the complete and systematical description. These indicators constitute the most basic elements of the indicator system.

A. Water disaster prevention

(1) Flood control standard

Urban flood control standard level directly relates to the safety of city people's life and property; it also is one of the key conditions of whether a city can develop sustainably or not; thorough flood control facilities are the basic guarantee of sustainable urban development.

(2) Drainage standard

Low standard of urban drainage not only brings the inconvenience of daily life for the city people, but also causes disaster and serious consequence because of flood; drainage standard also is one of the factors of the sustainable development of the urban water management.

(3) Integrity ratio of flood decision information system (%)

Thorough flood decision information system can quickly collect the information of flood, improving the level of scientific decision-making to reduce the disasters of flood and water logging to a minimum. It includes flood, project, disaster and other basic information, which will be put into the processes of collection, collation, analysis, decision-making, prediction and so on.

(4) Flood insurance ratio (%)

Flood insurance is effective way to solve the flood-related problems by using economic levers, and is a very important non-project measure for flood prevention and control. Flood insurance can reduce national burden. Through that, affected units and individuals have certain indemnity, which will enhance the flood consciousness.

(5) Hardscape ratio (%)

The surface of urban area transfers from vegetation cover into impermeable pavement, roof and so on, changing the surface characteristic and hydrological characteristic in urban area. As enhancing the hardscape ratio, flood peak comes earlier; peak flow and surface runoff coefficient increase. Water-related disaster will be occurred frequently in urban area.

B. Utilization of water resources

(6) Amount of water resources per capita (m^3/cap)

Total water resources are a sum of surface water resources and groundwater resources. There are different populations in different regions, so use per capita water resources to reflect the region's sustainable development of water resources.

(7) Adjustable water amount per capita (m^3/cap)

The amount of water resources in a region is relatively stable. With the expansion of city size and growth of urban population, urban water resources must be able to ensure water supply to achieve comprehensive and sustainable urban development. Therefore, adjustable external water resources should be as a part of foundation. The adjustable amount of water resources per capita also is one of the factors of sustainable development of water resources.

(8) Degree of supply-demand balance (%)

The urban water resources have an ultimate capacity for a city under certain technical and economic conditions. Thus, the development and utilization of urban water resources cannot exceed this limit; otherwise, there will be imbalance of water supply and demand, leading to over-exploitation.

(9) Water supply guarantee ratio (%)

Guarantee ratio of water supply is the important indicator of reflecting whether the water supply is proper functioning or not, and it is the basic guarantee for the city people's daily life. It should be taken as an evaluation indicator.

(10) Water resources utilization ratio (%)

Water resources utilization ratio is a reflection indicator of the degree of the rational development and utilization of water resources. Water resources utilization ratio is defined as the ratio of the total water supply to the total amount of water resources in urban area, under the condition that the water supply guarantee ratio is no lower than 75%.

C. Water environment protection

(11) Surface water quality

Surface water quality is an important indicator to reflect the quality of surface water. Through the water body surveying and the monitoring with the physical, chemical and biological indicators, the water quality is analyzed and assessed, in order to reflect the status and extent of surface water pollution, providing a scientific basis to protect surface water quality.

(12) Groundwater quality

Evaluation of groundwater quality is an important aspect of the water environment; it is a basis of rational development of water resources and scientific planning. The composite indicator method can be used to determine the status of groundwater pollution.

(13) Drinking water quality

Drinking water quality is directly related to the life quality and life safety of city people. It should be taken as an important indicator to evaluate the sustainable urban development.

(14) Integrity ratio of monitoring system (%)

Water environmental monitoring is the foundation to carry out water environment management, and is an important prerequisite to effective evaluation of water environment and utilization of water resources. The adequate and complete monitoring system is related to whether water-related affairs can be handled well or not. Water environment monitoring system includes monitoring of water quality and monitoring of water quantity.

(15) Integrity ratio of water pollution prevention and control system (%)

Prevention and control of water pollution is focused on four aspects of entire system, which are pollution sector, transfer sector, treatment sector and water body sector. The integrity ratio of water pollution prevention and control system can fully reflect the system configuration.

(16) Green coverage ratio (%)

The ecological effect of urban green land is at work in all aspects; it can improve the urban microclimate, environmental quality and urban landscape, reduce soil erosion and water pollution, etc. Ecological restore function can restore the natural function of matter and energy cycle. Other functions include the dust prevention, soil and water retaining, water purification, groundwater recharging.

(17) Sewage treatment ratio (%)

Sewage treatment can effectively reduce water pollution, and sewage treatment ratio can reflect an urban sewage treatment capacity, so use it as an indicator to evaluate the sustainable development of urban water.

D. Water saving

(18) Water intake of industrial output of ten thousand Yuan (m^3 / 10000 Yuan)

Currently, most small and medium cities in China are in the industrialization period. Therefore, industrial water use accounted for most of the urban water consumption; the rational and scientific usage of industrial water directly affects the reasonability of the urban water utilization. Water intake is computed by the unit of industrial output of ten thousand Yuan. This indicator is always used to reflect the macroscopic level of industrial water.

(19) Recycle ratio of industrial water (%)

Industrial water recycle ratio is an indicator for the water recycling in various industrial sectors, and an important indicator to evaluate the level of water utilization and water saving in macroscopic view. Improving the urban water recycling is one of the main methods of the water saving.

(20) Water intake of city's residential use per capita per day (L/cap.D)

Water intake of city's residential use per capita per day is a common indicator in the statistical analysis of China's urban water use for civilian. The quantity of water intake per capita per day reflects the statuses of the urban living, health and environmental quality, but it is not perfect as high as possible. Water wasting is still serious in many cities in China. Therefore, it is necessary to take indicator into the evaluation system of sustainable development.

(21) Reuse ratio of treated sewage (%)

Reuse ratio of treated sewage is an important indicator to evaluate the urban wastewater reclamation and reuse. Urban sewage recycling and reuse is able to save water and reduce the pollution of urban water to protect the water environment. Urban treated sewage reuse has the multi effects, which are to control pollution, provide new water source and cut costs. It has significant economic benefits, social benefits and environmental benefits.

(22) Water saving ratio (%)

Water saving ratio directly reflects the effectiveness and level of urban water conservation and saving. Its meaning is the ratio of the total quantity of water saving to total quantity of water intake in a city during the reporting period. It directly relates to the amount of saved water.

E. Science and technology

(23) Investment mechanism

It means that whether the investment policies and investment channel of the construction of urban water conservancy is perfect or not, it is a basic guarantee for the development of urban water management.

(24) Investment to GDP ratio (%)

A stable fund input is the basis for the development of urban water conservation, and is the basic reflection of the perfect investment mechanism. Taking the investment to GDP ratio as an evaluation indicator can scientifically reflect dynamic status of investment during different periods.

(25) Level of scientific and technical personnel

Overall quality of scientific and technical personnel, such as educational level, age structure and technical level, has a greater impact on the development of water conservation. It is relevant to accomplish the task of construction and development of urban water management.

(26) Utilization ratio of water culture (%)

Culture is the soul of the city; urban water culture is an important part of urban culture. Urban water culture has indispensable and irreplaceable special function in the urban construction. Researching and developing the urban water culture is conducive to the sound development of urban water management, and is helpful to adjust the appropriate relationship between water and urban development.

F. Administration of urban water

(27) Integrity ratio of management system (%)

Perfect and complete management mechanism can improve the cooperation among the units; coordinate the contradiction between upstream and downstream, the left and right bank, rural and city, and development and pollution. Therefore, establish an integrated and effective management mechanism is an important factor for the sustainable development of urban water management.

(28) Integrity ratio of management mechanism (%)

Integrated management of urban water conservation is an effective guarantee to the urban water function; setting and improving the management structure is a foundation for the unified management of urban water.

(29) Integrity ratio of management policies (%)

The policies of urban water management directly affect the management level of urban water management.

(30) Integrity ratio of control measures (%)

Control measure refers to adjusting the issues in the water management by using government function and economic lever, to improve the sound development of the city.

III. Relativity of indicator

Urban water management system is always changing and developing. At one moment, it reflects the main contradiction in the development of urban water management or the main aspect of contradiction; at another moment, it may turn into the secondary contradiction or secondary aspect of contradiction. Because understanding the characteristics of the development and changes is relativity, the evaluation indicator system based on changing and developing the urban water management is relative accordingly. Thus, must constantly revise and supplement the evaluation indicator system according to the changes and development of urban water management. At the same time, water management systems have spatial difference and development phases are different in different region in China. To establish the evaluation indicator system of sustainable development, must consider the specificity of different region based on understanding the urban water management system in general.

3.4.2 Evaluation Weighting

I. Determination of evaluation weighting

The assessment of the sustainable development belongs to the problem field of multi-objective decision-making. The indicator weighting of multi-objective decision-making method reflects the importance of the various indicators. Using the Analytical Hierarchy Process (AHP) determines the weighting of each indicator. The AHP was developed by Saaty (1980) in the 1970s to analyze complex decisions (Fig. 3-7), and its one important application is the support of decision-making involving multiple objectives (Goetze et al, 2008).

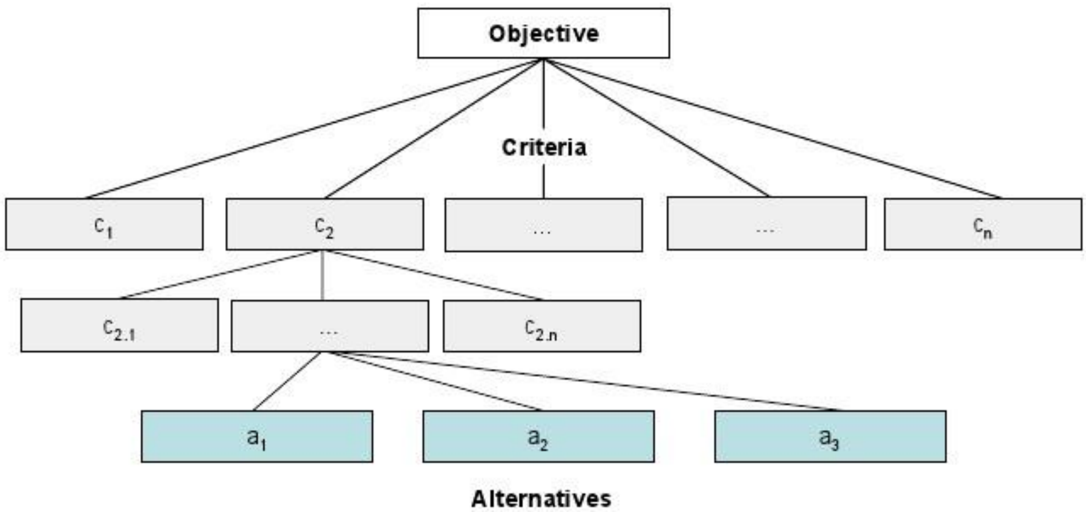

Figure 3-7: Hierarchical structure of a decision problem within the AHP process

Source: Locating Sites for Locally Unwanted Land Uses: Successfully Coping with NIMBY Resistance, Methods and Techniques in Urban Engineering (Siedentop, 2010).

This method involves "one-on-one comparisons between each element of a certain hierarchical level, and pairwise comparisons are used to assign relative weights on the objectives and criteria based on a standard ratio scale" (Siedentop, 2010). According to this approach, following steps are taken for the construction of evaluation system. Firstly, create a hierarchical structure, layering the evaluation indicator. Secondly, build matrix of pairwise comparison and judgments. After Indicator hierarchy is established, the affiliation of the indicators between the upper and lower levels can be identified, comparing between each pair in each cluster. This gives a weighting for each element within a cluster (or level of the hierarchy) and a consistency ratio (useful for checking the consistency of the data). The comparison results are shown by 1-9 scale method of Thomas L. Saaty (1980).

A. Building judgment matrix

Judgment matrix expresses the relative importance between a factor and other one of its upper layer or level; it can be investigated according to table 3-2 to understand the true view of some factors. Judges fill in the survey form shown in the table 3-3; the numbers are the scale value of relative importance, which are gotten by seriatim comparing the transverse to longitudinal criterion series. Judge can make their own judgments of the relative importance of the six indicators such as urban water environmental protection, water saving and water resources utilization. According to their own understanding and experience, they give the different scale value. Corresponding judgment matrix can be obtained from the table. The relative scale measurement is shown in the table 3-4.

Table 3-3: Questionnaire of general objectives judgment matrix

	B_1	B_2	B_3	B_4	B_5	B_6
B_1	b_{11}	b_{12}	b_{13}	b_{14}	b_{15}	b_{16}
B_2	b_{21}	b_{22}	b_{23}	b_{24}	b_{25}	b_{26}
…	…	…	…	…	…	…
B_6	b_{61}	b_{62}	b_{63}	b_{64}	b_{65}	b_{66}

Source: The Analytic Hierarchy Process: Planning, Priority Setting and Resource Allocation (Saaty, 1980)

Table 3-4: Pair wise comparison scale for AHP preferences

Numerical rating	Verbal judgments of preferences
9	Extreme importance
7	Very strong importance
5	Strong importance
3	Moderate importance
1	Equal importance

Note: The values of 2, 4, 6 and 8 are intermediate values. For example, the value 4 represents an intermediate level between moderate importance and strong importance.

Source: The Analytic Hierarchy Process: Planning, Priority Setting and Resource Allocation (Saaty, 1980)

The matrix constituted of which is:

$$P_k = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{16} \\ b_{21} & b_{22} & \cdots & b_{26} \\ \ldots & \ldots & \cdots & \ldots \\ b_{61} & b_{62} & \cdots & b_{66} \end{bmatrix} = \left(b_{ij}\right)_{6x6}$$

$$\text{Note: } k = 1,2,3 \ldots, P; \quad ij = 1,2, \ldots ,6$$

Wherein, *K* is k_{th} judge; b_{ij} represents the scale value of the judgment of the judge *k* on the row *i* and column *j*. Each judgment matrix of sub-indicator system is also constructed as described above.

B. Weight calculation method

Use summation method to calculate the weight of each indicator.

C. Single hierarchical ordering

Based on matrix calculation, hierarchical single ordering is the weight volume of the importance order of the associated levels. It can be attributed to the eigenvalue and eigenvector field of the calculation and judgment matrix. The judgment matrix should satisfy:

$$\mathrm{PW} = \lambda_{\max} \mathrm{W}$$

Wherein, λ_{max} is the largest eigenvalue about *P*, *W* is the corresponding normalized eigenvector, and W_i is the weight of single order.

The computing results should meet the requirements of the consistency ratio CR<0.1. It can directly synthesize the group determination. Suppose the judge k who constructs matrix P_k, then:

$$\mathrm{P_k W_k} = \lambda_{\max\ k} \mathrm{W_k}$$

Single order vector of calculating the matrix of the same properties:

$$\mathrm{W_k} = (\mathrm{W_{k1}}, \mathrm{W_{k2}}, \dots, \mathrm{W_n})^{\tau}$$
$$\mathrm{k} = 1,2,\dots,\mathrm{p}$$

Single order vector calculated according to the arithmetic average:

$$\mathrm{W} = (\mathrm{W_1}, \mathrm{W_2}, \dots, \mathrm{W_n})^{\tau}$$
$$\mathrm{W_i} = \frac{1}{\mathrm{p}} \sum_{\mathrm{k}=0}^{\mathrm{np}} \mathrm{W_{ki}}\,, \quad \mathrm{i} = 1,2,\dots,\mathrm{n}$$

D. Total hierarchical ordering

Based on the single hierarchical ordering, the total hierarchical ordering can be obtained from top to bottom. Suppose weight set of total hierarchical ordering is *P*, then:

$$\mathrm{P} = \{\mathrm{P_i}\} = \left\{\sum \alpha_{\mathrm{i}} \mathrm{b_{ji}}\right\}$$
$$\mathrm{i} = 1,2,\dots,\mathrm{m} \qquad \mathrm{j} = 1,2,\dots,\mathrm{n}$$

Wherein, α_i is the weight value of total order for the upper factors A_i, and b_{ji} is the result of single order of P_j corresponding α_i. Obviously, there is

$$\sum_{j=1,i=1}^{m} \alpha_i b_{ji} = 1$$

Therefore, after sorting and integrating the single order weights of all levels, the total order value of the levels of evaluation factors will be obtained.

Based on the above rationale, the weights of the evaluation system of sustainable development of urban water management can be calculated.

II. Relativity of the weights of evaluation

Indicator weight also varies with time and space like evaluation indicator. In different development stages of urban water management, each indicator for urban water management has different importance for sustainable development. Thus, its weight will change. Because the natural and social conditions, economic development level of cities are different, the weights of the indicators are also changing.

3.4.3 Evaluation criteria

I. Analysis of evaluation criteria

Choice of evaluation criteria depends on purpose of the evaluation. If the purpose of the evaluation is to establish the sequence spectrum of sustainable development of urban water management in different regions, then we can choose the average value of the same indicators in different regions in a time cross-section as the evaluation criteria; if the purpose of the evaluation is to understand the situation of the level of the changes for sustainable development in a region, to find problems and provide service for plan and management of sustainable development, we can select the indicator data in a sequence years in this region as the evaluation criteria. Evaluation results are not directly associated with the evaluation criteria, we can also formulate the evaluation criteria according to national status.

II. Relativity of evaluation criteria

The key problem of the evaluation of sustainable development is to determine the evaluation criteria, namely, what reference value should be used as a standard to measure the level and changes of the sustainable development of urban water management. Because of the different natural conditions and imbalance economic development in different regions, it is difficult to evaluate the different regions with unified criteria. Therefore, there is no absolute evaluation criterion for the sustainable development of urban water management. All criteria are relative, and are put forward based on reality. In a city, the longitudinal comparison of the time sequence is more important than the spatial transverse comparison, because it shows that the level for the sustainable development of urban water management is gradually improving or declining. If the purpose of the evaluation is to understand the situation of changes for the sustainable development in a certain region, to find problems and provide service for planning and management of sustainable development, then we can choose the indicator data at a time section as the evaluation criteria to compare longitudinally.

3.4.4 Comprehensive evaluation

I. Time scales of evaluation

Sustainable development of urban water management is a dynamic process that the system of urban water management approaches to idealistic status; the trajectory of the development degree of the urban water management is a combinatory logistic curve. In the long time scale it seemingly is stable development process, while in the short time scale it is the presence of fluctuations, which is inevitable; the index may not have been improved in a short period but can be possible in the long period, thus the evaluation time scale should not be too short. Evaluation services decision and planning to find the factors that restrict the sustainable development of urban water management, and take preventive measures early to overcome. Therefore, the minimum time scale of evaluation at least is 10 years, which is sound for establishing the sustainable development planning of the urban water management. If the evaluation time scales may be longer, it reflects the regional development trends better. Whether can make the evaluation of long time scale, it depends on availability of given data.

II. Comprehensive evaluation method

After determining the benchmark year and time scales of evaluation (m years), the calculation of regional development is $X_i \ (i = 1, 2, \ldots, m)$. Referring the adjustment of regional development, the regional sustainable development is the result of improved conditions for regional development, showing increased development degree of X (d_x> 0). There gives the criteria of sustainable development as follows:

$d_x > 0$, sustainable development;
$d_x = 0$, quasi-sustainable development;
$d_x < 0$, non-sustainable development.

Chapter 4. Construction Strategy for Sustainable Development of Water Management in SMSCs

Through an approach of documents induction and data analysis, this chapter puts forward construction strategies for sustainable urban water management in SMSCs, which involve the strategy for urban water disaster prevention and control, the strategy for urban water pollution prevention and control, the strategy for water resources utilization and the strategy for construction of urban water culture.

4.1 Strategy for urban water disaster prevention and control

Disaster prevention and control is an important content of urban water management. City is usually a regional economic epicenter in which most people live; therefore, floods in cities could be more hazardous and costly. The standard of flood control projects in SMSCs is lower than in big cities. Floods frequently occur in those cities, which is an important aspect of intuitive judgment for urban water management standard. Thus studying disaster prevention is particularly important. How to minimize losses caused by floods and harmonize relationship between floods and socio-economic development has been a significant problem that Chinese government works on (Liu Z, 2009). This section focuses on the strategy and countermeasure for the urban flood control in China.

4.1.1 Profile and challenges of urban flood control

The development of urban flood-control systems has been lagging behind the urban expansion and population growth, increasing China's losses by urban floods. About half of Chinese cities cannot meet national standards of flood control, even some cities without any infrastructure of flood prevention in newly expanded areas. Exceeding-standard flooding, high water level, dyke burst, and upper reaches dam burst can cause destroying urban floods (Liu Z, 2009).

Urban floods usually damage not only human property but also human life. It can result in complicated syndrome of more than one type disaster. Moreover, urban floods can jeopardize the city’s sustainable development as well as socio-economic stability.

An understanding is enhancing in China’s flood prevention and control sector. It is about transforming the flood control model from inflexible opposition to promotion of enduring capacity for flood, based on the theory of interconnecting systemic issues and risk awareness.

Along with developing of Chinese urbanization, urban flood prevention and control has become an important and significant component of the overall or regional flood prevention and control program. To promote the general flood-control capacity needs a number of efforts such as massive waterway dredging and restoration, engineering construction, enhancement of existing flood-preventing facilities. According to the report - *Strategies and Countermeasures for Integrated Urban Flood Management in China* by Zhiyu Liu, main challenges to urban flood prevention and control are present as follows.

- The standard for urban flood-control and drainage is low. Of the 642 cities where flood-control is necessary task, 355 cities, i.e., 55% of all, are utilizing a flood-control standard lower than the stipulation by central government. Drainage capacity is also low, mostly inadequate for a 10-year water logging.
- Urban flood-control planning and construction lags behind. Flood-control planning, construction and management have not kept pace with the fast urban development in China, especially in new economic zone and towns. Some new developments even do not have any protective facilities against floods.
- Urban flood management is imperfect. To be specific, collaboration and concurrent action among different departments is not strong enough; water-logging in downtown area is worsening; flood-control engineering construction is over-emphasized while flood management is neglected; new urban districts are under higher flood risk; emergency management is weak; flooding risk allocation system is absent; flood-control infrastructure is incomplete (Yuan, 2008).

4.1.2 Urban flood control strategy

The rapid development of modern industry and urbanization have satisfied the demands of human, expanded the needs of human social development and the human living space, and improved material living conditions. At the same time, the natural ecosystem structure, the model of inherent material cycles, and the model of energy conversion have been dramatically changed. The humankind has to be facing a series of drastic changes and caused pressures. The natural disasters have become more complex and more serious. Within the accelerated process of urbanization in China, especially in a number of SMSCs, prevention of urban flood will inevitably become the focus of the adjustment of flood control strategy.

I. *Coordination between urban flood control and river basin flood control*

Urban flood control planning is an important part of urban overall planning, and it should meet the requirements of the overall planning on the flood control. Meanwhile, the urban flood control planning should correspond to the comprehensive planning and deploy of river basin flood control. Urban flood control has its own characteristics and needs. To meet the requirements of urban flood control should establish an independent control system, however the impact on the regional flood control must be considered for its construction. The projects of the regional and/or river basin flood control should create the necessary external conditions for the urban flood control to help the city to alleviate the pressure of flood.

II. *Coincidence between urban flood control and economic development*

Urban flood control standard should be coordinated with urban economic development level. To determine the reasonable standard of urban flood control, it is necessary to study the development trend of urban economy. The construction planning of water conservancy should connect with the economic development layout, providing favorable conditions for economic development. Combining with the sustainable economic development strategy, correctly handle the relationship between the economic development and water conservancy construction. The unbalanced development of regional economy led to a huge gap between the eastern China and the western China. The construction layout of water conservancy project should adapt to the adjustment of the construction of national economy layout, which is favorable for the western development and construction, to provide conditions for the development in impoverished areas. Urban construction also needs to adapt to the conditions of water resources and flood control, to make sustainable development possible. In recent years, in order to accelerate the urbanization process, integrate the urban resources, and coordinate the urban development, many cities expand their urban areas quickly. Therefore, according to the specific conditions and the investment, it is possible to research and determine the different flood control standards for the urban center area and non-center area in different development stages.

III. *Combination of urban flood control and urban construction*

Construction of urban flood control projects is an important part of the city infrastructure, and belongs to the category of urban construction. However, the flood control project has its unique features and special requirements on construction and management. It is not equals to general project in the urban construction. Improving the relationship between the two is of significance for the sustainable development of urban water management.

Urban flood control project is generally beneficial for urban drainage. However, in China, the flood control measures mainly are building flood control levees along the river (sea, Lake), blocked the discharge passage for urban water. Planning should consider how to integrate with urban drainage project. Waterlogging caused by the flood facilities should take the necessary drainage measures. In recent years, along with the rapid urban development, in order to solve the traffic problems in the old urban areas, many cities occurred those phenomena like filling the river to build road and so on, greatly weakening the function of urban drainage. The combination of urban flood levees (or banks) and the city road can reduce the floor space and project investment. Waterfront road, which its location and landscape environment generally are better than other areas', should be used as a public recreation area. Waterfront road is unfit for urban traffic artery.

At present, the urban flood control projects mostly take concrete as construction material to build the masonry retaining wall. Although it blocks the floods, but it is isolated with the people, thus such construction model is contradictory with the citizen's requirements on hydrophilicity. Meanwhile, urban landscape is broken by it. Therefore, the height of urban levee should not be too high, and should analyze the water level and design a safe height according to the actual situation. If necessary, the relevant height can be reduced by raising the levee-back ground elevation or increasing the levee section. Nevertheless, there must be effective and feasible mechanisms and measures for the floods exceeded the standard.

Land resource is very valuable in city area, especially in old city area, in which the land occupation of urban flood control project should be as small as possible. It has special sense to urban sustainable development. Such as the urban flood control embankments and river section should take a variety of types according to the different geographical conditions. In the old city area, the construction of flood control project is better to take the erect-designing protection model as main measure, in order to reduce the impact of house demolition; in the new city area, construction model of slope embankment may be adopt.

IV. Compatibility between urban flood control and systematic water management

In China, the thinking mode of urban flood control transforms from the resistance pattern to the coordination pattern. The traditional mode emphasizes the resistance against floods. In the process of the construction of flood control project, the dam and levee were built taller and taller, riverbed was rising accordingly, and the potential threat became more serious. Unfortunately, the urban flood control stepped in a dilemma situation of "disaster prevention causes disaster" (Zhang W, 2000). Although the flood control achieved a great success in China, but in fact, nature has a reaction for every measure by human; it might be dominant or recessive, current or lagging behind, direct or indirect. In front of the powerful disasters, human gradually realize that the thinking and strategy for flood control should shift to the model of coordination, because the urban development not only need to adapt to the economic rules, but also need to follow the rules of nature. Development of urban water management should coordinate with nature development. Therefore, flood prevention dike should be built a certain height, which must be scientific and reasonable.

Improving the standard of urban flood control does not mean that we must improve the design flood level, simply using water instead of magnanimity to reflect the flood standard is not complete. After many cities in China build reservoirs in the river upstream, the downstream river is occupied seriously, in the case of low standards flood, the river water level increase on the contrary. The river straightening, bed lining reduces the river roughness and permeability, thereby speeding up the convergence speed, increasing the downstream flood control pressure. In recent years, the United States, France and other countries have returned some original straightening river to its original, because it is not only benefit for the system of flood control, but also conducive to the restoration of ecological environment.

The construction of urban flood control projects need to be changed from the single flood control to the systematic urban water management. Improving the capacity of the urban flood control cannot only consider solving a single water problem, but also should systematically study how to solve urban water-related issues, such as the excess flood utilization. Although there are many flood disasters in China, but actually the water resources is of great shortage. The flood also is a kind of resource; it is an irrational way to discharge surplus water in the flood season into the ocean. Therefore, we must consider the problem of water shortage during studying the flood control problems, studying the engineering measures of groundwater recharge and studying the possibility of interbasin water transfer in flood period. For example, the case of China's South-to-North Water Transfer Project (WaterTechnology.Net),

" … *is a multi decade infrastructure project to better utilize water resources available to China. The project involves drawing water from southern rivers and supplying it to dry north. Planned for completion in 2050, when finished, the work will link China's four main rivers – the Yangtze, Yellow River, Huaihe and Haihe – and requires the construction of three diversion routes, stretching south-to-north across the eastern, central and western parts of the country*."

A number of SMSCs located in this project area. The project study combined with the flood control strategy is significant that can help those cities to improve the abilities of flood and draught control on systematic and inter regional level. Otherwise, under the conditions of ecosystem and environment protection, reasonable construction and utilization of reservoirs are able to adjust and prevent floods. Meanwhile, the water storage also is an important function of reservoir and the water of which can be used when lacking water for water shortage areas, especially.

The measures of urban flood control may transform from the surface flood control to the multi-dimensional flood control. Currently, China's flood control measures are mainly focused on the ground through strengthening the construction of dikes, reservoirs and flood storage. With the development of science and technology, artificial control of meteorological factors is feasible and practical by using meteorology, chemistry, physics and other multiple methods and approaches, such as artificial rainfall.

4.1.3 Flood prevention and security city

I. *Concept and connotation of flood control security city*

Flood Control Security City is a new concept in the sector of urban flood prevention and control. Due to different research purposes, the definition method also is different. From the economic perspective, the concept is explained as follows: Flood Control Security City is the relative concept that is proposed for the urban flood safety. With the economic standard of flood control or by the economic social measures, the Flood Control Security City should manifest the maximum comprehensive ability for urban safety of economy and society, and the optimum effect of organizational behavior. The above explanation defines the economics of the Flood Control Security City, namely the output is greater than the input, the social benefit and the economic benefit is optimal.

The connotation of the Flood Control Security City should include the flood safety, waterlogging safety, countermeasures for over-standard flood, compensation for flood loss, flood forecasting, urban flood management, etc.

II. *Construction of flood control security city*

The construction of Flood Control Security City involves the following aspects:

- determine the reasonable standards of urban flood control and drainage;
- insist the combination of the engineering measures and non-engineering measures;
- implement the emergency countermeasures for over-standard floods;
- establish the flood forecasting and dispatching system;
- improve the flood consciousness and organizational leadership.

4.2 Strategy for urban water pollution prevention and control

At present, many SMSCs blindly pursue the economic benefits, ignoring the carrying capacity of urban water environment. That caused the degradation of urban water environment and adverse effects to the daily life of the residents and the industrial and agricultural production. This section puts forward and analyzes the protection strategy for the prevention and control of urban water pollution in SMSCs.

4.2.1 Urban water pollution prevention and control

I. Characteristics of water pollution in SMSCs

The annual amount of wastewater discharge from the over 400 small and medium-sized cities (with municipal government) is around 10 billion m^3 (Miao, 2009), and water pollution is very serious. The urban water pollution not only increases the shortage of water resources, but also causes the health condition to deteriorate. In summary, water pollution in SMSCs mainly has the following characteristics (the related data derived from “notice about strengthening the works of urban water supply and water pollution prevention and control” by Chinese State Council in 2000).

- Amount of the sewage producing per unit population in SMSCs is less than in large cities.

  The population of SMSCs general is between fifty thousand and one million, of which comprehensive water use index per unit population is 3,500 ~ 6,500 m^3 per ten thousand people per day. Thus daily water consumption of a city of 100 thousand population is about 35,000 ~ 65,000 m^3, urban sewage volume is about 18,000 ~ 34,000 m^3. Because of the gap of water resource per capita caused by difference of geographic position and the diversity of water demand structures caused by imbalance of economic development, sewage quantity of each city will be different. However, compared with the big city, amount of sewage producing per unit population reduce more than 30%.

- Dominant urban sewage is the domestic wastewater.

  The majority of SMSCs belong to the kind of comprehensive city with the multi-functions of residence, business, industry, etc. The urban sewage discharge mostly is from residents living sewage. Generally, BOD is 100-150 mg/L, COD is 250-300 mg/L, and SS is about 200 mg/L in urban sewage. A few cities have their own characteristics of industry cluster, for example, Shaoxing City has a large number of printing and dyeing enterprises and papermaking industry is famous in Fuyang City. Industrial wastewater is dominant in such cities, which will affect the structure and scale of urban sewage management.

- Combined Sewer System is obsolete.

  Drainage system in SMSCs often is the combined sewer system, rainfall and groundwater will enter such a system in the rain season or with high underground water level, resulting in the low sewage concentration. Fecal sewage in many cities is directly discharged into the water body through the septic tank; the BOD concentration is low with 30-40mg /L, which is adverse on biochemical treatment.

- Influencing factors on the sewage concentration are complex.

  In the abundant water resources and/or relevant developed areas, the water consumption and drainage in SMSCs are very large, and sewage concentration is low. Because of abundant water resources, the water body has a higher carrying capacity. In addition, water pollution feature is also shown in the obvious diurnal variation of sewage flow, fluctuating water quality and different requirements on wastewater treatment technology and process.

A comparison of the pollution characteristics in SMSCs and big cities are shown in Table 4-1:

Table 4-1: Comparison of characteristics of urban water pollution

Feature type	**Big cities**	**Small and medium-sized cities**	**Comparative result**
Sewage producing (10^4 m^3/10^4people)	2.5~4.5	1.8~3.4	SMSCs' 30% lower than big cities
Pollutants content	BOD:200~300mg/L COD:400~500mg/L SS: 200~250mg/L	BOD:100~150mg/L COD:250~300mg/L SS: 180~200mg/L	Some indexes of big cities are double of SMSCs
Drainage system	Separation of rainwater and sewage	Combination of rainwater and sewage	Some new medium cities build separation system
Sewage treatment rate	2005: above 60% 2010: above 70%	2005: above 45% 2010: above 60%	High requirements for some tourist cities

Note: data derived from "notice about strengthening the works of urban water supply and water pollution prevention and control" (State Council of China, 2000).

II. ***Water pollution prevention in SMSCs***

Urban water pollution prevention in SMSCs has been gone through the course of more than 30 years, and many effective measures have been taken for it. However, there are still many pressures, such as the industrial wastewater treatment, increasing discharge gross of urban sewage, new pollution sources caused by the suburban and rural development, and serious water shortage (D.J.Wang, 2009). Urban water pollution prevention in SMSCs still has a long way to go.

A. Pollution prevention of industrial wastewater

Industrial wastewater pollution in SMSCs has not been effectively controlled. The main reason is that the situation of the industrial production with high input, low output, high consumption and low efficiency have not been changed radically. Resources waste is still very serious, pollution producing and discharge keep on high level. Therefore, the implementation of sustainable development strategy for SMSCs should be in basis of adjusting the urban economic structure, optimizing the industrial production structure and promoting the cleaner production.

- Adjusting the urban economic structure

  According to the requirements and conditions of the national and regional development, reasonably plan the complex system of production; scientifically divide the scale of each economic region; comprehensively improving the cooperation among economic regions.

- Optimizing the industrial production structure

  Urban development should follow the principle of sustainable development and optimize the industrial production structure. Therefore, SMSCs are better to reject the development of the industry with high-energy dissipation, more land occupation, large traffic volume and heavy pollution. Reducing the quantity of water intake and wastewater discharge for unit product is of significance for urban environment protection.

- Promoting the Cleaner Production

  In recent years, the implementation of Cleaner Production and green industry mechanisms is a hot spot for the sustainable development of industry. The Cleaner Production means the continuous application of measures for design improvement, utilization of clean energy and raw materials, the implementation of advanced processes, technologies and equipment, improvement of management and comprehensive utilization of resources to reduce pollution at source, enhance the rates of resource utilization efficiency, reduce or avoid pollution generation and discharge in the course of production, provision of services and product use, so as to decrease harm to the health of human beings and the environment. Product industry should strengthen the innovation for the technology and production process.

B. Pollution prevention of domestic wastewater

Municipal domestic wastewater is a major source of water pollution. The drainage facility in most of SMSCs is seriously inadequate; the urban rivers have become the way for the sewage, some of which have fully become the polluted rivers and ditches, or even polluted the groundwater resources in city. Therefore, properly collection, treatment and discharge of urban sewage are important countermeasures to alleviate or prevent the urban water pollution.

- Renovation of toilets

  At present, a minority of families in SMSCs have not yet used the flush toilet. Human waste collection, removal, disposal and treatment are still an important problem of the water pollution prevention and control. In order to protect human health and surface water, it is necessary to renovate the toilet. There are normally three points to be considered: the first one is to transform the original dry toilet into the flushing toilet, in order to discharge the waste into the urban sewer system and finally enter the wastewater treatment plant for treatment; the second one is to build septic biogas tank beside the toilet, which will ferment manure and produce methane; the last one is to build health dry toilet, using biodegradable plastic bags to collect excrement, transporting to the waste treatment station for harmless treatment.

- Municipal solid waste disposal

  Municipal solid waste (MSW) includes solid or semi-solid materials that a possessor, in residential, institutional or commercial establishment, no longer considers of sufficient value to retain (Huang et al., 2006). The management of municipal solid waste by a community is related to human health and the environment. In 2002, the amount of MSW disposed of was 74.04 million tons, of which 89.30% was landfilled, 3.72% was incinerated, and 6.98% was composted (Yuan G, 2002). The low disposal levels of solid waste are still related to undercapitalization. There are 651 disposal facilities for MSW in China, including 528 landfill sites, 78 composting plants, and 45 incineration plants (Yuan G, 2002). The collection, transportation, and disposal of municipal solid waste have been operated by Local Environmental Sanitary Departments, which means that administration, supervision, and operation of municipal solid waste disposal were carried out by same organization. The solid waste management system is undergoing currently reform. Professional companies have been involved in solid waste management and a domestic market for solid waste management is forming. To regulate this market, a series of criteria, standards, and regulations on solid waste management is being compiled. The challenges being faced by solid waste management in China include reducing the quantity of waste from the source, promoting the recycling of solid waste, improving disposal levels and reforming solid waste management systems.

C. Pollution prevention of suburban agriculture water

Suburban water resources are one of the sources of urban water supply. In recent years, the suburban agriculture of SMSCs is moving toward modernization, which its characteristics are farm mechanization, chemical fertilizer using, and chemical prevention of plant diseases and insect pests. Although this is a high-yield agricultural production, the environmental cost is unacceptable with unrestrained development.

- Fertilizer pollution control

  In recent years, nitrogen fertilizer and phosphate fertilizer have been used excessively in the development process of suburb agriculture in a number of SMSCs. Most of fertilizer that are not absorbed by plants will be running into the surface water and/or groundwater through surface runoff and/or infiltration. Eventually, it will cause certain pollution for urban water quality. Therefore, it is necessary to popularize the application of organic fertilizer. According to different demands and conditions, fertilizing measures and methods should be reasonable and scientific, in order to reduce fertilizer runoff and nitrate leaching.

- Pesticide pollution control

  In general, 80% to 90% of the pesticides sprayed for farming are lost in soil, water and air, polluting urban water environment (Wang G, 2003). Therefore, considering the pesticide pollution problems of the agricultural development, using integrated pest management prevent or minimize the damage from insect pests, to reduce the amount and increase the efficiency of pesticide used in agricultural production. According to the manufacturer's instructions, the pesticides should be properly used, stored and mixed in order to avoid the accidents of spillage or leakage. It is better to adopt the organic agricultural technology as much as possible, and pay attention to maintaining a good soil environment and a health population of beneficial insects.

- Pollution control for intensive breeding

  Intensive breeding causes a certain degree of water pollution. The poultry intensive breeding is the main pollution source in the breeding industry. Normally, the poultry intensive breeding is concentrated in suburban areas and operated by farmers in China. With the influence of their living and economic conditions, farmers are pursuing benefits, so there is no adequate input for the breeding wastewater treatment. Therefore, the majority of farms directly discharge untreated sewage into the river, causing serious water pollution. Referring to those water pollution problems, the measures should be taken such as animal manure control and treatment, and construction of firedamp pool as adjuvant treatment, so that the pollutants are discharged after the treatment and purification instead of being directly discharged into water body.

To prevent and control the water pollution in the suburbs should develop the Ecological Agriculture, and combine with aquaculture to achieve high efficient utilization of a variety of resources. The ecological agriculture involves comprehensive using of sustainable agricultural technologies for water saving, fertilizer saving, pesticide saving and so on. It also needs to implement the reform of farming systems and innovation of irrigation and fertilizer spraying methods. Thus, the suburban water management should be focused on constructing the agricultural and rural ecosystem, ensuring the agricultural production efficiency, and enhancing the development and utilization of agricultural resources. All of those are significant to the ecosystem protection and rural economic development.

III. *Urban wastewater treatment in SMSCs*

Up to 2004, there were total 708 wastewater treatment plants (WWTPs) in small and medium cities in China, and the total capacity of treatment plants is approximate 49.12 million m^3 / day (MEP, 2005). There are 598 plants, which could undertake secondary treatment process, and the capacity is approximate 37.66 million m^3 / day (76.7% of total capacity). However, severe problem is the low utilization rate of wastewater treatment plants (WWTP). According to the statistic, up to 2004, the operation rate of wastewater plants in China is less 65% (MEP, 2005). Although it is 5% higher than the rate in 2001, there are still 35% of total facilities that were not taken fully use. The main engineering measures are focused on the following points.

A. Constructing the urban sewage treatment system

Compared with secondary sewage treatment, primary treatment has a characteristic with less initial investment and low operating cost. The same input of funds for construction or processing of primary treatment can reduce more pollutants. Therefore, in the phase of the popularization of urban sewage treatment, enhancing primary treatment process is an efficient technical Choice.

The optimization design for wastewater treatment process is the most important factor in the construction of sewage treatment plant of SMSCs. According to the *National Technical Policy for Municipal Wastewater Treatment and Pollution Prevention* (MEP, 2001), conventional activated sludge (CAS), anaerobic-aerobic activated sludge process (A/O), and anaerobic-anoxic-aerobic activated sludge process (A/A/O) are the priority processes recommended for large and medium-sized municipal wastewater treatment plants. The CAS process was widely used in municipal WWTPs constructed before 1994. According to a report "*Water Supply and Wastewater Treatment Market in China*" by U.S. Department of Commerce in 2005, the commonly used technologies since 1995 are described as the following:

- Oxidation ditch process, including almost all the derivative technologies developed by other countries (USDC, 2005).
- Sequencing batch reactor (SBR): activated sludge process, including almost all the derivative technologies developed by other countries, such as intermittent cyclic extended aeration system (ICEAS), cyclic activated sludge system (CASS), cyclic activated sludge technology (CAST), and demand aeration tank–intermittent aeration tank (DAT–IAT) (USDC, 2005).

- Other processes, such as absorption biodegrading (AB) process, University of Cape Town (UCT) process, and biological aeration filter (BAF) process and biological membrane process. From 1995 to 2000, 70 percent of more than 100 newly built WWTPs employed oxidation ditch, and from 1998 to 2000, at least 20 plants applied SBR process (MEP, 2001). In addition, the BAF, biological membrane, and hydrolysis acidification and aerobic processes have also been applied in small municipal WWTPs. Biological membrane, physical-chemical treatment, and biological treatment processes with good nitrogen and phosphate removal attributes are expected the imperative exploration in China (USDC, 2005).

Each process has different applicability. It has important significance for the design and construction of sewage treatment project in SMSCs. Analyzing advantage and disadvantage of various processes is helpful to choose a right applicable technology under a local condition. A general introduction is shown in the table 4-2.

Urban wastewater treatment system involves urban drainage system. In China, SMSCs should pay more attention to constructing and developing the sustainable urban drainage system, which means to rebuild or restore natural systems using cost effective solutions with low environmental impact to drain away dirty and surface water run-off through collection, storage, and cleaning.

Table 4-2: General introduction on wastewater treatment processes for SMSCs

Process	Advantage	Disadvantage	Adaptability
AB	It has good applicability and energy-saving benefit in the case of high concentration sewage treatment. For the utilization of sludge digestion and biogas, the advantages are obvious.	Sludge yield is large; organic matter content is high. If it causes insufficient carbon source, nitrogen removal process will be completed difficultly. For low concentration wastewater, it is difficult to produce its advantages. Requirements on the operation and management are higher.	It is more suitable for large and medium-sized WWTPs in which mainly treats high concentration sewage and has subsequent processing facilities such as sludge digestion.
A/A/O	The effect of nitrogen and phosphorus removal is good. Effluent quality is stable.	To set sludge return system and internal recirculation system respectively will cause increasing investment and energy consumption. Internal recirculation system is more complex, which has higher requirements on management.	It is suitable for large-scale WWTPs with high level of operation and management.

Modified SBR	It reduces sludge return flow, and benefits land-saving and energy-saving.	Requirements on the automation control system are very high. Lifting head is higher than in other technologies. Energy consumption increases slightly.	It is suitable for small and medium-sized WWTPs with certain level of operation and management.
BAF	The layout and structure are very compact to save land.	Operating management depends entirely on the automation of operation. Project investment and operating cost is too much high.	Its application is usually in areas with inadequate or limited land resources
UNITANK	Compact layout and structure benefit land saving. The sludge collection and return system can be omitted. Through the fixed effluent weir to discharge water, it can avoid the water head loss caused by mechanical fault and/or the water decanter. There is certain energy-saving effect.	The uncompleted utilization of activated sludge in the pool may affect water quality. The structure and arrangement of system are relatively complex. Operating management depends on the automation of operation and high level maintaining.	It is adapted to indoor layout or in land-scarce areas.
Carrousel Oxidation Ditch	The process is simple and has strong anti-impact load capacity. Effluent quality is stable. The facilities are relatively easy to be maintained.	Uneven flow velocity caused by the turbulence is able to lead to sludge settling and influence the operating performance. The investment and operation cost increase relatively.	It is suitable for small sized WWTPs.
Orbal Oxidation Ditch	The process is simple and land saving. It has strong anti-impact load capacity, good energy-saving performance, good nitrogen removal and oxygenation capabilities Effluent quality is stable. The facilities are relatively easy to be maintained.	Construction and layout of round or oval-shaped groove are relatively difficult. To build a sole settling pool covers relatively larger area. Equipment investment is slightly higher.	It is suitable for small and medium-sized WWTPs in cities with the combined drainage system.

Data Source: USDC, 2005.

B. Promoting the ecological engineering for sewage treatment

The ecological engineering aims at attaining high environmental quality, good quality, low consumption, and high efficient production of food and utilization of wastes (Rose, 1999). Considering the achievement of ecological wastewater treatment, it is necessary to transform the traditional linear treatment models into the cyclical treatment, in order to promote the protection of water and nutrient resources. An approach for the management of wastewater resources is taken into a process through the nutrient cycles of organic waste with the closed resource loop. The implementation of ecological wastewater management strategies has a significant to reduce pathogens in surface and/or groundwater for improve public health.

The ecological treatment techniques involve the constructed wetland systems (CWS), upflow anaerobic sludge blanket (USAB), soil aquifer treatment (SAT) and so on.

- The CWSs for wastewater treatment facility involve the use of engineered systems that are designed and constructed to utilize natural processes. These systems are designed to mimic natural wetland systems, utilizing wetland plants, soils and associated microorganisms to remove contaminants from wastewater effluents (EPA, 1993). CWS pretreats wastewater by filtration, settling and bacterial decomposition in a natural looking lined marsh (Farooqi et al., 2008). Constructed wetland systems have been used internationally with good results.
- The USAB degrade organic materials in the absence of oxygen and produce methane and carbon dioxide. The methane can be reused as an alternative energy source. Other benefits include a reduction of total bio-solids volume of up to 50-80% and a final waste sludge that is biologically stable can serve as rich humus for agriculture (Rose, 1999).
- The SAT is a geopurification system where partially treated sewage effluent artificially recharges the aquifers, and then withdrawn for future use. By recharging through unsaturated soil layers, the effluent achieves additional purification before it is mixed with the natural groundwater. In water scarce areas, treated effluent becomes a considerable resource for improved groundwater sources (SIDA, 2000).

4.2.2 Economic instruments for water environmental management

Water environmental management is limiting damages of human activities to protect water environment quality by using economic, legal, technical, administrative, and educational measures. Under the condition of the carrying capacity of urban water environment, water environmental management should consider how to achieve a satisfactory balance between economic development and water environmental protection by comprehensive planning to promote sustainable economic and social development.

According to a report on “Survey of Climate Change Policies and Other Approaches to Reducing Greenhouse Gas Emissions in the APEC Region”, the economic instruments (also namely market-based instruments) for water environmental management are “… *policy instruments that use price or other economic variables to* *provide incentives for polluters to reduce harmful emissions. They seek to address the market failure of negative environmental externalities either by incorporating the external cost of production or consumption activities through taxes or charges on processes or products, or by creating property rights and facilitating the establishment of a proxy market for the use of environmental services* (Correia and Murphy, 2010)".

According to ecological and economic laws, economic instruments are constantly adjusting all aspects of economic interests, such as combining personal or business interests and local social interests, regional interests and national interests, as well as short-term interests and long-term interests, to limit the destructive human activities and encourage the behavior for water environmental protection. Therefore, economic instruments for water environment management are more effective compared with other measures.

I. Pollution charges

Pollution charge (PC) is a market-based instrument that polluters are required to pay, based on their pollution emissions, damage cost caused by polluters and given charge rates set by related departments of government (Wang J, 2004). In general, pollution charge can provide polluters with economic incentives to reduce pollution, while raising fund to install environmental infrastructures. PC has been implemented in the world widely, as well as it is operating well, which has been approved by a number of practices. In China, not only enterprises but also governmental institutions have to pay pollution discharge fee according to their emissions quality and quantity. Since July 1st, 2003 a new pollution charge policy was brought into effect throughout the country (Wang J, 2004), which is different from the former charge instrument in four aspects described in "*The Development of Pollution Charge in China*" by Wang in 2004:

- The new one covers all pollution emitted from enterprises, while the former one covered only discharged pollutants exceeding emission standards.
- The charge base of new policy is total mass of pollutants, while the former concentration of pollutants.
- The charge unit in new policy is pollution equivalent, whereas the former the times of exceed of pollution concentration.
- The new policy levy on all pollutants emitted the former the pollutant that is of the highest times of exceeding discharge standards.

The two main types of pollution charges in water environmental management are the sewerage charges and the influent charges. Sewerage charges are tariffs paid for the discharge of used water. A sewerage charge is the amount of money paid for indirect discharges, that is domestic sewage or effluents discharged into the sewer system

(Hansen et al., 2001). Sewerage charges have the objective of providing environmental authorities with financial resources for water management activities.

"Discharger, who directly discharges their effluents into natural water body, must pay an effluent charge. Usually, the charge is paid to a public or para-statal authority. Payment is based on the measurements or estimates of the quantity and quality of a pollutant discharged into a natural water body (Hansen et al., 2001) ".

Polluters may reduce their pollutants discharge due to impact of pollution charges. In addition, financial function of pollution charges fulfils can improve water quality. It is no doubt that determination of optimal pollution charges must depend on the existence of a reasonable database and information on pollution damages which is based on the exact quantity and quality of the discharged wastewater (Kraemer, 1995).

II. Tradable water pollution rights

Tradable discharge permits (tradable water pollution rights) are aimed for the management and protection of surface water quality (Kraemer, 2004). The total allowable emissions of a pollutant can be limited by using this approach. The total amount among the sources of the pollutant could be allocated by issuing permits. Polluters could be authorized to release a stipulated amount of pollutant over a specified period. After their initial distribution, permits can be bought and sold. The trades can be external or internal (WHO/UNEP, 1997). Currently, its practice is only in the infancy in China.

III. Bring water resources into the national economic accounting system

Currently, as an important indicator, gross domestic product (GDP) per capita is extensively used for the measurement on a standard of living and social progress of a country or region. GDP growth shows the improvement of the economic conditions of a country or region and the development of people's living standards. However, the existing national accounts makes people cannot see the impact of the natural resources and environmental "deficit" on the economy and society, accordingly led to a consequences that people misunderstand the state of socioeconomic development. Although a set of laws and regulations related water pollution control and water environmental protection have been established by center and local governments, there are still a lot of polluters that keep excessively discharging pollutants in order to pursue the maximum economic benefits. A main reason relates to the current assessment index system. Chinese local governments only consider the city's economic development and employment. If many enterprises are in case of closure due to environmental pollution, it will bring lower local revenue and decline of GDP. In addition, from a view of enterprises, if sewage treatment facilities are off duty, operating costs and production costs can be reduced, as well as enterprise's efficiency will be increased. Therefore, water resources and environment must be included in national economic accounting system, in order to accurately reflect the relationship the between economic development and environmental protection on a national or regional level.

The accounting elements of water environment should be determined. It includes the water environmental assets, water environmental costs and water environmental incomes. Water environmental assets mean an environmental resource, which can be controlled or gotten from the matters that have taken place, and be measured in monetary, as well as bring benefits. Water environmental assets can be classified according to morphology, divided into two major categories: water resources assets and water-dependent ecological assets. Water resources assets mainly represent waters area, including rivers, lakes, and ponds, etc.; water-dependent ecological assets include water-related natural scenic spots and water-related nature reserves, etc. According to the expenditure forms, Water environmental costs involve the accumulated depreciation for water environmental assets, compensation fees for water environmental assets, water environmental management costs, water environmental protection costs, compensation fees for losses by water pollution, etc. Water environmental incomes can be divided into two categories of direct incomes and indirect incomes. The difference of both is that whether the environmental products are tangible or not.

The information of the accounting elements of water environment shall be announced officially and publicly with the aid of traditional accounting reports. An adjusted finance statement of water environment is able to reflect the state of the implementation of environmental protection policies, acceptance of social responsibilities, water environmental costs, and water environmental incomes. The water environmental assets, water environmental costs, water environmental debts and incomes may be involved in an Adjusted Balance Sheet of Water Environment or Adjusted Income Statement of Water Environment (see Table 4-3 and Table 4-4).

Table 4-3: A sample of adjusted balance sheets of water environment

Assets	**Liabilities, and creditor's equity**
Liquid assets	Current liabilities
Long-term investment	Long-term liabilities
Original value of fixed assets (deducting: accumulated depreciation)	Debt of water environment (including: loss compensation of water environment pollution)
Water environmental assets (deducting: accumulated depreciation for water environmental assets)	Creditor's equity (including: water environmental equity)
Net assets of water environment	
Total assets	Total liabilities, and creditor's equity

Note: Edition based on Adjusted Balance Sheet in “Chinese Accountancy” (Zhu et al., 2005).

Table 4-4: A sample of adjusted income statement of water environment

Category	Minus	Plus
Product sales income	Product sales cost Product sales expenses Tax fees and extra charges on sales of products	Other business profits Investment incomes
Management fees	Financial expenses Operating profit	Other business profits
Profit total	Water environment al costs (including: water environment depletion assets water environment assets compensation water environment management costs water environment pollution costs)	Water environmental incomes water environment adjusted profits

Note: Edition based on Adjusted Income Statement in “Chinese Accountancy” (Zhu et al., 2005).

With respect to specific accounting, the water environment adjusted profits are the real profits created by the enterprise for community. It is no doubt that other environmental damage should be deducted. In this dissertation, water environment is assumed as only one influencing factor. For enterprises implementing water environmental accounting system, they should set up not only business settlement bank account and assets special account but also water environmental guarantee account, which comes directly from the total profits of the enterprise, and is administrated by the government to overall manage water damage loss according to the water environment condition so as to make the water environment operate well.

IV. Selection of water environmental management instruments of SMSCs

Pollution Charges (PC) and Pollution Discharge Right Trade (PDRT) are two effective economic methods of the water environmental management. Comparatively, the PC is more flexible. Though polluters also need to buy the pollution discharge right, the price of the right is decided by the pollution control agencies, therefore, the total amount of pollution can be controlled indirectly by the discretion of the management charges or tax. Different from PC, PDRT controls water and air pollution through environmental management. When the maximal pollution load is certain in an area, the main issue is to allocate the load effectively between the present and potential polluters, which mainly considers the fairness and economic effectiveness of the distribution system. Therefore, as a product of environmental regulations and economic stimulus instrument, the PDRT controls the allowable discharge amount instead of price. Because the total discharge amount is limited, the administrative fees can be reduced. When economic grows or pollution treatment technology improves, the price of allowable discharge amount will automatically adjust to the required level to make pollution emissions adapt to the change. If the government takes the instrument of PC, the increase of the charge price must be decided by the pollution control agencies, which might not only encounter certain obstacles but also increase the management cost. Nowadays, in China most SMSCs adopt the instrument of PC to manage water environment. However due to PDRT can more easily control the influence of economic growth to environment quality, it is more reasonable and effective to take the instrument of PDRT than PC to control water environment pollution. Because of the limitation of various subjective and objective factors of pollution charges, more and more SMSCs will adopt the instrument of PDRT to manage water environment.

PC is consisted of two phases. The first phase, which is now implementing, includes collecting the fees for exceeded discharge from the enterprises which directly release the pollutants into the waterbody; collecting the treatment fee for domestic and industrial wastewater from all the urban sewage discharger (units and residents); The second phase includes collecting sewage charges according to the total amount of discharge from all the units that release sewage into the waterbody (including the sewage treatment plants); collecting extra fees for exceeded discharge from the units that release pollutants beyond standards; collecting extra fees from units that discharge industrial wastewater into the urban wastewater treatment system according to the quality of the pollutants.

4.2.3 Environmental value of water ecosystem

The process of the exploitation, utilization, protection, prevention and control, and management of water resources is the process of human beings' understanding and the realization of the value of water resources. The value of water resources in the development of cities is mainly reflected in the following aspects:

- The first value is to maintain the living and unliving system. Water is the basis of human life and the medium of metabolism. As water can be acquired from nearby rivers, water resource has various advantages such as low investment and high stability.
- The second value is to keep the urban ecological structure. The status of the rivers and lakes in a city are diverse. For example, the water system along the river includes natural rivers, artificial rivers, lakes and green land. Biodiversity is the most abundant in shallow water area and wetland. The rivers and lakes in a city have become the most important base for urban biodiversity. To maintain the biodiversity in the rivers and lakes of city has a supportive role to keep the sustainability, stability and development of urban ecological system.
- The third value is to reduce the urban heat island effect. Due to the characteristic changing of urban underlying surface and heat releasing by human activities, urban heat island effect is more and more obvious. However, the urban heat

island effect can be reduced by the high heat capacity and flowing property of urban rivers and lakes, as well as by the countercurrent air flow on the water.

- The fourth value is to be a base of green land construction. The size of urban green land affects the functions exertion of urban ecosystem. With a high opportunity cost of urban green land, its construction is obviously constrained by economic activities. Because of the mentioned reasons, the area around urban water body becomes a very important base of green land construction. Such riverbanks and islets provide the great natural and socioeconomic conditions.
- The fifth value is to provide places for resort and entertainment. It is an important factor to promote the quality of urban living.

4.2.4 Eco City

In this section, the concept and practical application of eco-city are researched based on the Case “Eco-City Planning and Management Programme” performed by Chinese and German Governments.

I. A brief survey of eco city in China

An eco-city is a type of city construction that takes into consideration ecological requirements combined with socio-economic conditions (Hald, 2009). Richard Register first coined the term "Eco City" in his 1987 book, Ecocity Berkeley: Building Cities for a Healthy Future. Richard Register has been tracking many of the dilemmas cities face and has written extensively on the eco-city building approach. While tracking the dilemmas, he has also highlighted the opportunities that exist in the building and developing of cities (Hald, 2009).

> *“Some of the specific principles he encourages and deems most important in the city building process include building the city like a living system on a three-dimensional, integral and complex model as opposed to a flat, uniform and simple one; make the city’s function fit with the patterns of evolution and be sustainable; follow the builder’s sequence by starting with the foundation and a land use pattern that supports the healthy anatomy of the whole city; reverse the transportation hierarchy; and build soils and enhance biodiversity… there are currently no international common criteria for what is considered an eco-city* (Hald, 2009) *”*.

Considering China’s actual conditions, the “Eco City” initiative of China’s Ministry of Environmental Protection (MEP) has established a plan for the creation of ecological model cities on the prefecture level. There is a set of 30 indicators in the plan, which is composed based on social progress, environmental protection and economic development. It also covers a large scope of issues, over a longer period than other existing plans, and may make actors or stakeholders to change their outlook on issues related to the conservation of energy, water and other natural resources (Hald, 2009).

Chinese and German Governments have coordinated to organize an Eco-City Planning and Management Programme for local and regional development of China. A report has described its progress in detail:

In August 2003, the prefecture of Yangzhou (Jiangsu Province) became the first city whose Eco City Master Plan was approved by MEP after consultancies from the Chinese Academy of Science and Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH. Changzhou City has also drafted an Eco City Plan with the programme's support. Commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ), the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH has been supporting the cities of Yangzhou and Changzhou since 2002 through advisory services and organizational support. According to the report,

> "…*this continuous commitment to issues of sustainability can be seen and experienced on the ground: both cities have allocated large sums to make their cities greener, expanding their urban green spaces by more than 100% in only five years. They have explored and implemented innovative approaches to selected key environmental issues of urban development with the programme's support, such as integrated and decentralized water management, urban transport, cleaner production and environmental-friendly construction. These pilot projects and trainings have contributed to the capabilities of government officials to pursue a more integrated approach in environmental management and spatial planning* (GTZ, 2010)".

The "Eco City Planning and Management Programme" is assisting both cities in creating and implementing concepts for sustainable urban development. It consists of a variety of activities, which can be segmented into six different focal areas:

- Eco City Development: assisting both Yangzhou and Changzhou in integrated environmental management and spatial planning
- Sustainable Urban Conservation: improving the living conditions of residents in traditional urban neighborhoods in a gradual, strategic approach including self-help initiatives
- Eco Residential Development: promoting sustainability criteria in urban construction (at average market prices)
- Urban Water Management: model solutions and capacity building in the fields of integrated water management, decentralized wastewater management and sustainable water cycles for public parks

- Industrial Environmental Management: reducing the environmental impact of industrial production with both government and private partners
- Public Participation: identifying spaces for active involvement of citizens in urban planning and management

II. *Urban water management of “Eco City”*

The lack of adequate centralized treatment plants and facilities in both suburban and rural areas leads to the low quality of China’s surface waters. Because of high investment, management and operation costs, large centralized water treatment system may be not the best option.

Constructed wetland technology is the one of better solutions for decentralized wastewater treatment and has been applied world widely, including in China. Through this Program, the decentralized wastewater treatment facility was built in the Tongjiang community of Changzhou City. A German technology provider designed the system according to state-of-the-art technologies. The construction of the decentralized wastewater treatment facility has been completed in July 2006. It is currently under full-scale operation and serves a capacity to treat wastewater of some 1,300 residents.

III. *A case of eco-park*

Rosebush Park as a case has been taken from the report on “Eco-city Management and Planning Programme” and described by it in detail:

> *“Public parks are an important and increasingly popular feature of urban life. Meanwhile, the large water consumption and operation costs of these parks appear as a problem, as both water resources and municipal budgets are limited. One solution to this dilemma was developed and implemented by the Eco City Programme in the constructed wetland of Rosebush Park in Changzhou. The original integrated water concept of Rosebush Park was designed by a German landscape architect in August 2005. After the assessment by the Changzhou Municipal government, the construction of Rosebush Park began in March 2006, with the design being modified twice by a German water management engineer to fit the specific climatic conditions of Changzhou. …Instead of using drinking water, which is the most common water supply option in Chinese gardens, Rosebush Park uses water from the neighboring Cailing River. Changzhou’s Rosebush Park demonstrates that an attractive park, with a system of connected ponds, at the same time can also help to save natural and financial resources. The water circulation system, which uses a vertical filter technology, continuously purifies and exchanges water from the polluted river and the ponds. The constructed wetland contains a two-stage sedimentation system*

that reduces the need to remove the silt from the ponds frequently. The latter is a common problem in conventional water cycles. This novel environment-friendly approach to water usage in a public park has a strong potential to be replicated on a broader scale, thereby improving water quality, reducing urban water consumption and the operation costs of urban parks (GTZ, 2010)*".*

4.3 Strategy for water resources utilization in SMSCs

Due to unequal distribution of water resources, serious water body pollution and unwonted clime change, China is not only suffering from water shortage but also from severe drought in recent years. Urban water supply is the most important core of water resources development and utilization. The domestic and eco-environmental water demand increase rapidly. Promoting the effective utilization of water resources and the transfer of the part of water for agricultural utilization into cities has a positive significance for reducing the crisis of shortage of water resources. This sector analyzes the strategy for water resources utilization in SMSCs.

4.3.1 Characteristics of urban water supply and water consumption

I. *Present state of urban water supply*

Urban water supply is a major issue as China is a country with a severe water shortage. Among the 661 cities, about 420 or more are short of water, with 114 in severe shortage (MEP, 2007). Some northern cities are forced to restrict water supply, such as Beijing, Tianjin and current water supply has been the toughest moment. In addition, due to the rapid population growth, China's water resources per capita will fall from 2,200 m^3 nowadays to 1700 to 1800 m^3 by 2030 (CCICED, 2005). Considering the requirement of socioeconomic development and the status of utilization of water, water shortages in China will become more and more prominent. Meanwhile, pollution, over-tapping of groundwater and water wasting aggravated water shortage besides lack of resources. The causes of water shortages in China may be described from following aspects.

- Along with the economic development and urbanization, industrial and urban water use is growing rapidly.
- Water use for agricultural irrigation is over seventy percent of all the fresh water in China (Henry, 2004).
- Over-exploitation becomes a serious problem. Especially in northern China, there are over two million pipe wells that be used for exploiting ground water.

- Unsound water price systems make worse situation of China's water shortages. Although the government has allowed prices to rise gradually in recent years, water is still much cheaper than its real cost in China. (Henry, 2004).
- Overpopulation is a main cause of shortages of water in China, even supply of water resources is not fit for human habitation in some places.

II. Characteristics of urban water consumption

The Chinese scholar Yan Han (Han et al., 2007) classified the urban water consumption as water consumption of domestic, industry, agriculture and ecology. In his article "*Modeling Multisource Multiuser Water Resources Allocation*" (2007), he described their respective characteristics in detail:

- *"Domestic water consumption: the domestic water consumption includes corporation, government, school, hotel, restaurant, bathroom, household, and so on. Domestic water consumption of city increases rapidly. The demand for the quality of domestic water is higher, which is mainly from tap water or groundwater. The guaranteed efficiency of water supply is higher* (Han et al., 2007)".
- *"Industrial water consumption: usually, the industry is one of the main water consumption sectors in a city. There is a high demand for the water consumption in industry, and the drainage amount of wastewater is large, which is the main pollution source to urban water environment. The demand for the quality of the industrial water consumption depends on the production type, facility and technology* (Han et al., 2007)".
- *"Agricultural water consumption: the proportion of agricultural water consumption accounting for total urban water consumption is related to urban industry scale and structure. Although the amount of water consumption is large, the efficiency is lower, and the seasonal peculiarity is evident. The demand for quality of agricultural water consumption is lower than domestic water* (Han et al., 2007)".
- *"Ecological water consumption: the ecological water consumption is usually used for improving the urban ecological environment or maintaining the ecological environment not to decline. It includes irrigating greenbelt, supplying water for river and lake, offering water for environment and sanitation. The demand for quality of ecological water consumption is usually lower, and the treated water can meet the requirement* (Han et al., 2007)".

4.3.2 Optimal allocation of urban water resources

I. *Principles of water resources allocation*

- Supply-decided allocation: the demand-decided model and supply-decided model are two different models of allocation of the urban water resources. Compared to the demand-decided model, the supply-decided model had the obvious characteristics including reducing prediction uncertainty, certainty in supply, coordination between water resources and socio-economic development, and better relationship between human being and nature.
- Sustainability: through historical review of urban development, a result could be drawn out that large cities usually located in downstream area of a river, and have developing themselves with ample water resources. The urban development of SMSCs has to rely on a regional development. SMSCs should take Eco City as a goal of development to utilize water resources sustainably.
- Optimum operation: it is necessary to implement the integrated operation of all water-engineering projects in SMSCs. Water storage, water intake, drainage and other aspects of urban water conservancy should be as a completed system to operate rationally and scientifically.
- Water saving: it is a precondition for implementation of the optimal allocation of urban water resources in SMSCs. Water saving not only can reduce the quantity of wasting water and discharged pollutants, but also can improve the efficiency of urban water supply.
- Equity: equity of the allocation process should be perceived by the prospective users, providing equal opportunity gains from the resource to every potential user.

II. *Model of optimal allocation*

The conflict of water supply and demand is more and more serious. Through using the structure measures and non-structure measures, the characteristics of water resources utilization could be changed to relieve the contradictions about urban water resources. The water resources in SMSCs should be protected while it is exploited and utilized. Through using the optimization method, all urban water resources are allocated uniformly. The traditional water supply pattern, which only the groundwater and surface water are viewed as water resources, should be changed. The groundwater, surface water, rainwater, reclaimed water, diverting water and seawater are regarded as the classification water source, then the multisource water are reasonably allocated based on users' demand for water quality and quantity. The goal of reasonable allocation of multisource water is to realize the sustainable utilization of urban water resources, and to promote the harmony developments of economy, society and environment. Therefore, it is a multi-objective decision-making problem. However, one of the major difficulties in formulating a water resource-planning model is the integration of those non-commensurable objectives. In this analysis, taking the sustainable development as the guidance, the maximal synthesis benefit of economy, society and environment is regarded as the overall objective.

$$\text{Objective function: } \mathrm{Max}\ \int[\mathrm{EC(Q)}, \mathrm{SO(Q)}, \mathrm{EN(Q)}]$$

$$\text{Subject to } \begin{cases} \mathrm{G(Q)} \leq 0 \\ \mathrm{Q} \geq 0 \end{cases}$$

Where, Q is the decision-making vector. EC (Q), SO (Q), EN (Q) is objective function of the economy, society and environment respectively. G (Q) is the restriction condition set.

4.3.3 Water saving

Water saving is an important aspect of the management of municipal construction and development. Along with the process of urbanization, the water-related issues, such as water shortage, water pollution and water wasting, force SMSCs to face a huge pressure from the conflict between water supply and demand. The extension of "Water Saving" idea can reduce water loss, use and/or waste, as well as preserve water quality. The following strategies of water saving should be taken for sustainable urban development of SMSCs.

I. ***Strategy of industrial distribution for improvement of urban water saving***

City construction and industrial distribution should consider the carrying capacity of urban water resources. According to the state of water resources, water environmental capacity and urban functions, city government should rationally determine the city scale, as well as adjust and optimize urban economic structure and industrial distribution. For example, SMSCs should adjust the industrial distribution to limit and constrict the development of high water demand industries in serious water shortage areas. Because of different natural conditions, water resources conditions and industrial structures, the strategy of water use should be flexible for SMSCs that located in different regions.

- In southern China, water resources are abundant for water supply of SMSCs. However, due to the increasing amount of water use per capita and wastewater discharges, the situation of the water pollution in water source areas is more and more serious. Therefore, the strategy of urban water use in this region should take the protection in water source areas as a goal to focus on the aspects of the pollution control, water saving and reclaimed water using.
- In coastal areas, with the high population density and highly developed industries, urban water resources are scarce relatively. Therefore, the strategy of urban

water use in this region should focus on the aspects of the adjustment of industrial structure and distribution, exploitation and utilization of seawater resources, and restriction on over-exploitation of ground water.

- In northern China, with the lower per capita water resources and serious problem of water environmental pollution, some of SMSCs are under the huge pressure of urban water shortage. Therefore, the strategy of urban water use in this region should focus on the aspects of the adjustment of industrial structure and distribution, restriction on the development of high water-consumption industries, enhancement of the water saving in product industries and agriculture, improvement of the urban sewage treatment, overall planning for urban and rural water use, and integrated utilization of urban water resources.

II. *Strategy of urban water price for improvement of urban water saving*

Urban water saving is significant to reach a reasonable supply-demand balance of urban water resources and reduce the management costs of urban water environment. The instruments for improvement of urban water saving are various, which usually included administrative, legal and economic instruments. Economic instruments mainly depend on the function of price lever to control water wasting, restrict water over demand, and enhance water use efficiency.

For a long time, China’s urban water use has concentrated on the natural property of water resource to extravagantly pursuer its use value. Urban water supply is seen as a public welfare or public good. Water supply companies originally are controlled by municipal administrative system. Unfortunately, such situation still exists in many SMSCs. The low water price policy not only influences domestic water use and industrial water intake, but also is a basic reason that caused water wasting. Therefore, in order to improve urban water conservation and build water-saving or water-efficient city, water price should be enhanced rationally.

III. *Strategy of water conservation management for improvement of urban water saving*

According to the Water Law of China, the administrative department for development and planning and the administrative department for water resources under the State Council are responsible for macro-allocation of the water resources nationwide. The medium and long-term plans of water supply and demand for the whole country or such plans that cover more than one province, autonomous region or municipality directly under the Central Government shall be drawn up by the administrative department for water resources under the State Council, in conjunction with the departments concerned, and shall be implemented after examination and approval by the administrative department for development and planning under the State Council. The local medium and long-term plans for water supply and demand shall, on the basis of the medium and long-term plans for water supply and demand at the next higher level and in light of the actual local conditions, be drawn up by the administrative departments for water resources under the local people's governments at or above the county level, in conjunction with the departments concerned at the same level, and the plans shall be implemented after examination and approval by the administrative departments for development and planning under the people's governments at the same level.

According to the Water Law of China, the medium and long-term plans for supply and demand of water shall be drawn up on the basis of the current supply and demand of water, plans for national economic and social development, river basin plans and regional plans and on the principle of coordinated supply and demand of water resources, comprehensive balancing of all interests, protection of ecology, strictly practicing of economy and rational development of water resources.

According to the Water Law of China, the administrative departments for water resources under the local governments shall, based on the approved water allocation plans and the predicted annual volume of in-coming water, work out annual water allocation plans and distribution plans for unified distribution of the volume of water.

According to the Water Law of China, the State applies a system for the use of water under which control over the total volume is combined with control over the quotas. The administrative departments for the relevant trades under the governments of provinces, autonomous regions and municipalities directly under the Central Government shall set quotas for water use by different trades in their administrative regions. The administrative departments for development and planning under the local governments at or above the county level shall, in conjunction with the administrative departments for water resources at the same level and on the basis of the quotas for water use, the economic and technical conditions and the volume of water available for use in their administrative regions as is determined in the water allocation plans, work out their annual plans for water use, in order to exercise control over the total volume of water to be used in their administrative regions annually.

According to the Water Law of China, governments at all levels shall promote water-conserving irrigation methods and water-saving technologies, and shall take necessary measures to prevent seepage in agricultural projects for storing and transmitting water, in order to increase the efficiency of water use in agriculture. For water use in industry, advanced technology, techniques and equipment shall be applied to increase the frequency of the use of circulated water and the ratio of the recycled water use. The State gradually eliminates the techniques, equipment and products that are outdated and are of high water-consumption. The specific list for them shall be complied and published by the department for comprehensive administration of the economy under the State Council, in conjunction with the administrative department for water resources and the relevant departments under the State Council. Manufacturers, sellers and users in the process of production and operation shall desist from manufacturing, selling or using the techniques, equipment and products included in the list.

According to the Water Law of China, urban governments shall take effective measures, as are suited to local conditions, to promote the use of water-saving household utensils, lower the leakage rate of the urban water supply network and increase the efficiency of domestic water use; they shall pay attention to centralized treatment of sewage water in cities and encourage the use of recycled water, in order to increase the utilization ratio of recycled sewage water. For construction, expansion or reconstruction of a project, plans for water-conserving measures shall be worked out to build water-conserving facilities in support of the project. The water-conserving facilities shall be designed, constructed and put into operation simultaneously with the principal part of the project. Water-supply enterprises and units that build their own water-supply facilities shall pay special attention to maintenance of the facilities to reduce water loss.

4.3.4 Water-saving City

I. Development of Water-saving City in China

Water saving (or water conservation) means that *"comprehensive measures are adopted to reduce unbeneficial loss and pollution in water delivery and use, improve the social, economic and eco-environmental benefits of water use, and utilize water resources scientifically and efficiently while keeping the people's life quality and the economic and social development capacity unchanged"* (GWP, 2003). Water-saving City (or Water Conservation City) is a reification and concrete practice based on the concept of Water-saving Society (or Water Conservation Society). "*Water conservation society is not a simple "water conservation plus society", but is the merge of water conservation into society, and means that efficient and intensive water use are fully reflected in water awareness, management system, social system, operation mechanism, engineering technology and economic structure to achieve efficient and rational use of water in production and consumption in the whole society and support for the sustainable economic and social development"* (GWP, 2003).

The implementation and actions of construction of Water Conservation Society have been started at the end of 1980s in China. In 1990, the Second National Meeting on Water Conservation in Urban Areas has put forward the concept of water conservation cities, which laid a good foundation for the practice and development of water conservation society. In 2002, water conservation society was officially enrolled into the newly revised Water Law (GWP, 2003).

Development of water conservation society is a long process. According to the overall arrangement of the Ministry of Water Resources, water conservation pilot projects will be implemented from 2001 to 2010 in two stages (GWP, 2003).

> *"The first stage is to carry out pilot work in representative areas where the water shortage and water pollution are severe; the second stage is to establish water conservation demonstration areas at provincial and basin levels. The pilot work will be done at two levels. The first is the national level that can promote the development of water conservation society in the whole country. The second is the provincial, municipal level that can provide demonstrations for the development of water conservation society within its administrative areas. The goal for the development of water conservation pilot is to establish a society where the urban and rural areas are managed in a integrated way, production is based on available water resources, water allocation is optimized, water is efficiently used, sewage water is reused, technology is advanced, the management system is perfect, water rights are clear, water price is reasonable and water conservation is widely promoted and accepted. With the establishment of water conservation pilot, a set of complete theoretical and practical experiences can be concluded for its extension in the whole country* (GWP, 2003)".

II. Characteristics of Water-saving City

In general, the characteristics of Water-saving City are high benefit and high efficiency of the use of urban water resources. Under the conditions of water-saving function in a city, water consumption, water waste and water pollution shall be minimal; outcome of water resource per unit shall be maximal.

- Modernization of water-saving management – based on computer and mathematical model, the management system of water saving should be created and developed, including affairs management system, information system, decision-making support system, and management system of urban water resources, in order to accomplish the modernization of water-saving management.
- Systematization of water-saving measures – organization system of water saving, urban socioeconomic development plan, urban water price policy, research and application of water-saving equipment should be accordance with standardized documents to proclaim publicly.
- Popularization of water-saving awareness – to create Water-saving City should focus on public participation and water-saving awareness. It is of great significance that all citizens participate in water-saving activities.

III. Evaluation index system of Water-saving City

Urban water saving is a multiobjective and multifunctional system. Therefore, it is necessary to establish an integrated evaluation index system with evaluation and control functions. The evaluation index must be investigative, contrastive and quantitative. Based on the research on sustainable utilization of urban water resources and urban economic development, an evaluation index system of water-saving city is shown in the Figure 4-1 and Table 4-5.

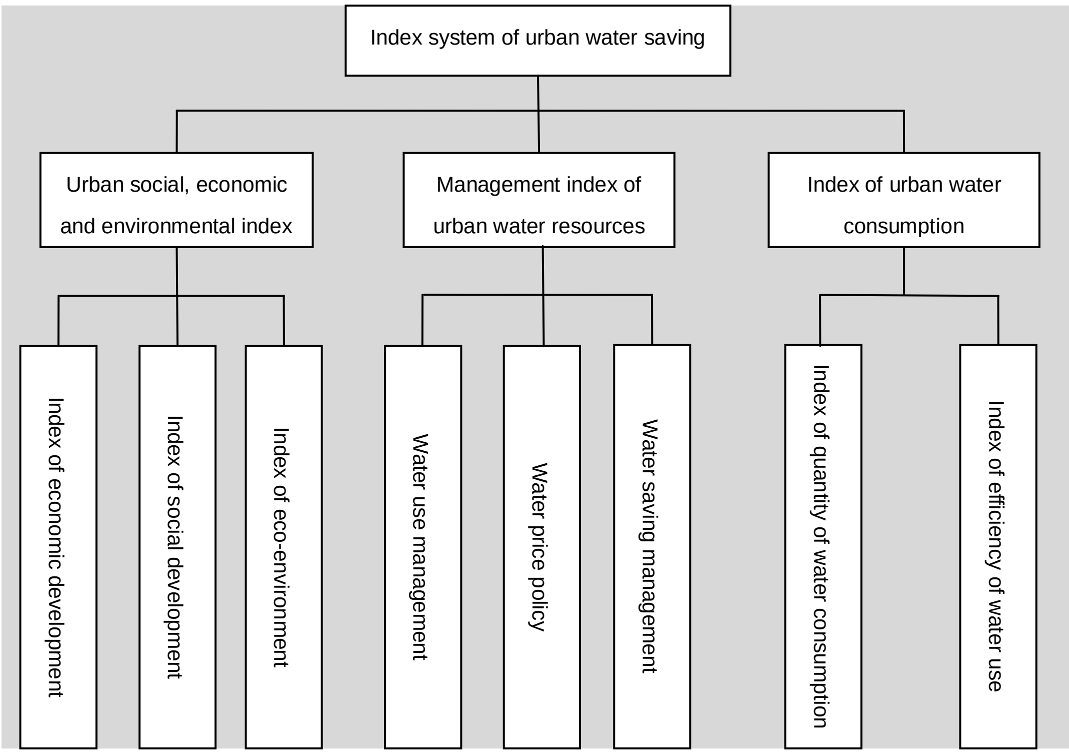

Figure 4-1: The primary and secondary grade indexes of evaluation index system of water-saving city

Table 4-5: The third grade indexes of evaluation index system of water-saving city

Secondary grade indexes	Third grade indexes
Index of urban economic development	Gross Domestic Product (GDP) per capita (Ten thousand Yuan)
	Gross National Income (GNI) per capita (Ten thousand Yuan)
	Local Government Fiscal Revenue (Ten thousand Yuan)
	Annual electricity consumption per capita (kW.h)
	Industry proportion (%)
Index of urban social development	Annual income per capita (Ten thousand Yuan)
	Annual consumption expenditure per capita (Ten thousand Yuan)
	Percentage of people with college degree in urban population (%)
Index of Urban eco-environment	Public green area per capita (m2)
	Quality standard-reaching rate of drinking water (%)
	Wastewater treatment rate (%)
	Living garbage treatment rate (%)
Urban water use management	Water demand plan (days)
	Water supply plan (days)
	Tap water supply rate (%)
Urban water saving management	Water saving organizations
	Water saving awareness of citizens
	Research, development and application of water saving equipments
	Implementation of measures of lost circulation control and plugging
	Drought emergency plan
Urban water price policy	Tap water price (Yuan/m3)
	Price for industrial water use (Yuan/m3)
	Price for business water use(Yuan/m3)
	Proportion of annual water expenditure in resident income (%)
	Proportion of highest water price in lowest water price (%)
Index of quantity of urban water consumption	Water consumption per capita (L/d)
	Water consumption of output of ten thousand Yuan (m3/104Yuan)
	Water consumption of urban total product of hundred million Yuan (m3/108Yuan)
Index of efficiency of urban water use	Efficiency ratio of urban water use (%)
	Recycle ratio of urban industrial water use (%)
	Reuse ratio of treated sewage (%)
	Utilization ratio of rainwater (%)

4.4 Strategy for construction of urban water culture

Water resource is a major natural resource and an essential element of environment and is closely related to our life. The survival of humanity is inseparable from the water; ecological balance cannot do without water; the formation of a beautiful environment also needs water. The rapid development of China's urban construction has entered a historical phase. The analysis and parsing on urban water culture can help us to understand the ideal living environment for the demand. Thus, a rational and scientific creation and maintenance of urban water culture can actively promote the eco-living environment and the image of a modern city construction.

4.4.1 Connotation of water culture

I. *The concept of water culture*

Culture has an extensive category of meaning. Generalized culture makes a general reference the total of material wealth and spiritual wealth; narrow culture refers particular to spiritual wealth, such as the ideology about literature, art, religion, philosophy etc. Generalized water culture is the concept of big culture, it is also the total of spiritual wealth and material wealth when the urban water management forms and develops. Narrow water culture means that people will have feeling and associate from the stimulation of human sense organs by all kinds of phenomenon in landscapes such as river and lake, and they will express the works and activities through the carrier of culture. Because of humans' lives and production cannot do without water, having accumulated abundant of water culture from the long-term. With the development of the times, the connotation of water culture is getting rich and its extension is enlarging.

II. *The contents of water culture*

A. Art works

Art includes literature, painting, sculpture, architecture, dance, drama, movie, etc. In a sense, China's five-millennium civilization phylogeny is the history that Chinese people fight against flood and drought. The art works that reflect the water culture from the history concludes the below content:

- Poetry: In the Chinese poem, there are many works eulogize the great river; many miserable ballads record express people become destitute and homeless after flood.
- Stele: Engraving on the steles and rocks notes the water phenomenon that had happened. For example, the Fish Grain Stone Carvings by Bai MengLian and the related words record the low water level of Yangtze River that happened in the history.
- Painting: Landscape painting is Chinese culture's mainstream all the time, it expresses human pursue and look forward to the water area landscape. Among them, the Riverside Scene at Qingming Festival by Zhang zeduan in Song dynasty is typical, and it subtly records prosperity in downstream area of Yellow river from the past.
- Legend: In process of flood prevention and control of China's thousands of years, it emerges in large numbers of heroic figures. Their stories have recorded by words or verbal spread for a long-term, and have formed rich history and literature. For example, Dayu passed home three times no entering in term of flood control, and nowadays it is widely known.
- Idiom and proverb: They are humans' experience summary through the long-term production and living. They contain profound philosophy and culture connotation. For example, the water that bears the boat is the same that swallows it.
- Architecture: Building is concretionary music. Hydrophilic buildings include kiosk, porch, hall, building, pavilion, palace, temple, tower, etc. Their plat surface and roof covering are rich and colorful. Their meanings and functions are different, this category also conclude water culture exhibition center, memorial hall and museum.
- Sculpture: It often makes history events and characters as themes. The water culture as mainline is artistically concentrated what happened to the people, and the related events that have significant impact on social economic and politics at that time.
- Waterfall and fountain: It makes the use of waterfalls, innervations, sound, momentum to make sense of beauty and impact. Such as Canada's tooth William galas cataract, China's Huangguoshu Falls both humans ideal place they want to go.
- Water curtain movie: It is a syncretic means about modern science and technology; also, it is expending water culture extension.

B. Water conservancy culture

From the ancient Dujiang Weir to the modern Three Gorges Project are both the civilized epitomes that people make use of water and defeat water disaster. They are also the water management incarnation of times water culture. Dujiang Weir makes

Sichuan plain as the land of abundance benefits for thousand years. Dujiang Weir's culture taste is not noly the competitive goods of water conservancy culture but also the essence of Chinese ethnic culture. Bridge link up people's communication and material transportation on both sides of the river. Lichun of Sui dynasty designed the Zhaozhou Bridge. It is the earliest stone arch bridge that has existed in the world. It perfectly unifies graceful modeling and structure. No matter scientific or technological level and artistic merit has reached the world peaked ness at that time. It is the competitive goods of water culture.

C. Water transport culture

Before human invented plane, train and car, water transport was the main means of communication and transportation. Canal culture was the important achievement in ancient water transport. Hangzhou canal is one of the greatest engineering projects in history; nowadays it still plays a prominent role.

D. Religious belief

- Belief: Due to people is afraid of flood and adore the personages who prevent flood by water control. It grows up the belief of religion, such as Dragon King temple.
- Fete: When people meet drought and flood, they hold all kinds of fete activities for rainfall and safety in history.
- Folk-custom: People or nation lives on the bank for long-term, the activities they hold to express the affinity with water, or remember an event and a figure, or express the joyful feeling of good harvest evolutes as folk-custom. Such as, the dragon boat racing in the Dongting Lake area.

E. Scientific paper

People deepen the cognition of water. It emerged in large numbers experts, then formed theories and collected as books. The better well known is as the Classic of Mountains and Rivers and Pan Jixun's Water Control Strategy etc.

F. Physical culture and sport

Many sport activities, such as swimming, boat sailing and water diving, combine harmony with people as water culture.

III. The characteristics of water culture

- Water culture, human civilization and city civilization in one continuous line

According to the researches of archaeology, history and anthropology, almost the civilizations started from riverside. River culture promoted the development of human civilization. Such as the Nile to Egypt and the Ganges River to India, Chinese civilization is no exception. The Yellow River is the cradle of the Chinese nation. City built by water, human live around water. "Water is a mirror of the human civilization". The seriously polluted water areas demonstrate people live there have low civilization level and lack excellent and advanced water culture. Advanced water culture can promote the coordination of water and human, the behindhand water culture makes the relationship tension of water and human. In the modern construction of urban water conservancy should sparkplug advanced water culture; should pay attention to protect and mining excellent water culture left from history, and to create modern water culture of keeping with the Times. In modern society, due to the change of human and water, water culture has also changed.

- The increasing content of water culture

The history of the development of water management actually is a history of the development of Chinese civilization. For thousands of years, people have been pursuing flood control safety and water security for production and life. However, limited to economic ability and technical level, it was not well realized this goal, flood disaster has been troubled China for thousands of years. From other side, human's interference ability to rivers is also small, until now most rivers can still keep the more natural landscape and figure. Since 1949, China's water conservancy construction is developing with a high speed. Through water conservancy project construction, human recognize that the interference on the natural rivers and lakes by human activities is too serious. Especially in SMSCs, many problems such as water pollution, degradation of eco-environment, and natural features disappear are occurred frequently. As the development of people's living standard, many new requirements are put forward. Human beings want rivers to provide more service to the society living. In addition to the security of flood and drought control, people begin to pay attention to water environment, water ecology and water landscape. The objective requirements of the society will promote the construction of urban water conservancy. The basic principle of the construction of modern water culture is to meet the human demand for modern water culture, and to reflect the relations between human and water. Through the water culture development, it can guide society to establish harmonious modes of production and life.

- The expansion of the water culture extension

  As people living standard rise, they pay more and more attention to water environment. Now, the public's attention not only focused on the city of rivers and lakes, water environment and water ecology, and water landscape, but also on the renewal and transformation of urban water environment, as well as on construction of urban water ecology and urban water cycle system.

- The enrichment of water culture facilities

  Along with the enrichment and expansion of the connotation and extension of water culture, people's spiritual life and material life demand growth and development of tourism are unceasingly rich cultural facilities; waterfront spaces get more attention. Many of architectures such as the famous Sydney opera house and the Hong Kong cultural centre have become the symbols of the city.

4.4.2 Principles of water culture construction

I. People-oriented principle

People-oriented principle is one of the basic principles of all kinds of cultural pattern created by modern society. Currently, the phenomenon of departure from the people-oriented principle is not rare in the construction of water conservancy.

II. Inheritance and development principle

Inheritance is exploring and protecting the historical and cultural heritages that are the non-renewable resources. The protection of historical and cultural heritages is a very difficult task. For a variety of reasons, water culture heritages in many of SMSCs have damaged or disappeared. It is necessary to adhere to the principle "protecting in basis and saving in first", outstanding the protection of historical and cultural heritage. Culture characterized by the times, different age has different culture forms. All the traditional culture resources are contemporary resources. When they combined with modern aesthetics, values and ethics, it can reflect the real cultural value.

III. Personalization principle

In order to keep vitality, appeal, radiation and cohesion of urban water culture, must maintain their own distinct features. Culture features are the most active forms of expression, culture plays a role of guiding, enriching and enhancing urban material.

IV. *Ecological principles*

For a long time, in the construction process of many SMSCs neglect or even destroy the urban water systems. Water environmental pollution, water loss and soil erosion are serious. These problems perplex the development of SMSCs and restrict the urban ecological process. Ecological city construction should have a perfect water system to meet production, living and ecological water demands. It should form a moderate water cycle system, improve water quality, and provide urban residents a rest, entertainment of water environment.

4.4.3 Water culture repair

As the urban construction, the natural features of urban water are disappearing gradually, the natural landscapes is becoming artificialization. Urban river levees are packaged with concrete. Urban rivers, lakes, canals, swamps and natural wetland are facing strength of development and construction. Urban ecological system and security are being threatened. For sustainable urban development, how to solve these problems must study.

I. *Ecological restoration of urban river canal*

The principles of sustainable development put forward to protect the concept of biodiversity, and protect biodiversity is essential conditions of maintaining the ecological system balance, safeguarding the human development, and supporting the sustainable development of society. Therefore, it is not only a landscape problem to protect the natural features of environment, but also the necessary conditions to protect the biodiversity. The key task of the modern construction of water landscape is to restore the nature features of water landscape.

II. *Water landscape restoration*

To construct an eco-garden city should have a perfect urban water system. Water system restoration can make stagnant water into the living water and form water cycle system, in order to reduce getting water from outside and improve water quality. It can also provide a graceful and clean water environment as the entertainment space for city residents. Water affinity restoration and culture restoration are also very important factors of water landscape construction. Water can increase the aesthetic feeling and make people closer. To promote the development of the tourism industry and the development of tourism in turn will promote the development and perfection of water culture. In the process of construction of water conservancy project should pay full attention to protect local water culture. In the place where has the prevalence of water culture activities, should retain enough places for residents to engage in water culture activities.

Chapter 5. Analysis on Regulation and Control of Sustainable Urban Water Management in SMSCs

The systems of water supply, water environmental protection, water disaster prevention and water policy regulation are four main support systems of sustainable urban water management in SMSCs. The water policy regulation includes the regulation and control of water-related policy, mechanisms and management. This chapter analyzes and discusses the reforms of water market and water management in urban water sector.

5.1 Reform of water market management

5.1.1 Reform of water price system in urban water sector

For a long-time, comprehensive water prices was only one type of water price system in Chinese cities to support the traditional urban economic development. It comprised two parts: water supply tariff and wastewater treatment fee (Zhong and Mol, 2009). The price proportion between the two parts is different from city to city. Currently, the water price system in China consists of the following:

- Water resource price: the levy of a water resource fee was determined through the Water Resource Law. The relevant water administration departments drafted the Management Methods or Water Resource Fee Levy.
- The water supply price of the water resource system: the Regulation for Management of Pollutant Discharge Fee Levy and Uses emphasizes the monetary value of water and treats water as a special commodity, and prescribes a water tariff approach, comprising water production costs, expenses, profit, and tax (USDC, 2005). Water production costs include labor, materials, capital assets depreciation, repair and maintenance, and water resource pricing.
- The municipal water supply price: according to the Municipal Water Supply Price Management Method, municipal water plants are operated by municipal water supply enterprises. The price of water includes water supply costs, relevant expenses, taxes, and profit (USDC, 2005).
- The wastewater treatment price: according to the Management Methods of Municipal Water Supply Price, a municipal wastewater treatment fee is collected along with a water supply fee, which is based on the actual water consumed by users.

For a long time, water supply industry has been working with monopolized characteristics and water enterprises has been suffering a serious deficit and difficultly financing to the sub-companies. About 30 percent of sewage treatment companies and 79 percent of water enterprises were not in a healthy condition at the beginning of 2009 (MEP, 2010). Considering the unsatisfied situation, the issue of enhancing water tariff reform has drawn a lot of governmental attention. Water tariff reform had been listed into the agenda by National Development and Reform Commission (NDRC). NDRC also organized several internal meetings to discuss about adjustment of water price. To raise the fees of water resources would not only resolve the deficit problems resulting from low water tariff, but also reflect the real value as a kind of scare resources. There are two kinds of reform models, which water supply companies are listed in the stock market or transfer shareholdings, to be recognized as reasonable mechanisms to adjustment of water price.

5.1.2 Reform of investment and financing system in urban water sector

I. *Status of investment and financing in water management sector*

According the “Annual Report 2007 – 2008” released by Ministry of Water Resources of PRC,

> “*in 2007, the actual investment allocated by the Central Government for waterworks construction was 30.852 billion Yuan, which was 1.011 billion Yuan or 3.38% higher than that of the year before. In the total investment, funds from Central Budget was 13.863 billion Yuan, or 2.016 billion Yuan less than that of the year before; state bond was 15.789 billion Yuan, or 2.847 billion Yuan more than that of the year before; and fund for waterworks construction was 1.2 billion Yuan or 150 million Yuan more than that of the year before*. *In addition, the Central Government allocated 3.2 billion Yuan to reinforce small defective and dangerous reservoirs. The 2007 investment plan of the Central Government for waterworks construction included 12.321 billion Yuan for flood control, accounting for 39.91% of the total; 14.274 billion Yuan for water resources projects, 46.27% of the total; 2.026 billion Yuan for soil and water conservation and ecological recovery, 6.56% of the total and 2.240 billion Yuan for special projects, 7.26% of the total* (MWR, 2009) “.

Water conservancy facilities are the very important urban infrastructure. Due to rapid development of urban economy and population, most of water conservancy facilities in SMSCs are often overloaded. The quantity shortage of urban water conservancy facilities has resulted in the degradation of urban water environment. The main reasons are the investment insufficiency, inefficiency of funds utilization and limited investment channels.

There is an example in wastewater management sector. In China, most of the wastewater treatment infrastructure and facilities are invested by central government. Local government could only put limited investment on the projects that could bring benefits of obviously increasing GDP. Therefore the projects relating to wastewater treatment depend greatly on state government investment, which is however very limited. It was estimated that China has invested 368,000 million Yuan on the wastewater infrastructure since 1999 (NBS, 2005). However, compared with current demand and the investment on wastewater infrastructure in other countries, it was insufficient. According to the official statistic, the annual investment on wastewater infrastructure in other industrial account for 0.53%~0.88% of the local GDP the local GDP, while the investment in China only account for 0.02%~0.03% of GDP (NBS, 2005 / MEP 2005). Chinese government should keep augmenting the investment on the infrastructure of water supply and wastewater treatment through macro control. China has opened up the market of urban wastewater treatment facilities and urban water supply facilities to foreign investments. A number of rules and regulations have been promulgated by the government for standardizing the utilization of private and foreign investments in the construction of water infrastructures. There will be a big gap of funds of the construction and operation of water projects, which only depend on government investments. It is important and necessary for urban development to develop the water market and to carry out market-oriented construction, operation and maintenance of urban water projects.

II. Reform of investment and financing system

The guiding ideology of the reform of Investment and financing in urban water sector is to establish a scientific and efficient operation system of the investment and financing. This system must provide the enough water conservancy facilities, which adapts to urban development. Investment management of the urban water conservancy facilities can be taken different approaches, based on the classification of products or services of the economic theory. Generally, the projects can be divided into three types, namely the commercial project, quasi-commercial project and non-commercial project. The main investors, operation modes, fund channels could be determined based on the project properties.

- Non-commercial projects - Non-commercial projects mainly refer to the project without charging mechanism and capital inflows, including urban flood control, drainage and so on. The Government is the main investor of non-commercial project, and is in charge of the project operation. The sources of funding should be based on the input of governmental finance (including the fixed tax) primarily. At same time, it is necessary to introduce competitive mechanism to improve the scientific and normative investment decisions. If the government is temporarily unable to meet financial and investment needs, should try to broaden the financing channels, and pay special attention to the use of the function of capital markets. Nevertheless, an appropriate repayment mechanism must be established, the debt ratio should be controlled strictly.

- Commercial projects - Commercial projects of water conservancy facilities mainly refer to the project with sufficient capital inflows and charging mechanism, which can be achieved profits or balance through the market, including water treatment, water supply and so on. Government should gradually withdraw its investment from the field in which social capital will enter, and encourage relevant investments from various economic sectors of society. Commercial projects of urban infrastructure can be opened up to social capital. Under the precondition of the strict control by government, it is better to encourage and attract social capital and funds through franchise mode, BOT mode and others, in order to form a pattern of diversified investors.

- Quasi-commercial projects - Quasi-commercial projects mainly refer to the project with a certain degree of charging mechanisms and capital inflows, which have the potential profit, but cannot recover the cost due to the factors such as market and policy, including river canals management, water diversion projects and so on. Government should consider such projects to transform the exclusive investment and operation by the government to the mix and competition model gradually. System reform of water-related project management should be accelerated; Social capital should be absorbed to participate in competition through preferential policies.

5.1.3 Water market reform

At the end of 2002, the central government of China initiated a market-oriented reform of municipal utilities (State Council, 2005). The market mechanism is introduced into the localized and inefficient utility sectors such as water, wastewater, solid waste, public traffic, city gas, heating, etc. Three main goals should be achieved in this reform, which are to attract non-state-owned capital to reduce the financial burden of governments; introduce advanced management and technology to increase the operational efficiency of municipal utilities; improve government regulation in the relevant fields. Therefore, the Chinese government enacted two additional policies to enforce the reform of water-related sector: "*the Notice on Accelerating the Industrialization of Municipal Wastewater and Wastes Treatment*" and "*the Decisions on Accelerating the Market Conversion of Municipal Public Utilities*". Two key points provide the basis for the first policy:

- Market mechanisms should be introduced into the construction of new municipal wastewater treatment facilities (USDC, 2005).

- In constructing municipal wastewater treatment facilities, investors are encouraged to either invest using a build-operate-transfer (BOT) mechanism or cooperate with enterprises authorized by the government (USDC, 2005).

The second policy focused on selling public utilities to private investors. Two key points provide the basis for this policy:

- Social and foreign capital should be encouraged in the construction of public utilities, such as water supply and wastewater treatment (USDC, 2005).
- The government will authorize enterprises to operate water supply and wastewater treatment facilities (USDC, 2005).

In china, the public funds of governments are always dedicated to the maintenance and improvement of urban infrastructures, and they are becoming increasingly scarce. It forces many local governments to seek private and social capital instead of inadequate public funds. The current water price system and its developing trend provide opportunities for investors to profit in water market. The above two policies can improve the reform of China’s public utilities and make the water market more attractive to investors. It is in a great significance of using various forms of public private partnerships (PPP) to encourage and attract social capital and funds. The most popular forms of PPP are summarized in Table 5-1.

Table 5-1: The most popular forms of PPP

Option	Ownership of assets	Financing	Operation	Average duration (Years)
Technical assistance	Public	Public	Public and private	1 to 3
Management / O&M agreement	Public	Public	Private	3 to 7
Leasing	Public	Public	Private	7 to 15
Concession	Public	Private	Private	25 to 30
BOT / TOT	Private, then public	Private	Private	15 to 20
Partial privatization (joint ownership)	Private and public	Private and public	Private and public	Perpetual
Total privatization	Private	Private	Private	Perpetual

Source: Vernay, 2006

China reformed the regulations to adapt infrastructure projects. The reform was mainly characterized by the adoption of the Administrative Licensing Law of the China

(Vernay and Ganesan, 2006). The National Concession Measures establish the general regulatory framework to adapt urban infrastructure projects in China, which include projects in water, gas or heat supply, public transportation, treatment of wastewater and garbage (Vernay and Ganesan, 2006). These measures now constitute the only legal basis for concession projects in China.

It is necessary to introduce the BOT mode because it is very popular and widely used in the construction of water-related infrastructure projects. BOT (Augenblick, 1990) is a new mode (see Figure 5-1), which is based on private investment to construct infrastructure. The central or local government first brings forward a potential project and undertakes a feasibility-study relating BOT Mode. Thereafter through bidding, a project sponsor will be selected to establish Project Company. The project company will sign a concession agreement with government and will be in charge of financing, construction, operation, and loan-return. After the concession term is over, the project will be transferred to government. After signing a concession agreement with government, the project company will find a contractor responsible for project design, construction, equipment purchasing, installation and production.

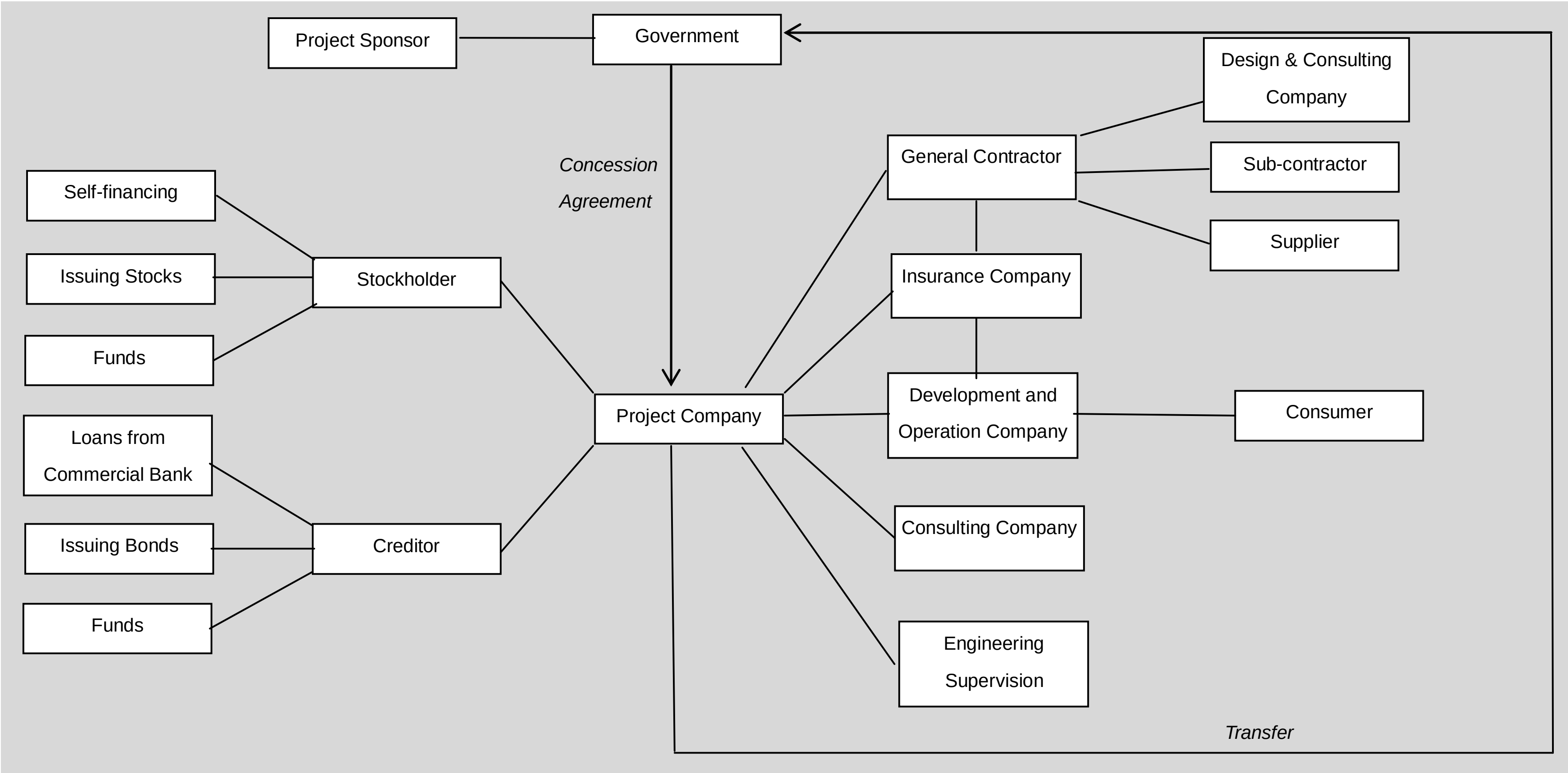

Figure 5-1: Main factors of project management of BOT Mode

5.2 Reform of urban water management

5.2.1 Overview of water administration in China

I. Institutional arrangement at national level

China's water management arrangements are primarily set through national laws and policies for implementation by provincial, prefectural and county governments. Generally, the institutional division of responsibilities at the national level is reflected in equivalent line agencies at each of the lower levels of government. Presently, there are two laws, more than 60 national and ministerial regulations and more than 300 local regulations (Zheng and Zhao, 2009). The management systems adopted for each of the aspects, such as water supply, quality protection and wastewater disposal, are not well integrated in practice, resulting in problems for water resource management and urban water management. The cooperation and coordination between the different management aspects are not always warranted. The China's urban water management system is not perfect to ensure the effective exploration, utilization, allocation, and conservation of water resource. In China, the framework of administration institution of water resources is not rational and reasonable for the developing trend of sustainability.

Water management affairs are divided among the Ministry of Water Resources (MWR), the Ministry of Environmental Protection (MEP), the Ministry of Housing and Urban-Rural Development (MHURD), the Ministry of Agriculture, the State Forest Bureau, the State Development and Reform Commission, the State Electric Power Company and the Ministry of Communication (see Table 5-2).

For example, the Ministry of Water Resources (MWR) is the department directly under the State Council in charge of unified management of water at the national level (Feng et al, 2006). The scholars Yan Feng, Daming He and Beth Kinne (2006) described the key responsibilities of MWR as follow:

- *Promulgation of the official national report on water resources;*
- *Study of the planning of water resource protection, including the creation of water function regions and the control of drainage to water bodies in drinking water source areas; monitoring water quality and quantity of rivers, lakes and reservoirs to examine and approve the capacity of water bodies to accept pollutants and self-purify; and advancing opinions on limits for gross drainage;*
- *to coordinate and arbitrate water-related conflicts between different government departments and different administrative regions (provinces, municipalities); and*

- *to organize and guide the management and protection of hydro-projects, water bodies and shorelines.*

Table 5-2: Water administration agencies under the State Council and their functions in China

Department	Scope of water administration responsibilities	Major functions
Ministry of Water Resources	Surface and ground water management, river basin management, flood control, water and soil conservation	The planning of water development and conservation, flood control, water and soil conservation, designation of water function regionalization, unified water administration
Ministry of Environmental Protection	Prevention and treatment of water pollution	Water environmental protection, water environmental function regionalization / zoning, to establish national water environmental quality standards and national pollutant discharge standards
The Ministry of Housing and Urban-Rural Development	Urban and industrial water use, urban water supply and drainage	Planning, construction and management of water supply projects and drainage and sewage disposal projects
Ministry of Agriculture	Water uses for agriculture (irrigation), fishery aqueous environment protection	Non-point source pollution control, protection of fishery water environment and aquatic environmental conservation
State Forest Bureau	Water resources conservation	Forest protection and management for protecting watershed ecology and water resources
State Electric Power Company	Hydro-power Development	Construction and management of large and mid-scale hydro-power projects
State Reform and Development Commission	Participation in the planning of water resource development and ecosystem building	Planning of water resource development, allocation of production force and ecological environment construction, coordinating the planning and policy of agriculture, forest and water resources, development
Ministry of Communication	Pollution control related to navigation of ships on rivers	Pollution control and management of inland navigation
Ministry of Health	Supervision and management of environmental health	Supervision and management of the drinking water standard

Source: Feng, He, Kinne 2006

According to the Plan of the Restructuring of China's Government Organizations approved by State Council in 2007, the duties of the Ministry of Water Resources are partially adjusted. The biggest change is to strengthen the unified management of water resources, including renewable water, and other non-traditional water management. It can be concretely expressed in the following areas (Wang, 2007):

- The function of the development and utilization of groundwater resources, which was previously assigned by the MOHURD, are handed over and assigned to the MWR.
- The specific Management Services relating to urban water are handed over to the municipal government, the same like MOHURD. The Municipal Government will determine the management systems of water supply, water saving, drainage and sewage treatment. The relevant departments of State Council Committee will perform guidance for related industries according to the own responsibilities.
- The management functions on renewable water and other non-traditional water resources are clearly defined.

Even if the administrative management system pertaining to environment is constantly reformed and developed, there is still a considerable gap between what is decided nationally and what is actually enforced on the local level.

> *"The main problem stems from local governments protecting local political, social and economic interests while resisting non-local policies and laws. The implementation gap occurs because national laws are sometimes in conflict with the social and economic interests of local communities* (Wu, 2008)".

The main reasons for occurred status are as follows:

- Drive by local self-interest and benefit
- Inadequate administrative performance examine system
- Incomplete punishment implementation

II. Institutional arrangement at municipal level

In the earlier period, the authority of water resources was mainly responsible for the construction of urban water source projects as well as the construction and management of rural water conservancy projects; the authority of construction was mainly responsible for the management of underground water resources in urban areas as well as the construction and management of urban water supply and drainage facilities; the authority of environmental protection was responsible for sewage control and management as well as the overall planning of sewage management; some cities also had bureaus of public utilities that were in charge of drainage systems and urban water conservation offices that were in charge of the management of urban water resources and water conservation. With the progress of urbanization and the rapid development of water supply and drainage undertakings, the management system characterized by the universal separation of responsibilities for water supply, water drainage, sewage treatment and water recycling, the division of cities and rural areas and the division of authorities in water resources management became more and more unsatisfactory for the development of urban water services (Wu, 2009).

The institutional arrangement of urban water management in Shanghai City is taken as an example of ordinary analysis (Cosier and Shen, 2009). The Water Affairs Bureau in Shanghai undertakes the overall management of water affairs in both the city's urban and rural areas. The Bureau's responsibilities for resources management, supply security and environmental management issues are grouped into five function areas: water supply for urban and rural areas; drainage and wastewater treatment; management of groundwater; planned water use and water saving; and flood prevention. The policy formulation, policy implementation, and enforcement and support aspects of these function areas have been institutionally separated (see Figure 5-2).

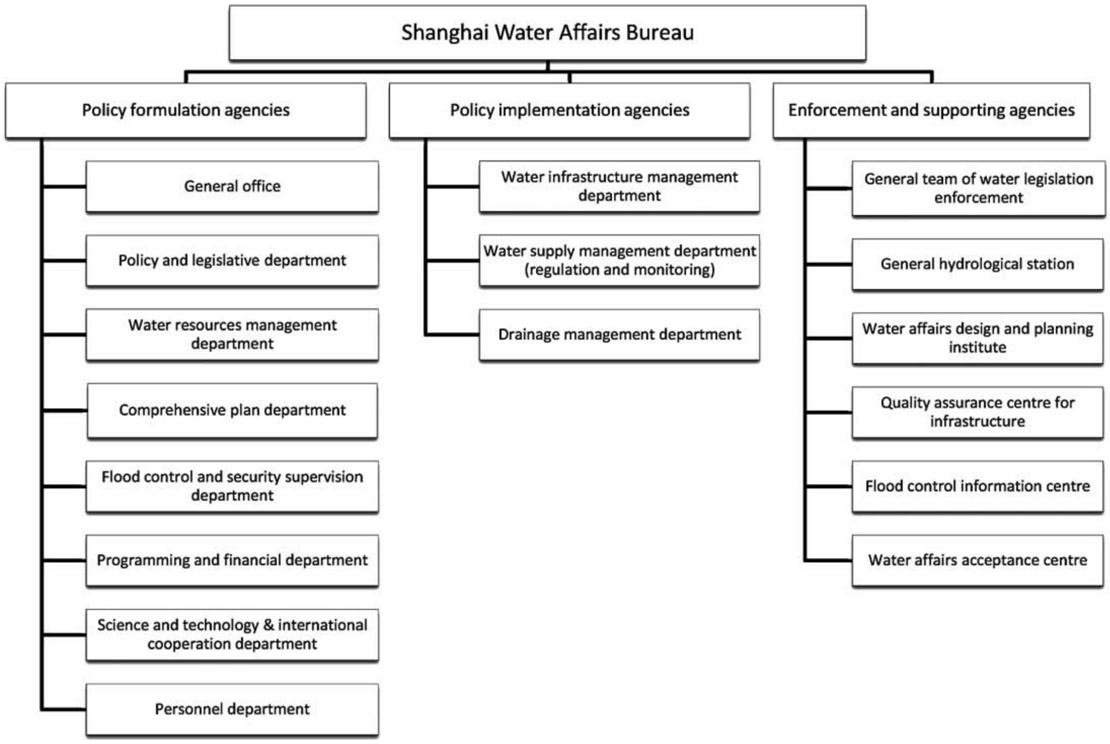

Figure 5-2: Structure of the Shanghai Water Affairs Bureau

Source: Cosier, Shen 2009

The Bureau's Water Resources Management Department is responsible for preparing water management policies relating to

> "the *supervision of water abstraction permits; collection of water resource fees; management of the water supply sector; planned water use and water saving system; supervision of drainage and sewage treatment; protection of water source areas; hydrological and water quality monitoring systems; and management of groundwater. Several agencies are responsible for the implementation of these policies… The Water Supply Management*

Department (incorporating the regulation and monitoring centre) is responsible for implementing the water abstraction permit system, collecting water resource fees, overseeing waterworks enterprises and undertaking water efficiency measures… The Drainage Management Department manages the daily operations of the drainage network and wastewater treatment plants… The Water Infrastructure Management Department oversees small-scale irrigation engineering, watercourse management and sectoral management of floodgates and dikes (Cosier, Shen 2009)".

5.2.2 Reform of urban water management

According to the presentation by Wu Jisong, Head of the Water Resources Department of the Ministry of Water Resources and Executive vice director of the National Water Conservation Office, in 2009 Sino-British Forum on Water Resources Management, the following phenomenon exists at the level of water resources management in most cities: different authorities are in charge of water; water resources management is under multiple leadership; the authorities in charge of water sources are not responsible for water supply; the water suppliers are not responsible for water drainage; the authorities in charge of water drainage are not responsible for sewage treatment; and the sewage treatment plants are not responsible for water recycling. Because of crossed jobs and unclear responsibilities, such a situation has many defects, which are mainly reflected in the following aspects: water management by different authorities increased the difficulty of municipal management and makes it impossible to realize the unified dispatching of modernized water resources networks; because nobody is entirely responsible for the balance of supply and demand, it is difficult to find the responsible authority in case of water shortage; water conservation cannot be really realized under multiple leadership; pollution cannot be controlled effectively; it's very difficult to determine a reasonable water price for the lack of unified management and the disagreement of different authorities' opinions (Wu 2009).

Wu Jisong also put forward the target, focus and general orientation of urban water management in China.

- The target of urban water management is to guarantee the balance of water supply and water demand in quality and quantity, to guarantee the safety and beautifulness of both urban and rural water environments, including the safety of flood control and the expansion of water areas in urban planning districts, to maintain the balance of both the ground and underground water ecosystems, including restricting the over-exploration of underground water, connecting urban surface water systems with each other and maintaining water circulation.

- The focus of urban water management is to guarantee the safety of drinking water for urban residents, to protect the water sources for supplying water to cities, to realize the unification of water conservation and sewage control, the unification of urban construction and water resources allocation and the unification of urbanization and water ecosystem construction and to form a complete circulation of resources in urban areas from water source to water supply, water consumption, water drainage, sewage treatment until water recycling.
- The general orientation of urban water management is to take the policies of the Ministry of Water Resources on water control in the new period as the guidance, satisfy the needs of urbanization and social and economic development and implement the spirit of the Notice of the State Council on Strengthening Water Conservation and Water Pollution Control in Cities for establishing an urban water management system characterized by the unified management of water resources in each jurisdiction, for establishing an urban water operating system that is suitable for the conditions of socialist market economy and featured by the diversification of investors, the market-oriented development of industries and the ruling of industrial supervision by law, for establishing a system of laws and regulations aimed to give a full scope to the advantages of system and strengthen industrial management and for enhancing the unified management of urban and rural water resources.

It is significant to promote the integrated urban water management for the reform of water resources management system, to establish the urban water management bureaus to be responsible for the integrated management of water resources, flood control, water sources, water supply, water drainage and sewage treatment and the unified management of urban and rural water resources. The improvement of integrated urban water management by water management bureau should be focused on the aspects of unified formulation of laws and regulations, unified implementation of policies, unified planning, unified monitoring, unified dispatching, unified management, unified assignment of water consumption quotas, unified determination of water price, unified issuance and revoking of licenses for taking water and unified collection of water resources management charge.

Considering the present situation of urban water resources and environment, the needs of urban socio-economic development, and the requirements on sustainability of both sides, the urban water management in SMSCs should be reformed in following aspects:

- SMSCs should establish the rational and scientific system of laws and regulations for urban supply, water saving and water pollution control, in order to adjust the relationship among the protection, development and utilization of urban water resources.

- SMSCs should establish the efficient and rational administrative system, in order to assume the responsibility of the management of urban water affairs.
- SMSCs should implement the integrated and unified management model of urban water resources, in order to reduce the artificial interference and coordinate the management of the urban flood control, drainage, water supply and water conservation.
- SMSCs should develop the application of economic and technological instruments, in order to enhance the investment and financing in urban water sector, as well as improve the efficient functions of water-related infrastructure and equipments.
- SMSCs should strengthen the public participation in the urban water affairs management, in order to build the scientific and reasonable decision-making process and the public monitoring and supervision mechanism, as well as promote the public environmental awareness.

5.2.3 Public Participation (PP) and urban water management

China's political system is centralized and governance is top-down (Wang, 2006). It is difficult and unreasonable that government alone solves the water-related issues and problems, because diverse stakeholders involved in the water resources management are representing the various interests. The interests of all parties need to be considered. Public participation, which means here active involvement of people in making decisions about the implementation of processes, programs and projects which affect them, is one basic element of environmental planning which permits to protect natural resources and support the sustainable development (Wang, 2007).

In China, the public participation is insufficient and unsatisfactory, and has been one of important problems for environmental protection. The reasons are described as follow:

- Influence by tradition views and government factors

  Some local governments are unwilling to listen to public opinion, due to influence by traditional views of their status. They are used to alone respond to it. Decision-makers usually believe that their views represent the public interest and public participation reduces efficiency. Some decision-making processes are easily influenced by strong interest groups, which lead to rejection of public participation. Such local practice has been part of the culture of governance of China for thousands of years.

- Incomplete legal framework

  Although a preliminary public participation system has been established in China, there is a regulatory vacuum concerning citizens' rights and interests (Turner, 2004).

- Citizens' own limitations

  The prevailing awareness is at a low level. The public usually cannot get the government information in a timely fashion. It also reduces their interest, due to a lack of public policy-making mechanisms and platforms.

- Poorly developed civil society

  China's civil society is still at the initial-phase. The development of Non-governmental Organizations (NGOs) is restricted by many factors, such as human resources, capital and organizing ability, and remain as loose voluntary groups un-networked. (Hildebrandt & Turner, 2003).

Many problems cannot be solved without public participation, such as water resource management, the tax policy adjustments after the flood risk zones were designated, flood warning and evacuation and so on. Therefore, effective public participation should be constructed and developed as soon as possible. It should include the public representatives of the groups affected by environmental change.

Chapter 6. Study on Mode of Water Recycling Economy in SMSCs

Water shortage has become a great issue which not only China but also the whole world pays great attention to it. A water resource not only supports every aspect of the economy, society and environment, but also plays an important role in terms of production and human living. The proper exploitation and sustainable management of the water resources have become an important issue. Through technical research and case analysis, this chapter discuses the water recycling mode of circular economy in SMSCs, and is proposed the technical support systems of sewage treatment corresponding the large or small urban water cycle. The main contents include municipal water recycling treatment and utilization system, and water recycling treatment and reuse system for enterprises, services and residential area.

6.1 Water recycling economic theory of water resources

The basic purpose of sustainable utilization of water resources is to satisfy the water demand of human society and ecological system, and to protect water quality for human health. Under the pressure of increasing population, accelerating urbanization and developing economy, the conflict between social and ecological water demand is more and more outstanding. In order to solve the problems of fresh water shortage and water environmental pollution, a fundamental aspect is the implementation of water recycling based on circular economic theory.

6.1.1 Water resource – Society – Economy – Eco-environment Composite System (WSEECS)

Water resource – Society – Economy – Eco-environment Composite System (WSEECS) has been developed from the system of resource, society, economy and environment. The WSEECS is a complex, composite and coupled system, including the four subsystems of water resource, society, economy and eco-environment (see Figure 6-1). They are of mutual influence and interdependence to form an organic and integral whole. The functions and relationship of each subsystem are as follow:

- The water resource subsystem and ecological environment subsystem are the indispensable and irreplaceable material base of the existence and development of regional society subsystem and economy subsystem, continuously providing natural resources and environmental resources.

- The society subsystem and economy subsystem are operating through the consumption of resources and emission of wastes, which are polluting and damaging the water resource subsystem and eco-environment subsystem to reduce their carrying capacities. Through investment and promoting actions, the society subsystem and economy subsystem are protecting, managing, restoring and compensating the water resources subsystem and eco-environment subsystem with engineering or non-engineering measures to improve their carrying capacities.
- The water resource subsystem is as the link around the society subsystem, economy subsystem and eco-environment subsystem. Water resource is a basic element of the eco-environment and an integral part of the structure and function of eco-environment subsystem. Water resource subsystem is a natural and artificial complex system, relying on hydrological cycle to show its material feature and depending on water conservancy construction to achieve its resource-related feature. Rational protection, utilization and development of water resources are of significance for stabilizing and improving the carrying capacity of water resources. Sustainable utilization of water resources must be combined with the socio-economic development and ecological protection. The ecological environment subsystem is an important part of the WSEECS and a basis of the completely complex system. The material and energy required by the production and reproduction of entire system both are derived from the ecosystem. Without the eco-environment subsystem, the WSEECS will cease to exist. Ecological environment not only is the material basis and conditions of the socio-economic development, but also controls and restricts the types and patterns of socio-economic development directly and indirectly. Standard and status of eco-environment are influencing the breadth and depth of the development and utilization of water resources, and affecting the human survival and health. Economic development is able to improve and enhance the quality of human life and guarantee the progress of social civilization continuously. At the same time, economy subsystem plays a significant and important role of capital and technologic provider for eco-environmental protection, management and compensation. Population is a momentous element in society subsystem. Sustainable Development Theory is put forward to solving various problems and issues caused increasing population in the world. Along with the rapid population growth, the activities of social production and human living increases the pressure on the earth's resources and environment, making the energy and material exchange process between human and nature unsustainable. The quantity control and optimization structure of population is the precondition for sustainable development of human society and economy.
- In the WSEECS, any subsystem with serious troubles is dangerous to the development of other three subsystems, and the problem will be amplified and expanded by the systemic feedback effect, eventually leading to the decline of the entire system.

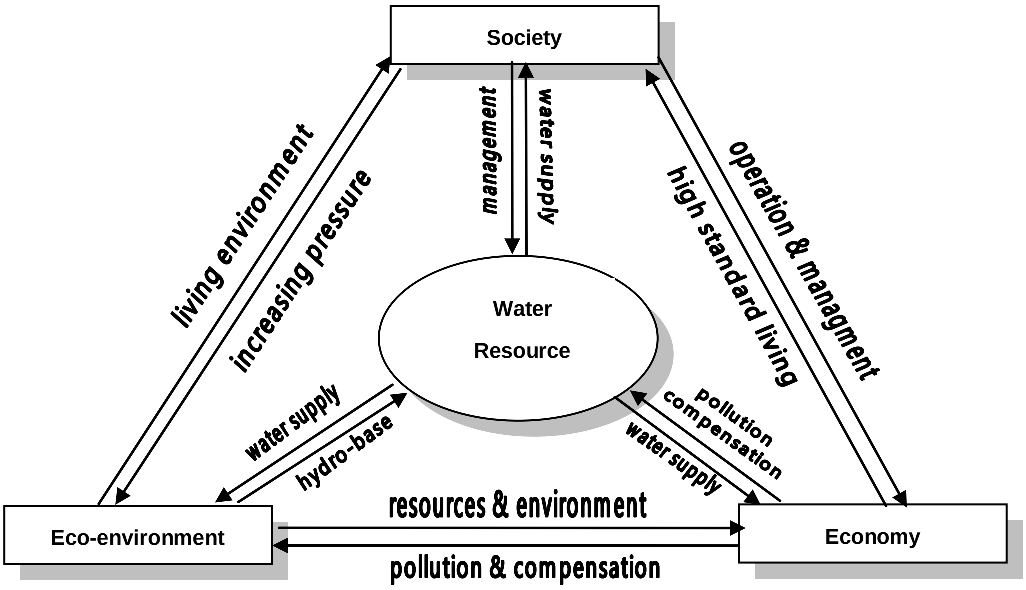

Figure 6-1: The WSEECS and its systemic operation

The sustainable development and utilization of water resources is an important support condition for the sustainable development of human society. The WSEECS is an interrelated, interactive and interrestrictive synthesis in which each element as a chain influences the other link chain in variation. Through the systemic coupling effect, the variation of system is strengthened or weakened. Certainly, there is another possibility that the tiny vibrancy may occur in the system. This process could be described by following mathematical function:

$$R = f\ (W, S, T, V)$$

Where, R – Level of sustainable development of society
W – Water resource
S – Social factor
T – Economic factor
V – Ecological factor

W, S, T, and V are compound functions, and each of them involves other sets of factors. For example, social factors include policies and overall plan and so on; ecological factors include land resources, biological resources, and climatic resources and so on. There is a simple analysis on the relationship between the ecology and economy in the process of water resources utilization under a hypothetical condition that the social factors would be unchanged in a certain scope. The Figure 6-2 shows the diagram of the coordinate system for the variation of ecology and economy.

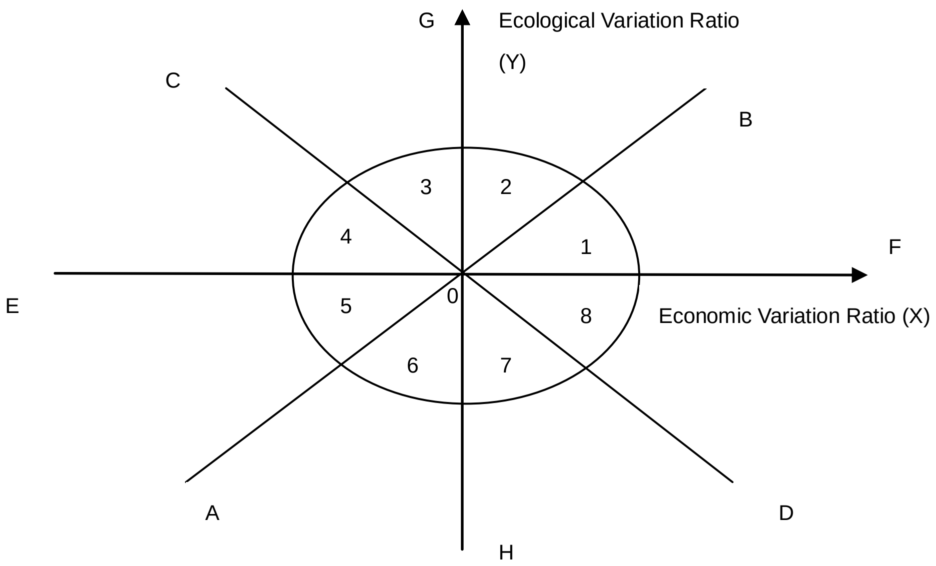

Figure 6-2: The diagram of the coordinate system for the variation of ecology and economy
Source: Jiang, Tang and Lei 2005

In the diagram, E0F represents economic variation caused by utilization of water resources; H0G represents ecological variation caused by utilization of water resource. A0B and C0D are the borderlines to divide the four quadrants into eight quadrants evenly. The coupling effect can be described in Table 6-1.

Table 6-1: Coupling relationship between economy and ecology during variation of water resources utilization

Type	Ecological Variation Ratio (Y)	Economic Variation Ratio (X)	X / Y (Absolute Value)	Result of coupling for water resources utilization
1	>0	>0	>1	Economic preference
2	>0	>0	<1	Ecological preference
3	>0	<0	<1	Ecological superiority
4	>0	<0	>1	Ecological superiority
5	<0	<0	>1	Non sustainability
6	<0	<0	<1	Non sustainability
7	<0	>0	<1	Economic superiority
8	<0	>0	>1	Economic superiority

Indeed, to evaluate the sustainable development and utilization of water resources has to consider the variation of social factors in the whole WSEECS with systematic theory of which the entirety, relevance, objectivity and dynamic characteristic are the main ideas.

6.1.2 Water recycling

I. Types of Water cycle

The existing form of water resource has the characteristics of the diversity, nonuniformity of spatial and temporal distribution, and limitation (see Figure 6-3). Although freshwater is a renewable resource based on the laws and characteristics of the natural water cycle (i.e. hydrological cycle), freshwater resources are a scarce resource in the circulation system of earth's water. The renewability of fresh water depends on functioning of the nature water cycle, but according to a certain circulation rate of the hydrological cycle, the regeneration capacity of fresh water is limited.

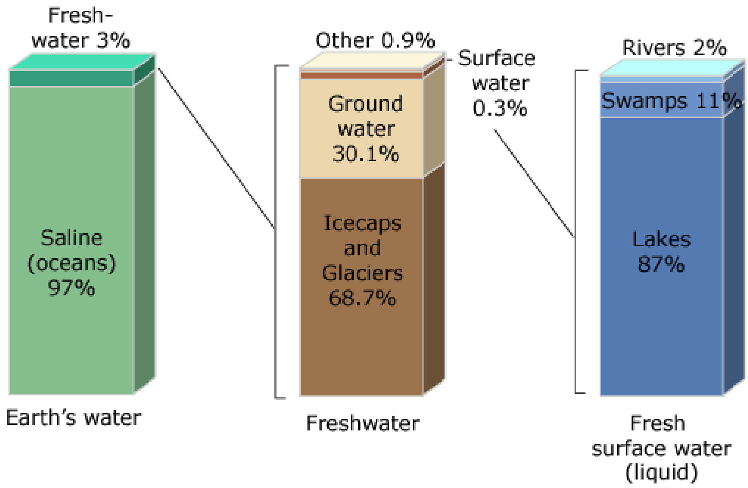

Figure 6-3: Distribution of earth's water

Source: USGS: Earth's water distribution

In the process of water circulation, water environment has a certain self-purification for pollutants through physical, chemical and biological effects. However, the self-purification capacity is limited. Additionally, water bodies have different water environmental carrying capacities under various spatial and temporal conditions. According to the law of water circulation and its significance, solution of water-related problems should take full account of the environmental carrying capacity of water circulation and the water cycle rate.

Water cycle can be divided into following three types.

- Natural water cycle: water exists in three states - solid, liquid and gas. Earth's water is always in movement, and the natural water cycle, also known as the hydrological cycle, describes the continuous movement of water on, above, and below the surface of the Earth. Under the functions of solar thermal energy and terrestrial gravitation, the state of water is exchanging ceaselessly and mutually among the atmosphere, hydrosphere, lithosphere, and biosphere.

- Social water cycle: social water cycle can be thought as a process of water cycle in socio-economic system. The term social water cycle has several analogous meanings depending on the temporal and spatial scales being considered. Social water cycle is becoming more important than hydrological cycle that has been studied for long time from various aspects. The concept of social water cycle can provide the platform for design and evaluation of data networks about water flows in human system, syntheses of existing information, enhancing transfer value of information from well studied to unstudied areas. In addition, the concept of social water cycle provides a common conceptual framework for comparing of different human water use system in different studied areas (Cheng, zhou and Xue 2004).
- Urban water cycle: urban water cycle (Fig. 6-4) derived from natural water cycle during the development of human society. Embedded within the natural water cycle is the urban water cycle, which describes the collection of water for use within urban areas and its return to the natural water cycle. The urban water circulation system is composed of artificial circulation system and a part of the natural circulation system. Urban artificial circulation system is composed of urban water supply, drainage and their treatment. In fact, on the process of the system operation, in addition to that some are absorbed and consumed by human, plant and products, most are discharged to the urban drainage network, and the quantitative changes is small while the main change is quality.

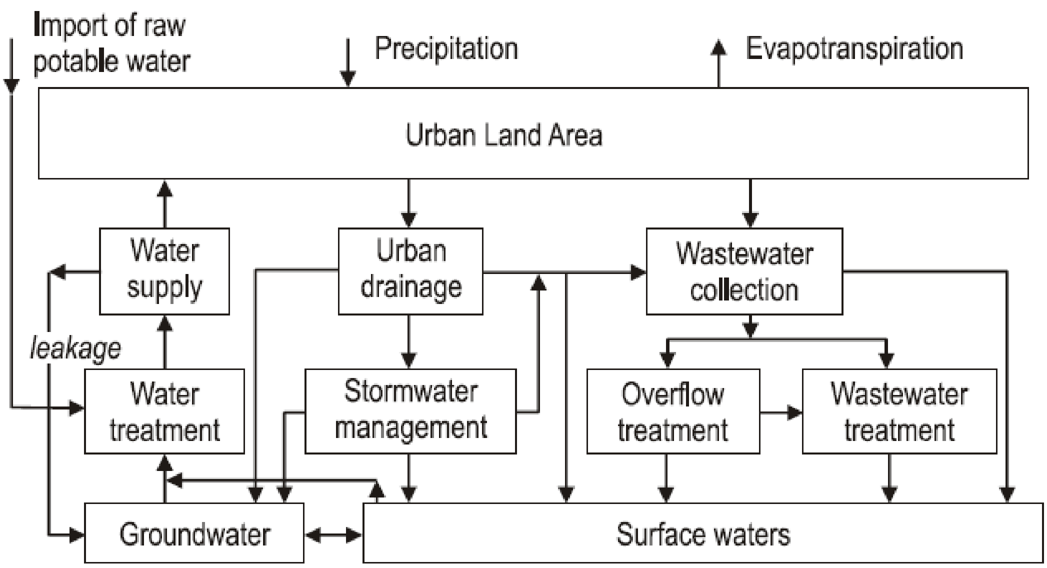

Figure 6-4: Urban water cycle – main components and pathways

Source: Marsalek et al., 2006

Building a well social water cycle needs respect and follow natural rules and character of water. While scientific and rational utilization of water resources should focus on the treatment and recycling of sewage and industrial wastewater. In a natural basin, human activities and water environmental protection should be achieved an appropriate balance, in order to ensure the satisfaction of various water demand from both human society and environmental protection. Because of the rapid and excessive economic and social development, water cycle system has been destructed on the different levels. Therefore, all efforts should be aimed at the restoration of the natural water cycle in the process of coordination between human activities and water environment. In this way, water resources utilization could be achieved a well level of sustainable development, also to maintain a good water environment.

II. *Concept and feature of water recycling*

The concept of water recycling have been expressed by United States Environmental Protection Agency (U.S. EPA) that "*water recycling is reusing treated wastewater for beneficial purposes such as agricultural and landscape irrigation, industrial processes, toilet flushing, and replenishing a ground water basin (referred to as ground water recharge)"*. Water recycling offers resource and financial savings. Wastewater treatment can be tailored to meet the water quality requirements of a planned reuse. Recycled water for landscape irrigation requires less treatment than recycled water for drinking water (EPA, 1998).

Recycled water is wastewater that has undergone a partial process of treatment and purification, and has obvious advantages and disadvantages. The advantages can be described briefly as follow:

- Low cost and water saving for socio-economic system

  Low cost of recycled water production is a major advantage compared to treating, processing and consuming "new" water. One of reasons is non-necessity of recycled water transportation for a long distance, putting less strain on infrastructure and public utilities. By reusing recycled water, water saving becomes a remarkable advantage compared to the water lost of other water resources through runoff or contamination. Recycled water is most commonly used for nonpotable (not for drinking) purposes, such as agriculture, landscape, public parks, and golf course irrigation (EPA, 1998). Other nonpotable applications include cooling water for power plants and oil refineries, industrial process water for such facilities as paper mills and carpet dyers, toilet flushing, dust control, construction activities, concrete mixing, and artificial lakes (EPA, 1998). Therefore, recycling water can also save drinking water for the public.

- Environmental protection and ecological restoration for eco-environmental system

  Water recycling can decrease the diversion of freshwater from sensitive ecosystems. The serious water shortage caused by demand and consumption of human living and production can lead to deterioration of water quality and ecosystem health. Recycled water as a reliable source can be reused in various fields, which can free considerable amounts of water for the environment and increase flows to vital ecosystems (Miller, 2006). "…*For streams that have been impaired or dried from water diversion, water flow can be augmented with recycled water to sustain and improve the aquatic and wildlife habitat. The impetus for water recycling comes not only from a water supply need, but also from a need to eliminate or decrease wastewater discharge to the ocean, an estuary, or a stream. Using recycled water for agricultural and landscape irrigation can provide an additional source of nutrients and lessen the need to apply synthetic fertilizers* (EPA, 1998)*"*. Therefore, it is also greatly helpful to protect hydro-environment and eco-environment.

However, a major disadvantage of recycled water is the potential health risk. "…*In the case of irrigating fields, the possibility of an outbreak of food-borne illness may be raised greatly. However, no documented cases of human health problems due to contact with recycled water that has been treated to standards, criteria, and regulations have been reported* (EPA, 1998)*"*.

6.1.3 Circular economy of water resources

I. Definition of Circular Economy

Circular Economy Law of the People's Republic of China has been adopted at the 4th Meeting of the Standing Committee of the 11th National People's Congress on August 29, 2008. In this law, circular economy (i.e. recycling economy) has been defined as "*…is a generic term for the reducing, reusing and recycling activities conducted in the process of production, circulation and consumption* (CEL, 2008)", and its aim is to boost sustainable development through energy saving, resource saving and reduction of pollutant discharges.

The economic model of water recycling refers to reconstruction of water recycling economy system based on the motion regularity of water circulation in the natural ecosystem, in order to get the social water circulation into the process of water circulation of natural ecosystem harmoniously and form a healthy social water cycle pattern. Its connotation is to build a society with water recycling economy pattern and achieve sustainable utilization of water resources. It is necessary to change the traditional linear economic model into "water resources - consumption - wastewater treatment - water recycling" economic system with reciprocating circulation.

II. 3R principles of water recycling economy

Water recycling economy is a part of the circular economy, thus it has to follow the 3R (reducing, reusing and recycling) principles that have been defined by Circular Economy Law (2008).

- *"Reducing refers to reducing the consumption of resources and the production of wastes in the process of production, circulation and consumption* (CEL, 2008)*".*
- *"Reusing refers to using wastes as products directly, using wastes after repair, renewal or reproduction or using part or all wastes as components of other products* (CEL, 2008)".
- *"Recycling refers to using wastes as raw materials directly or after regeneration* (CEL, 2008)".

Developing a circular economy is an important strategy for the economic and social development in China. "…*It requires making overall plans, making reasonable layouts, adjusting measures to local conditions and focusing on actual effect. The development of a circular economy shall be propelled by the government, led by the market, effected by enterprises and participated in by the public* (CEL, 2008)*".*

A concept of 3R principles in a sound material-cycle society may be described by a diagram (see Figure 6-5). "…*The development of a circular economy shall follow the principle of giving priority to reduction under the precondition of being technically feasible, economically rational and good for saving resources. In the process of reutilizing and recycling wastes, production safety shall be guaranteed so as to ensure that product quality satisfies the state standards and prevents secondary pollution* (CEL, 2008)*".*

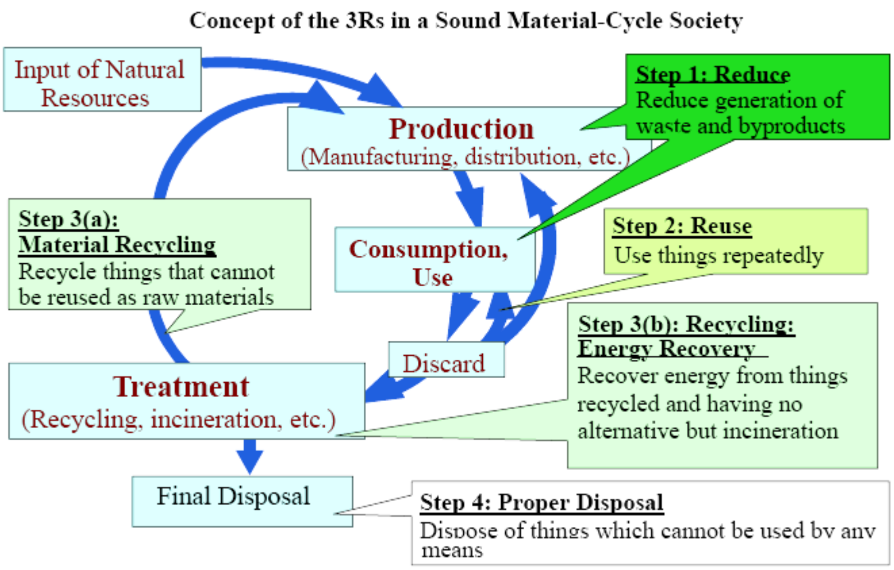

Figure 6-5: 3R principle in a sound material-cycle society

3R principles of water recycle economy in urban water cycle can be understood in a specific way:

- Through cleaner production, development of new technology and equipment of water saving, decreasing leakage, control of water demand, improving water use efficiency, etc., should reduce water consumption and wastewater pollution from the source with the reducing principle.
- Within the industrial and mining enterprises, schools, offices, hotels, residential districts, etc., should reuse preliminary recycled or reclaimed wastewater and collected rainwater, which belongs to a small recycling of urban wastewater.
- The effluent after advanced treatment of urban sewage treatment plant or rain water retained by harvesting projects are reclamation water that can be useful for industrial production, agricultural irrigation, urban greening, groundwater recharge, landscape water use, ecological water use, etc., which belongs to a large recycling of urban wastewater.

With the 3R principles, an important aspect of sustainable utilization of water resources is the recycling of treated wastewater. It should proceed from China's actual conditions and different levels of water cycle to develop and implement the water-recycling model. Through technical research and project analysis, this chapter describes the theory of water recycling, especially studies on wastewater recycling and its technique application in different water recycling scopes, which are the technique of small scope wastewater recycling for services, enterprises and institutions, as well as residential estate; the technique of large scope wastewater recycling for municipal wastewater treatment plant.

6.2 Technology application for small and large scale recycling of urban wastewater

6.2.1 Approach comparison

Urban water shortage is a major issue in process of Chinese urbanization, restricting urban development. At present, there are three main measures to be taken to solve this problem. They are seawater desalination, long-distance water transfer and wastewater recycling. Considering the actual conditions of China, they are compared for finding the optimum measure in Table 6-2.

Table 6-2: Feature comparison of seawater desalination, long distance water transfer and wastewater recycling

	Seawater desalination	**Long-distance water transfer**	**Wastewater recycling**
Condition of water resource	Coastline with 18x10^3 km; Abound seawater resources	Limited quantity of surface water; Maldistribution of water resources; Influencing ecosystem	Abound wastewater resource; Low efficiency of treatment; Stable Effluent
Suitable area	Coastal areas	Inland near river basins	Densely populated areas
Investment	Medium	High	Low
Construction period	Shorter	Long	short
Cost	Medium fixed asset cost; High operation cost	High fixed asset cost; Lower operation cost	Low fixed asset cost; Low operation cost
Recharge for eco-environment	---	Recharge for groundwater, agriculture, ecology, etc.	Recharge for groundwater, agriculture, ecology, etc.
Technical progress	Good developing scope; Great possibility of operating cost reduction	Small developing scope; Less possibility of operating cost reduction	Small developing scope; Less possibility of operating cost reduction
Application object	Direct potable water; Specially industrial water	Potable water; Municipal water ; Industrial water	Industrial cool water; Industrial water; Municipal non-potable water; Agricultural irrigation water

The approaches of seawater desalination and long-distance water transfer can provide additional sources to direct potable water, drinking water, municipal water and industrial water; however, project investment and operating costs are high. Additionally, the approach of seawater desalination is only suitable for coastal areas; unsuitable application and operation of the approach long-distance water transfer might cause ecological imbalance. Although recycled wastewater is only recognized as non-potable water instead of some industrial water, municipal water and irrigation water, wastewater recycling is adopted by many countries of world to be an important regeneration resource, because wastewater resources are abundant and stable, and project investment and operating costs are relevant low.

In order to mitigate urban water shortage and protect urban environment, the urban water governors, users and other stakeholders should pay more attention to following aspects:

- Scientific and rational allocation of water resources;
- Reasonable classification of water using according to category of water quality and quantity;
- Quality-divided water supply or dual water supply;
- Improvement of urban water use efficiency;
- Achievement of wastewater reclaimation and recycling.

6.2.2 Recycled wastewater for urban, industrial and agricultural reuse

I. *Urban reuse*

Wastewater as a renewable water resource is stable and reliable for the reuse. Full development and utilization of wastewater is one of important means of effective conservation, development and utilization of water resources to solve the critical problem of urban water shortage. Urban wastewater is a valuable resource for the cities facing severe water shortage crisis, and wastewater reuse may be a fundamental way of solving the issue of China's urban water shortage because of the sufficient amount of urban sewage, efficient collection, mature treatment technology, and affordable investment and costs.

According to the "*Guidelines for Water Reuse*" by U.S. EPA in 1992, urban reuse systems provide reclaimed water for various nonpotable purposes including:

- *Irrigation of public parks and recreation centers, athletic fields, school yards and playing fields, highway medians and shoulders, and landscaped areas surrounding public buildings and facilities* (EPA, 1992)
- *Irrigation of landscaped areas surrounding residential building, general wash down, and other maintenance activities* (EPA, 1992)
- *Irrigation of landscaped areas surrounding commercial, office, and industrial developments* (EPA, 1992)
- *Commercial uses such as vehicle washing facilities, laundry facilities, window washing, and mixing water for pesticides, herbicides, and liquid fertilizers* (EPA, 1992)
- *Ornamental landscape uses and decorative water features, such as fountains, reflecting pools, and waterfalls* (EPA, 1992)
- *Dust control and concrete production for construction projects* (EPA, 1992)

- *Fire protection through reclaimed water fire hydrants* (EPA, 1992)
- *Toilet and urinal flushing in commercial and industrial buildings* (EPA, 1992)

Urban reuse can include systems serving large users. Examples include parks, playgrounds, athletic fields, highway medians, and recreational facilities. In addition, reuse systems can supply major water-using industries or industrial complexes as well as a combination of residential, industrial, and commercial properties through "dual distribution systems" (EPA, 1998). Distribution system usually includes storage and pumping facilities, which with water reclamation facilities compose an urban water reuse system.

II. Industrial reuse

Due to water shortages, increased populations, and legislation regarding water conservation and environmental compliance, worldwide industrial reuse has increased substantially and has gained popularity. In China, the availability of reclaimed water to industries should be increased to meet such increased demand. Utility power plants are ideal facilities for reuse due to their large water requirements for cooling, ash sluicing, rad-waste dilution, and flue gas scrubber requirements. Petroleum refineries, chemical plants, and metal working facilities are among other industrial facilities benefiting from reclaimed water not only for cooling, but for process needs as well (EPA, 1992). According to the "*Guidelines for Water Reuse*" by U.S. EPA in 1992, industrial reuse can comprise three main aspects:

- *Cooling Water*

  For the majority of industries, cooling water is the largest use of reclaimed water because advancements in water treatment technologies have allowed industries to successfully use lesser quality waters. These advancements have enabled better control of deposits, corrosion, and biological problems often associated with the use of reclaimed water in a concentrated cooling water system (EPA, 1992).

- *Boiler Make-up Water*

  The use of reclaimed water for boiler make-up water differs little from the use of conventional public water supply; both require extensive additional treatment. Quality requirements for boiler make-up water depend on the pressure at which the boiler is operated. Generally, the higher the pressure, the higher the quality of water required (EPA, 1992).

- *Industrial Process Water*

  The suitability of reclaimed water for use in industrial processes depends on the particular use. For example, the electronics industry requires water of almost distilled quality for washing circuit boards and other electronic components. On the other hand, the tanning industry can use relatively low-quality water.

Requirements for textiles, pulp and paper, and metal fabricating are intermediate. Thus, in investigating the feasibility of industrial reuse with reclaimed water, potential users must be contacted to determine the specific requirements for their process water (EPA, 1992).

III. Agricultural Reuse

The significance of reusing reclaimed water for agricultural irrigation is unusually great. The fresh water shortage of agricultural irrigation in China has brought on a severe crisis of food production. In the past, recycled water used for agriculture has always been selected primarily. For now, agricultural reuse is still popular and widely applied in the world based on such reasons as huge water demands for agricultural irrigation, sound water conservation benefits, and ability to integrate agricultural reuse with other reuse applications.

"The chemical constituents in reclaimed water of concern for agricultural irrigation are salinity, sodium, trace elements, excessive chlorine residual, and nutrients. Sensitivity is generally a function of a given plant's tolerance to constituents encountered in the root zone or deposited on the foliage. Reclaimed water tends to have higher concentrations of these constituents than the groundwater or surface water sources from which the water supply is drawn (EPA, 1992)*"*.

As mentioned in the section 6.1.2, a major disadvantage of recycled water is the potential health risk. In the case of irrigating fields, the possibility of an outbreak of food-borne illness may be raised greatly. Therefore, besides quality requirements of reclaimed water, it is necessary to build sound supporting systems such as maintaining management and monitoring system.

6.2.3 MBR Technology for small scale recycling of urban wastewater

In a residential district as well as a hotel, a variety of wastewater and rainwater should be rationally collected as well as processed to achieve the required water quality standards, in order to reuse for the residential environment and miscellaneous water consumption. For different purposes, there are two approaches. One is to treat wastewater with drinking water (i.e. potable water) standards to be used directly back to daily life, that is the direct recycling of wastewater. This approach would be applied in areas where water resources are of extreme shortage, but high investment and complex process. Another is to treat wastewater with the non-drinking water (non-potable water) standards, and recycled water non-directly contacts with the human body in reusing process, such as toilet flushing, car cleaning, and green land irrigation.

Membrane Bioreactor (MBR) corresponding with the second approach will be taken as an example in this thesis.

Membrane Bioreactor system (see Figure 6-6) is the combination of membrane filtration technology with biological treatment for municipal, commercial and industrial wastewater treatment and water reuse applications. Due to increasingly stringent legislation and continuing advancement of membrane technology, MBR systems as an available technology of wastewater treatment are getting popular to be applied at an ever-increasing number of locations around the world.

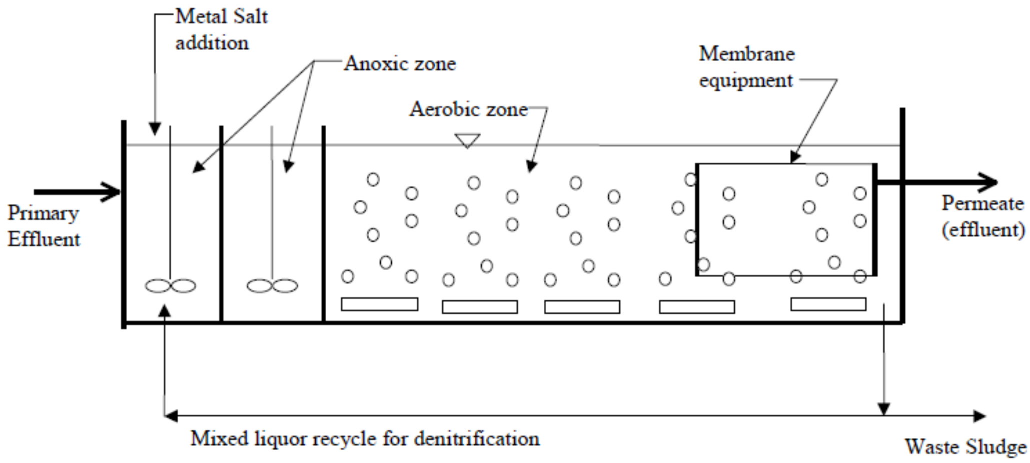

Figure 6-6: Typical schematic for membrane bioreactor system

Source: Stephen Chapman, Greg Leslie, Ian Law

MBR systems offer several operational and economic advantages over conventional Wastewater Treatment Plants (WWTPs), which include the following:

- less odor;
- high effluent quality;
- almost complete solids and bacteria removal;
- extremely compact footprints caused by modular design with good expandability;
- Strong capability of abirritation to shock loadings or peak and fluctuating flows;
- flexible and stable controlling due to separate control of sludge age or solids retention time (SRT) and hydraulic residence time (HRT);
- less sludge discharge due to long SRT
- simplified operation.

6.2.4 SBR technology for large scale recycling of urban wastewater

The large scale recycling of urban wastewater mostly relies on centralized WWTPs. Municipal wastewater treatment became one of the most important consideration aspects of water environmental protection in China. Since the 1990s, China's wastewater treatment industry developed various technologies and equipments. The wastewater treatment technology is the key factor if the wastewater facilities are expected to function efficient. For a long time, the wastewater treatment technology in China has adopted and followed the technologies, which has been prevailed in the western countries in last century. According to the National Technical Policy for Municipal Wastewater Treatment and Pollution Prevention (MEP, 2001), conventional activated sludge (CAS), anaerobic-aerobic activated sludge process (A/O), and anaerobic-anoxic-aerobic activated sludge process (A/A/O) are the priority processes recommended for large and medium-sized municipal wastewater treatment plants. Large amount investment has been put in the construction of wastewater treatment facilities. However, the treated water was rarely recycled in China, and even combined with untreated wastewater in some areas. Additionally, the treated water was usually discharged to the surface water without any cycling.

In the past, Chinese local governments often tended to pursue for popular and modern technologies to construction of urban WWTPs, instead of considering local individual situation. In some areas, the technology (e.g., A/A/O) that is efficient for N and P removal was applied, despite the fact that the treated wastewater was intended for agricultural irrigation, therefore the construction investment and operation cost were increased.

SBR will be taken as an example for large scale recycling of urban wastewater in this thesis. According to introduction of the "Onsite Wastewater Treatment Systems Manual Revised 2002" by U.S. EPA, the sequencing batch reactor (SBR) process is a sequential suspended growth (activated sludge) process in which all-major steps occur in the same tank in sequential order (see Figure 6-6). There are two major classifications of SBRs: the intermittent flow (IF) or "true batch reactor," which employs all the steps in figure 6-7, and the continuous flow (CF) system, which does not follow these steps. SBRs are very helpful to removal of nitrogen, phosphorus, and ammonia, in addition to removing TSS and BOD. The intermittent flow SBR accepts influent only at specified intervals and, in general, follows the five-step sequence, which have been described in the *Review on Sequencing Batch Reactors* by Wisaam, He and Wei in 2007.

- *Fill: the influent to the tank may be either raw wastewater (screened) or primary effluent. It may be either pumped in or allowed to flow in by gravity. The feed volume is determined based on a number of factors including desire loading and detention time and expected settling characteristics of organisms. The time of Fill* *depends on the volume of each tank, and the number of parallel tanks in operation. Once the reactor is full, the influent valve is closed and the influent is routed to the other (*Wisaam, 2007)*.*

- *React: biological reactions, which were initiated during Fill, are completed during React. As the basin is aerated, air is bubbled through the liquid. Biological oxidation takes place similar to the aeration basin in the conventional activated sludge process. The liquid level remains at the maximum throughout React and sludge wasting can take place during this period as a simple means for controlling the sludge age. By wasting during React, sludge is removed from the reactor as a means of maintaining or decreasing the volume of sludge in the reactor and decreases the solids volume. It behaves like a conventional activated sludge system, but without a continuous influent or effluent flow (*Wisaam, 2007)*.*
- *Settle: solids separation takes place under quiescent conditions (e.g., without inflow or outflow) in a tank, which may have a volume more than ten times that of the secondary clarifier used for conventional activated sludge plant. This major advantage in the clarification process results from the fact that the entire aeration tank serves as the clarifier during the period when no flow enters the tank. All of the biomass remains in the tank and some fraction must be wasted. On the contrast, mixed liquor is continuously removed from a traditional activated sludge aeration tank and passed through the clarifiers only to have a major portion of the sludge returned to the aeration tank (*Wisaam, 2007)*.*
- *Draw: the clear water is discharged and removed using a decant mechanism. The withdrawal mechanism may include a pipe just beneath the liquid surface. It should be designed to prevents floating matter from being discharged. The biomass settles, and the floating matter is removed (*Wisaam, 2007)*.*
- *Idle: the period between Draw and Fill is termed Idle. During this time, excess biomass is wasted and sludge is removed from the bottom of the basin using pumps. With SBR there is no need for return activated sludge pumps and also primary sludge pumps, like those associated with conventional activated sludge systems. At the end of the idle phase, the cycle begins again with the fill phase (*Wisaam, 2007)*.*

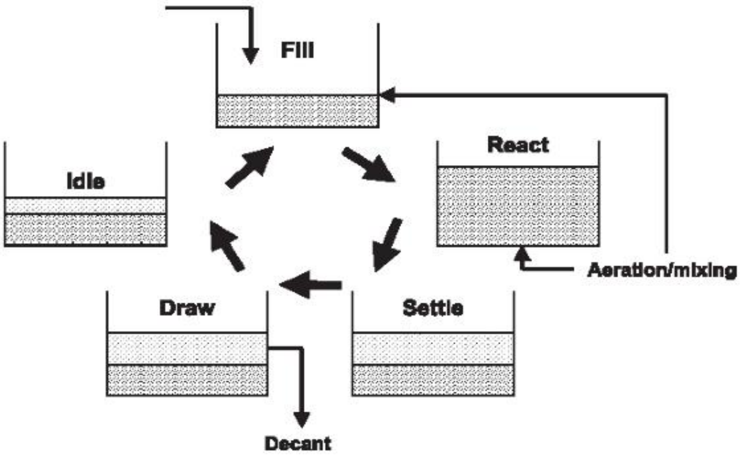

Figure 6-7: Sequencing batch reactor (SBR) design principle

Source: EPA 625/R-00/008

Advantages of SBR systems comparing with conventional process are as follow:

- Low installed cost
- Less equipment to service and maintain
- Less footprint for SBR treatment plants
- more capability of abirritation to the variational organic loading and shock loadings
- No requirement of chemicals for nutrient removal
- high-quality effluent with low nutrient level
- No requirement of clarifier
- Simple sludge process management
- Good applicability of SBR process for remodeling and reconstruction of conventional process
- Better control over filamentous growth and settling problems

6.3 Case study 1 – Wastewater treatment and recycling system of Da Jiu Dian Hotel

In the section 6.3 and 6.4, two case studies of wastewater treatment and recycling systems in Huludao City are introduced to SMSCs of China, in order to make a discussion that how to construct a sound wastewater recycling system adopted for a small or large scale water recycling. This will be conducive to enhancing entire level of water resources utilization and water environmental protection by water recycling and reusing.

6.3.1 City introduction

The following data were provided by Huludao Statistical Bureau on Jan. 7th, 2011 and by Huludao Environmental Protection Bureau on Jan. 14th, 2011 as well as by Huludao Construction Committee on Jan. 14th, 2011.

I. *Geographic characteristic*

As the first city outside the Shanhaiguan Pass, Huludao is located at Liaoxi Corridor by Bohai Sea and served as the west gate of Northeast China (see Fig. 6-8). Xingcheng City, Suizhong County, Jianchang County, Lianshan District, Longgang District, Nanpiao District are under the jurisdiction of Huludao. The east of the city is 315 km apart from Shenyang, the provincial capital city, and the west is 480 km apart from the Beijing, capital of China. The geography sits a mark 39°59'-41°12' at the northern latitudes, east longitude 119°12'-121°02'. Owning coastline 237 km and sharing 11.3% of province coastline length in Liaoning. The east-west breath of Huludao is 150 kilometers, and the south-north breadth is 130 km and the total area is 10,415 km^2.

II. *Social and economic factors*

The total population of Huludao City is 2.96 million up to 2007, including 0.86 million people in township. The central urban area consists of Longgang District and Lianshan District. Highways, railways, ocean shipping, air transportation and underground pipelines form the three-dimensional transportation network of Huludao City.

Over 30 kinds of underground mine resources, such as zinc, lead, molybdenum, have been discovered. Huludao is endowed with considerable petroleum reserves and natural gas resource under the sea near its coastline. With backbone industries of petrochemical processing, nonferrous metallurgy, shipbuilding, machinery and power generation, a complete industry configuration has been established.

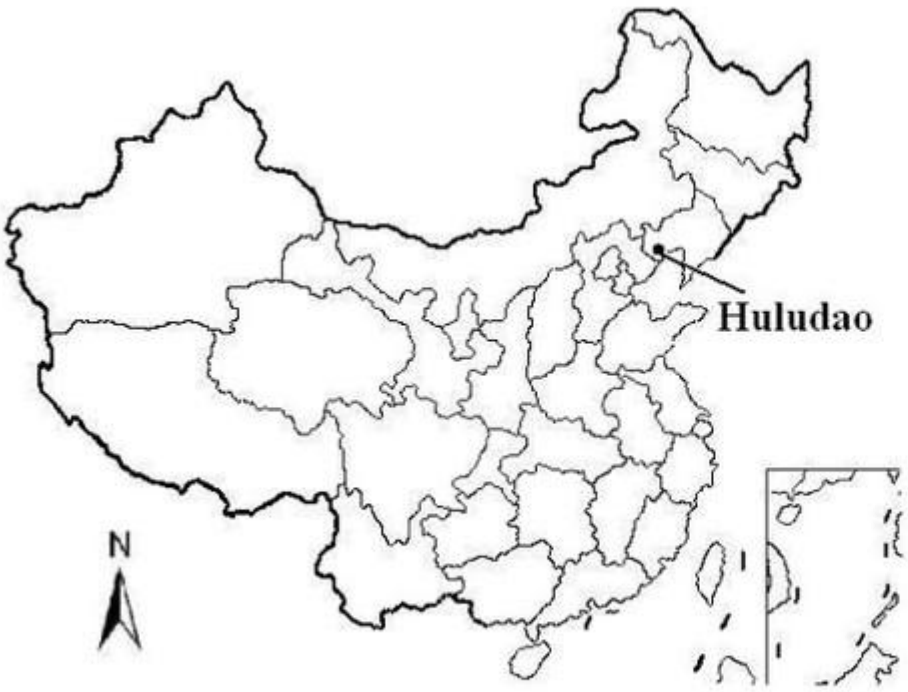

Figure 6-8: Location of Huludao City

Source: Guan et al., 2009

III. Weather characteristic

Huludao is located the middle latitude district and situated in the North Temperate Zone with a continental monsoon climate. With clearly seasonal characteristic in all year round, the spring is featured with great sandstorm, while the summer is quite hot with considerable rainfall. The autumn turns out to be cool, while the winter is dry cold. With great temperature difference, yearly average temperature is 9.8℃, the highest is 32.9℃ and the lowest is -22.8℃. The predominant wind direction is southwesterly, annual average wind velocity is 3.3m/s and the highest wind velocity is 17.7m/s. The typhoon season is from end July to middle September and general wind velocity is between 12 m/s and 21 m/s. Huludao's annual rainfall varies between 560 and 630 mm, of which over 60% occurs in July and August. The annual average evaporation rate is at 895 – 1160 mm.

IV. The water resources

The water resource of Huludao city is scarce. The total amount of the water resources is 2,060 Million m^3, 1,820 Million m^3 from surface water and 640 Million m^3 from ground water resources. There are three river systems, namely Daling River, Liugu River and Nueer River. The total drainage area is 5,608 km^2. In addition, there are eight rivers in Huludao City ended into sea. In the central city, three rivers are considered as receiving water of discharging treated wastewater:

- Lianshan River - length 33.9 km, drainage area 169.4 km^2, runoff 3,071*107 m^3/year;
- Wuli River (see Figure 6-9) - length 36.4 km, drainage area 139 km^2, runoff 2,52*107 m^3/year;
- Cishan River - length 20.2 km, drainage area 40.2 km^2, runoff 8.65*105 m^3/year.

The middle- and down-stream of these three rivers flow through the center urban area of Huludao City.

Figure 6-9: Wuli River in winter (16.01.2011)

6.3.2 Wastewater treatment and recycling system of Da Jiu Dian Hotel

Da Jiu Dian Hotel (DJD Hotel) is a three-star hotel with 150 guests rooms, located in business district of Huludao City Center. Before the latest renovation in 2004, the maximum discharge quantity of wastewater generated from shower equipments was 160m^3 per day, and this part of wastewater (grey water) after a treatment process was discharged into municipal sewer system directly. The demand of water for toilet flushing could reach the maximum amount of 60 m^3 per day, relying on the supply of urban tap water system. For this situation, to design and construct a wastewater treatment facility could treat wastewater to reach the standard of urban miscellaneous water consumption, and then reuse recycled water for toilet flushing, greening, car washing, and cooling water of air-condition. In this way, the wastewater treatment and recycling system of the hotel can bring economic and environmental benefits under the guidance of the principles of water recycling economy.

I. *Treatment process design*

The required capacity of a water recycling system is 60m^3/d; running time of self-priming pump should be 18 hours a day; the quality of treated water should reach

BOD_5≤10mg/L, COD_{cr}≤10mg/L, and SS≤10mg/L. Due to low value of COD_{cr} and BOD_5 of raw water (Table 6-3), the biological process combined with the physical process is suitably applied into the grew water recycling system for DJD Hotel. The process diagram is shown in the Figure 6-10.

Table 6-3: The quality of influent

	COD_{cr} (mg/L)	BOD_5 (mg/L)	SS (mg/L)
Concentration	≤ 100	≤ 50	≤ 150

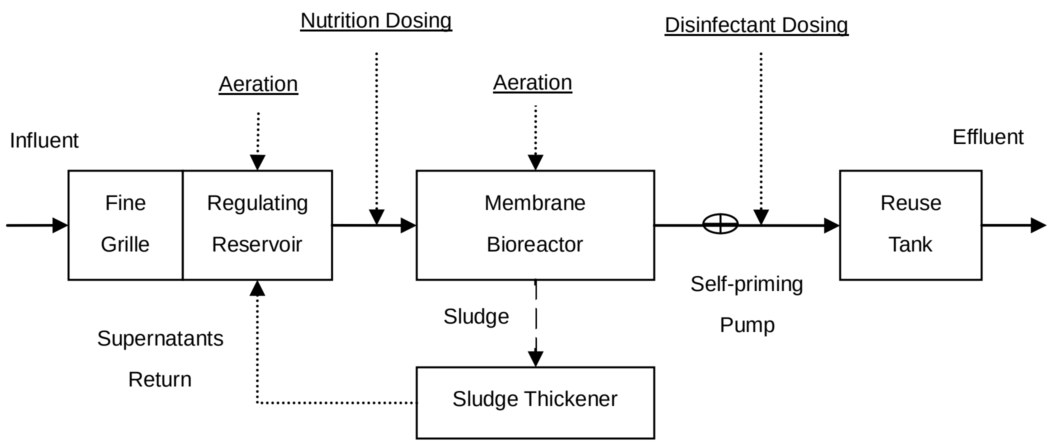

Figure 6-10: The diagram of biophysical process

In the primary phase, the grille removals large solid impurities, preventing the clogging of pump and ultrafiltration membrane. The regulating reservoir (Table 6-4) regulates quality and quantity of grey water, so that the subsequent processing equipments will be working in the relatively stable conditions. The functions of aeration blowers are aeration, deodorization, and cooling.

In the next phase, grey water will be treated through composite process of biodegradation and physical filtration in the MBR (Table 6-4). Aerobic microbial metabolism can decompose organic matter. The installation of hollow fiber membrane was placed in the MBR, grey water submerged the membrane module by the pump suction, and liquid-solid separation materialized through the performance of negative pressure suction of the membrane. The filter hole diameter of hollow fiber membrane is 0.4μm, which can effectively obstruct the suspended solids, colloids, bacteria, etc., and make the effluent quality reliable and stable.

Dissolved oxygen (necessary for microbial growth) can be supplied by aeration of blowers. Additionally, rising bubbles and resulting turbulent flow can clean the surface of membrane to prevent sludge accumulation and maintain stable passing capacity of membrane. The sludge generated in MBR can be transferred into the sludge-thickening tank (sludge thickener) by the pumps, in which the sludge will be concentrated, and then the supernatants flow back into the regulating reservoir.

Because the values of COD_{cr} and BOD_5 in raw water are relatively low, nutrition dosing could be operated in accordance with specific conditions to maintenance the growth of organisms in the MBR. After above treatment processes, water also contains many harmful bacteria. It is necessary to dose disinfectant into water by a dosing system destroy, in order to destroy most bacteria. Additionally, the disinfection capability of residual chlorine in water can also ensure that the water in the recycling process does not be re-contaminated with bacteria.

Table 6-4: Main parameters of construction of Regulating Reservoir and MBR

	Useful Depth	Useful Capacity	Hydraulic Retention Time (HRT)
Regulating Reservoir	2.5m	48.7m^3	19.5h
MBR	2.7m	34.7m^3	14h

II. ***Operating performance***

After the accomplishment of renovation in 2004, the water treatment and recycling system at the hotel covers 42m^2 and formally put into operation. COD_{cr} and BOD_5 of average effluent quality are about 10mg/L and 1.0mg/L or less, and the effluent quality (Table 6-5) is better than the treated water quality required by design. Therefore, the effluent from this wastewater treatment and recycling system at the DJD Hotel can be used as reclaimed water for non-potable domestic or industrial water use.

Table 6-5: Analysis of effluent quality of MBR system for first three months

	COD_{cr} (mg/L)	BOD_5 (mg/L)	SS (mg/L)
Minimum value	7.84	0.67	0
Maximum value	3.92	0.45	0
Advantage value	6.16	0.57	0

III. ***Cost analysis of water treatment and recycling system at DJD Hotel***

There is no sludge return system. The energy consumption of the system mainly came from the transferring pump, self-priming pump and blower. The installed capacity of blower is 1.5 kW, operating 24 hours; transferring pump and self-priming pump are with the installed capacities of 0.4 kW and 0.75 kW, a daily total running time by 18 hours. The unit energy consumption is 0.945 kW · h/m^3. In addition, this unattended system can reduce the labor costs. The total operating cost per cubic meter is 1.665 Yuan. The analysis on it is shown in Table 6-6.

Table 6-6: Information of the system operating cost

Item	Quota	Price per unit	Operating expense (Yuan/m^3)
Electricity	0.95 kW.h/m^3	0.6 Yuan/ kW.h	0.57
Depreciation			1.052
Disinfectant	3 g/m^3	12 /kg	0.036
Nutrient Solution	3.5 g/m^3	2 /kg	0.007
Operating Cost			1.665

6.2.3 Conclusion analysis on the case study 1

The wastewater reuse project of DJD Hotel adopted Membrane Bioreactor (MBR) technology. Since October 2004, it has been put into operation with satisfied performance. The effluent quality from this system is outstanding to fully meet the China’s "Water Quality Standard for Urban Miscellaneous Water Consumption" (GB/T 18920-2002). The operating cost of this system is 1.665 Yuan / m^3. This MBR system is operating with high efficiency of pollutants removal, stable effluent quality, and simple management. Therefore, the model of MBR system with remarkably economic and environmental benefits can be used for small scale recycling of urban wastewater, such as hotels, office buildings, and resorts.

6.4 Case study 2 - Wastewater treatment and recycling system in Huludao City

Before 1996, there was no any municipal wastewater treatment plant in Huludao City (UPB - Huludao Urban Planning Bureau, 1996). In order to mitigate the negative environment impact caused by fast growing population and urbanization, it was necessary to set up a municipal Wastewater Management System at that time. According to the Overall Planning of Huludao City (1996–2020), which was released by Huludao Urban Planning Bureau in 1996, two municipal wastewater treatment and recycling plants and related pipeline systems were built up in central city of Huludao during the 5 years from 1999 to 2004. This case study is focused on the building, operation and management of the New District Wastewater Treatment Plant, as well as introduces SBR technology to construction of large scale recycling of urban wastewater.

6.4.1 Water-related infrastructure and water pollution of Huludao

I. *Water supply in central city*

In 1998, the domestic water consumption norm of the central city was about 90 - 100 L/cap.d (HSB, 2008). The total population about 350,000 and 98% of total residents would be supplied with drinking water (HSB, 2008). Up to now, Huludao belongs to water shortage region. The water supply is depended largely on surface water (artificial reservoir) for the consumption of household, municipality and industry (HEPB, 2008). Table 6-7 presents the general situation of water consumption of Huludao City in 1998.

Table 6-7: The general situation of water consumption in central city of Huludao in 1998

	Domestic Water Consumption in Urban Community ($10^3m^3/d$)	Domestic Water Consumption in Industrial Zone ($10^3m^3/d$)	Process Water Consumption ($10^3m^3/d$)	Account ($10^3m^3/d$)	Total Account ($10^3m^3/d$)
Lianshan District and Longgang District	47.1	20.9	219	287	297
Longwan New District	7	0. 8	2.2	10	

Data Source: Huludao Environmental Protection Bureau, 2008

Note: 1. the data is based on the average daily coefficient. 2. The data does not include the water consumption at military post.

According to the Overall Planning of Huludao City, domestic water consumption norm by the year 2020 could be reached 150 L/cap.d (see Table 6-8).

Table 6-8: The quantitative forecast of maximum water use availability in central city by the year 2020

	Water consumption (m^3/d)	Remark
Domestic Water	97 500	- Population forecast: 650000 - Domestic water consumption norm: 150 L/cap.d
Industrial Process Water	325 958	- Industrial estate: 1917 h - Process water consumption norm: 170 m^3/h.d
Public Building	29 250	30% of domestic water
Fire Demand	1 728	
Street Flushing Demand and Green Plot Sprinkling	10 000	
Unforeseen Demand and Leakage	92 890	20% above-mentioned data
Total	557 326	≈ 560 000 m^3/d

Data Source: Huludao Environmental Protection Bureau, 2008

II. The drainage system and the discharge sites

The drainage system of Old District (namely Lianshan District and most of Longgang District) is combined system, which rainwater and wastewater are collected together. In addition to a few newly constructed areas, the rest in Longwan New District (namely part of Longgang District) has already set up to drain piping all for the confluence system. The diameter of pipeline is Φ300 mm – Φ500 mm, average slope 1.5‰ – 7.0‰, and the wastewater was discharged into the receiving water (namely Lianshan River, Wuli River and Cishan River), finally flow to Lianshan Gulf. In the Old District, along the Wuli River, the interception pipelines have already been set up, in order to discharge the contaminated wastewater that was discharged from industry factories in the upper flow. The municipal wastewater in the New District has been directly discharged to the surface water without any treatment.

The geography of old city area is northwest high and southeast low. The average slope is 1%. The Lianshan District is locates at the north side of old city area, and Wuli River flows through it. The combined pipeline systems were set up inside the area based on the agreeable geography. The rainwater and wastewater were discharged into two rivers nearby.

Along the south shore of Lianshan River, there are 10 discharge sites totally (8 from municipal wastewater and 2 from industrial wastewater − Cement Factory and Refrigeration Factory). Along the Wuli River, there are 13 discharge sites totally (12 from municipal wastewater and 1 from industrial wastewater – congealed water from the Hospital). The Cishan River flow through the Longwan New District, the wastewater generated from the new district has been discharged into Cishan River. Along the Cishan River, there are 14 wastewater discharge sites (include wastewater discharge from the Heat & Power Plant of north side of railway, and from the 313th hospitals in the south area, as well as from International Hotel etc.). The wastewater flow and quality in discharge sites could be shown Table 6-9.

Table 6-9: The wastewater flow and quality of Lianshan, Wuli and Cishan River

River	Amount of discharge sites		Wastewater flow (m^3/d)	COD_{cr} (mg/l)	SS (mg/l)	NH_3-N (mg/l)	TP (mg/l)
	Municipal	Industrial					
Lianshan	8	2	37701	179.9	99.25	22.5	1.6
Wuli	12	1	24633	161.5	86.2	23.13	1.2
Cishan	12	2	25517	125	86.6	17.4	1.83

Data Source: Huludao Environmental Protection Bureau, 2008

The most of drainage pipe networks are combined systems and small parts are separating systems. The wastewater discharging occurred along riverbanks, and the output points are numerous. However, the diameter of pipelines is usually small, and wastewater was always blocked especially during flooding. The river in the old city area has been heavily polluted since the wastewater was directly discharged into the river without any treatment. In particular, the capacity of river’s self-purification is weak during drought in summer. Therefore, the problem of river pollution has been deteriorated.

Due to direct discharging of wastewater into the river, the quality of water in the bath field of south seashore has also been heavily polluted. It directly influenced the hygiene condition of surroundings and the exploration of local tourisms.

III. Circumstance of water pollution in center city area

There was none wastewater treatment plant in the city before accomplishment of this project. The wastewater from household would be without any treatment directly discharged into Lianshan River, Wuli River and Cishan River, and ended into the gulf of Lianshan, which was heavily polluted by the wastewater contamination. Since red tides have already taken place for many times near the offshore, algae bred in great quantities, which serious influenced fish existence, and influenced mankind's health through the food chain.

There are more than 47 business enterprise in central city (HEPB, 2008), among them, the Huludao Petrochemical Processing Factory, Huludao Zinc Plant, Huludao Chemical Factory are the large business enterprise that contribute to the largest amount of wastewater. The reduction of wastewater discharge could be realized through several strategies, e.g., improvement of production technique, extending of construction of wastewater processing facilities, and increasing of wastewater recycling rate. Along the Wuli River, interceptor sewer systems have been set up, in order to lead the wastewater from upper stream (mainly from the Petrochemical Processing Factory and the Chemical Factory) to be discharged into downstream. The current situation of wastewater discharge from five largest industrial enterprises in Huludao City is presented in Table 6-10 and Figure 6-11.

According to the characteristics of the industrial wastewater, the wastewater generated from the Petrochemical Processing Factory, the Chemical Factory and the Zinc Plant have been handled separately. This project did not include the wastewater processing of the above-mentioned business enterprise.

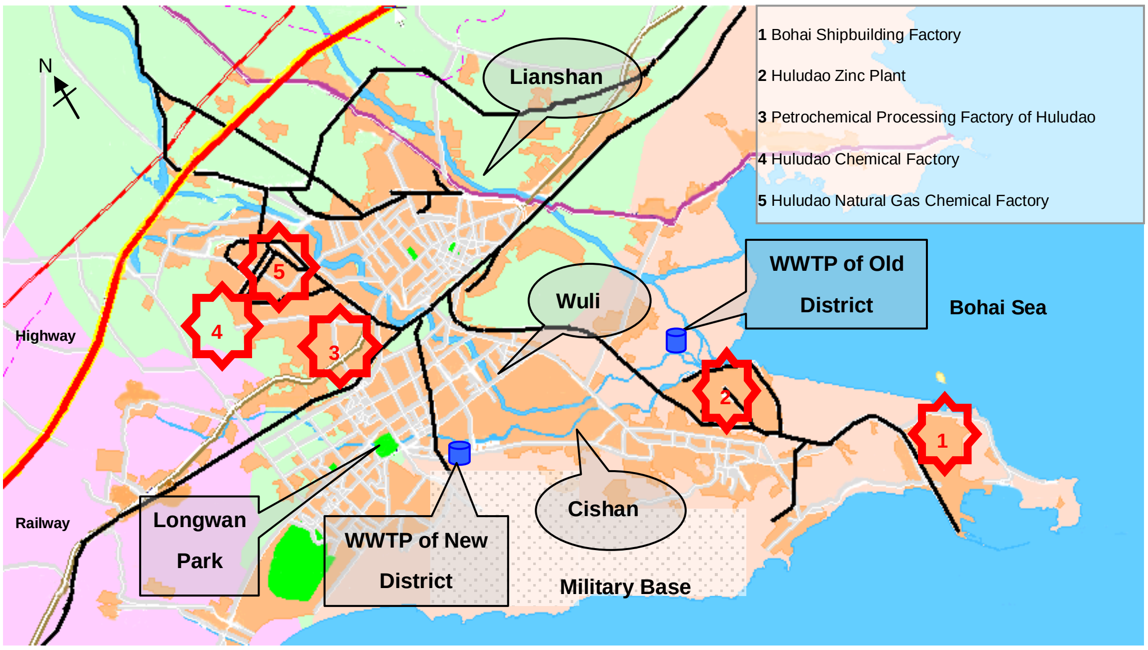

Figure 6-11: The schematic of Huludao City

According to Overall Planning of Huludao City, and the reference to the wastewater discharge situation in Tangshan City, in central city the domestic wastewater accounts for 85% of the waste water; the wastewater drainage from public building and municipal construction accounts for 40% the domestic water; the unforeseen demand accounts for 20% the wastewater drainage; the sewer connection rate will reach 65% - 95% by the year 2010 and 100% by 2020; the daily variation coefficient of domestic water is 1.20. The Table 6-11 shows the result of wastewater drainage forecasting.

Table 6-10: The pollution investigation of 5 industrial enterprises in 1998

	Petroleum Contents (mg/l)	Volatile Phenols (mg/l)	COD (mg/l)	SS (mg/l)	Hg (mg/l)	Cd (mg/l)	Pb (mg/l)	Cu (mg/l)	Zn (mg/l)	AS (mg/l)	NH_4-N (mg/l)	SO_2 (mg/Ndm^3)	Smoker (mg/Ndm^3)
Huludao Petrochemical Processing Factory	33.0	15.2	5.30	96.0								20.4	1164.5
Huludao Chemical Factory	4.9	18.8	1146	338	0.0401							586	1410
Huludao Zinc Plant		8.42	520		0.3777	12.12	5.34	1.29	152	16.01		1127	1644
Huludao Natural Gas Chemical Factory			227								616		
Bohai Shipbuilding Factory	1.24		76.84	50.38				0.27	0.69				

Data Source: Huludao Environmental Protection Bureau, 2008

Table 6-11: The forecasting of wastewater drainage by the years 2010 and 2020

		2010		2020		Remark
		Old District	New District	Old District	New District	
A	Population prediction	400 000	100 000	500 000	150 000	
B	Domestic water consumption norm	150	150	150	150	(L/cap.d)
C	Daily variation coefficient of domestic water	1.20	1.20	1.20	1.20	
D	Generation rate of domestic wastewater	85	85	85	85	(%)
E	Domestic wastewater	42 500	10 600	53 100	15 900	(m^3/d) average daily
F	Wastewater drainage of public building and municipal construction	17 000	4 300	21 200	6 400	(m^3/d) 40% of E
G	Industrial wastewater	34 000	4 000	42 000	6 000	(m^3/d)
H	Unforeseen demand	18 700	3 800	23 300	5 500	(m^3/d) 20% of E+F+G
I	Sewer connection rate	65	95	100	100	(%)
J	Subtotal	73 000	25 600	139 600	32 800	(m^3/d) (E+F+G+H)*I
K	Total	98 600		172 400		(m^3/d)

Data Source: Huludao Statistic Bureau, 2008

6.4.2 The project design of wastewater treatment system

The project was denominated The Wastewater Treatment Project of Huludao City, Liaoning Province. According to the Overall Planning of Huludao City (1996 - 2020) (HUPB, 1996) and the wastewater disposal planning of Huludao City, the center area of city was main objective region, including the Old District and New District area. This project includes the injection of pipeline system and wastewater treatment plants in both old and new area (see Fig. 6-10), including the pump stations. Wastewater and rainwater collection, treatment, and discharge of some large-scale industrial enterprises in city center were not included in this project.

I. *The objective and principle of the project*

With the political reform and the industrial development, the fast growing rate of urbanization and increasing population, the wastewater production had increased dramatically, especially in 1990s in the New District of Huludao City. As the wastewater treatment infrastructure had not been constructed simultaneously with the fast city development, the surface water and the adjacent inshore had been polluted heavily and the environmental quality was deteriorating. The agricultural ecosystem and the inshore marine had also been influenced severely. The data of water quality of Cishan River and Lianshan Gulf in 1998 are presented in Table 6-12 and 6-13. From the tables we can see, there was great distance between the surface water quality of Cishan River and the state standard of surface water Ⅳ, especially during drought, the quality of Cishan River deteriorated seriously. Also, the surface water quality of Lianshan Gulf could not reach the state standard Ⅱ.

Table 6-12: The quality of Cishan River during drought in 1998

	COD_{cr} (mg/l)	BOD (mg/l)	NH_3-N (mg/l)	T-P (mg/l)	SS (mg/l)	Mineral Oil (mg/l)	Linear Alklybezene Sulfonates (LAS) (mg/l)
Monitoring Point under **Longwan** Bridge	118.87	53.49	15.93	1.54	95.63	1.25	1.33
Monitoring Point under **Qitun** Bridge	172.53	77.64	21.18	2.38	103.90	14.01	1.75

Data Source: Huludao Environmental Protection Bureau, 2008

With the fast development of the economy in Bohai Sea, the wastewater from peripheral cities had been directly discharged into Bohai Sea without any treatment. It was reported at that more than 2.780 Billion tons wastewater would be discharged into Bohai Sea every year including 700,000 tons of pollutants (HEPB, 2008). The oil, phosphorus and nitrogen discharged into the Bohai Sea had an increasing growth trend in 1990s. Additionally, red tide occurred frequently. In the summer of 1998, a red tide took place 5,855 km^2 in the Bohai Sea that caused directly economic lose of 250 million RMB (HEPB, 2008).

In order to protect surface water, alleviate the pollution from red tide, and improve the investment environment in local region and promote sustainable development, according to “The decision relating environmental protection” (State Council, 1996), “The regulation of construction of wastewater treatment infrastructure in fast developing cities” (MC and MEP, 1991), “Blue Sea Action Program in Bohai Sea” (MEP, 2001), the construction of city wastewater treatment infrastructure is imperative to control the contamination of Lianshan Gulf and inner shore.

Table 6-13: The Monitoring Data of Monitor Points from No.1 to No. 10 in 24. 05. 1998

	COD (mg/l)	Petroleum Contents (mg/l)	Volatile Phenols (mg/l)	Hg (mg/l)	Zn (mg/l)	Ni (mg/l)	Pb (mg/l)	Active Phosphorus Contents (mg/l)	Nitrate-Nitrogen (mg/l)
Monitor Point No.1	6.01	0.41	0.0045	0.0016	0.241	0.054	0.016	/	/
Monitor Point No.2	7.90	0.55	0.0045	0.0025	0.016	0.016	0.017	/	/
Monitor Point No.3	5.54	0.37	0.002	0.0003	0.004	0.004	0.003	/	/
Monitor Point No.4	5.21	0.30	0.001	0.0003	0.002	0.002	0.002	/	/
Monitor Point No.5	4.50	0.26	0.001	0.0002	0.003	0.003	0.001	/	/
Monitor Point No.6	6.25	0.43	0.002	0.0008	0.011	0.010	0.010	/	/
Monitor Point No.7	5.77	0.38	/	0.0011	0.020	0.004	0.004	/	/
Monitor Point No.8	4.87	0.30	0.002	0.0011	0.482	/	0.003	0.007	0.016
Monitor Point No.9	6.70	0.47	/	0.0044	0.143	0.014	0.008	/	/
Monitor Point No.10	6.22	0.38	/	0.0003	0.044	0.002	0.005	/	/

Data Source: Huludao Environmental Protection Bureau, 2008

The objectives of the project are as follow:

- Social economic objective: enhance comprehensive city's competitive competence, strengthen the construction of city infrastructure, reinforce public facilities, improve residents' living environment, the business investment environment, and promote sustainable development.
- Environment objective: protect the local surface water environment, control wastewater pollution and contamination (especially N, P), support ocean ecosystem balance.
- Construction objective: construct the cost-effective wastewater plant with good function, advanced technique and satisfactory effluent performance.

The principles of design and planning are as follow:

- Strictly carry out relevant laws concerning the water environmental protection and water pollution as well as wastewater discharge of nation and Liaoning Province. According to the environment function request, strictly control with management of wastewater treatment and prevent water pollution.
- Under the instruction and management of the *Overall Planning of Huludao City*, guarantee the engineering construction compatible with city development, and protect environment as well as achieve operation performance.
- Adopt advanced, reliable, efficient, and economical wastewater and sludge treatment process with low energy consumption, in order to ensure good performance of wastewater effluent, reduce the investment and operation cost.
- Appropriately handle the generated trash and sludge in the wastewater treatment process and avoid secondary pollutions.
- Choose advanced, reliable, and efficient as well as maintenance-easy wastewater treatment facilities with low energy-consumption and operation- cost.
- Adopt reliable and safe control system.
- Adopt advanced technological design in the consideration of the future development trend and system upgrading.

II. Sewer system

A. Drainage system

There are 3 main rivers in the center city (Lianshan District, Longgang District and Longwan New District). According to the geography alignment, the distribution of rivers and administration areas, four discharge areas could be classified based on the City Wastewater Disposal Planning (HCC, 2008):

- Taking Beijing-Shenyang railway as boundary, the Old District of Lianshan is as the first discharge area (DA Ⅰ);

- The second discharge area (DA Ⅱ) is limited to the east of Shenshan railway, the south of Lianshan River and the north of Wuli River;
- The new area of Longwan is as the third discharge area (DA Ⅲ);
- The rest area of Longgang is as the fourth area (DA Ⅳ).

Due to the geographic reason, the Bohai Shipbuilding Factory is not included in the city wastewater discharge system. The pipeline systems would be set up based on its own feature.

Before the construction of the new wastewater treatment system, along the three rivers most enterprises had established or would establish wastewater treatment facilities. Near the bank of Wuli River, two interception pipeline systems had been set up, in order to lead most of industrial wastewater to the downstream of Wuli River (HCC, 2008). Thus the municipal wastewater treatment systems mainly focus on rainwater, household wastewater and some parts of industrial wastewater.

How to make full use of an original pipe networks, make use of the construction funds effectively, and smoothly convert from combined pipeline system to separating system are the key consideration of this project. Based on similar experiences from other cities (e.g., Anshan City, Fushun City), the wastewater discharge system in the New District area could be determined as follows:

- In short-term, the separating pipeline system, which is used to separate rainwater and wastewater, should be established in the New District area. For the existing pipeline system, additionally new interception pipelines would be set up.
- In long-term, the construction of complete separating system is the ultimate goal. The previous combined system would be used to transport only wastewater. The new sewage systems will be set up for rainwater transportation. During the conversion from combined system to separating system, the previously existing combined system should be further used in order to reduce waste (HCC, 2008).

Interception combined system is an alternative for the transition. Along the riverbank, additional interceptor sewers could be laid and intercepting wells would be set up near the sewer for overflow of rainwater. During dry seasons, the wastewater will be transported to the wastewater treatment plant through newly interceptor sewer; during wet weather, some amount of rainwater and complete wastewater will be transported to the wastewater treatment plant through newly interceptor sewer, and the rest rainwater will flow into intercepting well and finally flow to the river. Therefore, the cost for the construction of infrastructure in short-term could be reduced. And this method is suitable for the modification of previous combined system. Similar successful examples are Anshan City and Fushun City.

B. Pipeline layout

Along the river, the interceptor sewers were set up at the previous discharge point using combined systems. And at the crossing point, an intercepting well was set up for rainwater overflow. The interceptor sewers of Lianshan River were set up along the southern bank, and the interceptor sewers of Wuli River and Cishan River were set up along the northern and southern bank.

The rainwater and wastewater from interceptor sewers of Lianshan and Wuli are transported to the treatment plants in the Old District area; and the rainwater and wastewater from interceptor sewers of Cishan are transported to the treatment plants in the New District area. The interceptor sewer systems of three rivers (Lianshan River, Wuli River, and Cishan River) transport wastewater and rainwater in short-term, and will only separate wastewater in long-term (Wang, 2008).

- The pipeline systems of the first and third discharge area are combined systems. In order to separate rainwater and wastewater in long-term, rainwater pipeline systems will be set up.
- The pipeline system of the second discharge area is in the new city area and easy to separate rainwater and wastewater. The pipelines connect to the interceptor sewer systems.
- The pipeline systems of the fourth discharge area are complicated. The northern and southwestern are separated systems, and pipeline system were set up near the interceptor sewer systems. The southern are combined systems, and wastewater and rainwater will be separated in long-term. Thus, rainwater pipelines need to be set up according to the planning.

The engineering information about construction of the pipeline system could be seen from Table 6-14, 6-15 and 6-16.

Table 6-14: The quantity bill of interceptor sewer

Site of Interceptor Sewer	Average Pipe Diameter (mm)	Length of Pipeline (km)	Average Gradient (‰)	Burying Depth (m)
South Bank of Lianshan River	600 - 1000	6.0	1.1	3.0 – 4.0
North Bank of Wuli River	600 - 1000	8.0	1.2	3.0 – 4.0
South Bank of Wuli River	600 - 800	6.0	1.3	2.5 – 3.5
North Bank of Cishan River	600	2.5	0.9	2.5 – 3.0
South Bank of Cishan River	600	4.0	1.5	2.5 – 3.5

Data Source: Huludao Construction Committee, 2008

Table 6-15: The quantity bill of trunk sewer

Discharge Area	Average Pipe Diameter (mm)	Length of Pipeline (km)	Average Gradient (‰)	Burying Depth (m)	Term of Construction
I	450 - 600	3.0	1.8	2.0 – 3.0	Short-term
II	600 - 800	5.0	1.5	3.0 – 3.5	Short-term
III	450 - 600	6.0	1.8	2.5 – 3.0	Short-term
IV	600 - 800	4.0	1.5	3.0 – 3.5	Short-term

Data Source: Huludao Construction Committee, 2008

Table 6-16: The quantity bill of pumping station

	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Pump Capacity ($Q=m^3/s$)	0.35	0.20	0.40	0.55	0.20	0.65	0.33	0.30
Pump Head (H=m)	4 - 5	4 - 5	4 - 5	4 - 6	4 - 5	4 - 5	4 - 5	4 - 5
Term of Construction	Short-term	Short-term	Short-term	Short-term	Short-term	Short-term	Short-term	Short-term

Data Source: Huludao Construction Committee, 2008

The water resource of Huludao City is scarce. The Cishan River that flows through Longwan New District is a seasonal river (HEPB, 2008). Its average runoff is only 8.65 million m^3 per year and belongs to the smallest one among the three rivers. The constructed Longwan Park serves as a dam of the downstream of Cishan River, in order to increase the water level of the upper stream of Cishan River. The new pipeline systems and plants should consider the environment of Cishan River, in order to reach Standard V before 2010 and Standard IV after 2010 (HEPB, 2008).

III. The location and scales of treatment plants

According to the planning and site-survey, there were two proposals for the project (HUPB, 1996):

Proposal 1: set up one treatment plant that is located near the discharge point of downstream of Wuli River. It is used to treat wastewater from both old and new city areas. After treatment, wastewater will be discharge into Wuli River.

Proposal 2: set up two treatment plants. In the Old District, the treatment plant is located near the discharge point of downstream of Wuli River, and is aimed to treat wastewater from old city area. In the Longwan New District, the treatment plant is located near the downstream of Cishan River, and is aimed to treat wastewater from new city area. After treatment, wastewater will be discharge into Wuli River and Cishan River.

According to the construction principles that have been indicated by municipal government, and considering the Overall Planning of Huludao City, the Proposal 2 has been selected. There are several merits (Edition based on personal communication with Wang Guowu, who is the Director of Huludao Wastewater Treatment Co., Ltd.):

- It is compatible with The Overall Planning of Wastewater Treatment System in Huludao.
- The location is in low hypsography and in downstream of Cishan River. Thus it is easy for the pipeline layout and to minimize the total length of pipeline.
- According to the Overall Planning, large green belt is located the surroundings and it is far way from center settlement of New District. Thus, the negative environmental impact could be reduced to minimum.
- Comparing with Scenario 1, the total length of pipeline from newly constructed plant (in new district) to old treatment plant (in old district) is diminished. On the way of downstream of newly constructed plant, there are petrochemical plant, chemical Factory and Zinc plant. According to the requirement of Environmental Protection Department in Huludao city, all of the industrial wastewater from those plants should be treated in their own enterprises and discharged separately. In

another words, industrial wastewater will not flow into domestic wastewater pipeline system. Therefore, through adopting scenario 2, the treatment cost is reduced, energy consumption is deducted and raw material for pipeline construction is saved.

- The layout, which enables one treatment plant located in the New District and another one located in old district, is in accord with the principle of “overall planning and gradual implementation” made by the City Municipal Construction Department.
- There are several industrial plant surrounded by the treatment plant in new district, e.g., Electronic Equipment Factory, Zinc Plant and so on. The wastewater from secondary treatment processes could be recycled and reused in the production generation processes in various industrial plants, e.g., as cooling water for the equipment of electricity generation, as water supply for boilers. Thus, recycling treated wastewater could bring economical and environmental benefits.
- The water quality in middle- and downstream of Cishan River could be largely improved, and it could become one of recreational sight rivers.

In order to provide water for landscaping in Longwan Park, the following two proposals were to be compared for the decision of the site of plant in the New District:

Proposal 1: The wastewater from the new city area will be transported to the treatment plant located in the New District. After treatment, the reclaimed water transported to Longwan Park for landscaping.

Proposal 2: Two small treatment plants will be set up both in Caotun and the Radio & TV University of Huludao. The treated wastewater will be transported to Longwan Park, in which a small constructed wetland will be built up for the further treatment of wastewater. After treatment, the wastewater will be used for landscaping in Longwan Park.

After comparison of the above-mentioned two proposals, Proposal 2 was selected and it was based upon following reasons:

- The treatment plant in the New District is 2 kilometers away from Longwan Park. In case of Proposal 1, the transport of wastewater will be used 140 kWh/day of electricity due to the pump station, according to the treatment capacity 5 000 m^3/day and 8 working hours. Thus, the operation fee is expensive.
- If two small treatment plants will be established in both Caotun and the Radio & TV University of Huludao, and treated wastewater will be used as landscaping for Longwan Park, the operating cost is low. The two treatment plants could be built underground, so that the investment and land requirement are low. The treated

water from two plants will be transported to the constructed wetland for further treatment.

- The adoption of Proposal 2 could reduce the burying depth and the length of pipeline, as well as the energy consumption of pump station.

The construction of the wastewater treatment plants could be accomplished in short- and long-term (see Table 6-17).

Table 6-17: The target-planned period of the wastewater treatment plans

	Wastewater Treatment Plant of Old District	Wastewater Treatment Plant of New District	Wastewater Treatment Station of Caotun	Wastewater Treatment Station of Radio & TV University
Short-term 1999 - 2010	70 000 m^3/d	30 000 m^3/d	2 400 m^3/d	1 200 m^3/d
Lang-term 2011 - 2020	140 000 m^3/d	40 000 m^3/d	3 600 m^3/d	2 400 m^3/d

Data Source: The Feasibility Research Paper of Wastewater Treatment Project of Huludao

6.4.3 Wastewater treatment and recycling process

I. *The influent and effluent quality*

According to the monitoring of influent quality in both old and new city area, the prediction of wastewater influent is as follows (Table 6-18):

Table 6-18: The influent quality of the wastewater treatment plants

	CODcr (mg/L)	**BOD5 (mg/L)**	**SS (mg/L)**	**TKN (mg/L)**	**T – P (mg/L)**	**pH**
Wastewater Treatment Plant of New District	300	150	200	45	4.0	6 - 9
Wastewater Treatment Plant of Old District	360	180	250	45	4.0	6 - 9

Data Source: The Feasibility Research Paper of Wastewater Treatment Project of Huludao

The wastewater is discharged into Cishan River, Wuli River and Lianshan River. According to the *Notice of Management of Surface Water based on Environment Function*, which was released by the government of Huludao, the Environment Function of surface water of these three rivers is defined as Category V (for the use of landscaping) before 2010, and as Category IV (for the use of industry and creation) after 2010. According to the *National Overall Standard of Wastewater Discharge (GB8978－1996)* and the *Wastewater and Waste Gas Discharge Standard of the Liaoning Province (the regional standard)*, based on the local situation, the effluent standard follows the secondary discharge standard of Liaoning Province. The effluent quality is presented in Table 6-19.

Table 6-19: The effluent quality of the wastewater treatment plants

	CODcr (mg/L)	BOD5 (mg/L)	SS (mg/L)	NH3-N (mg/L)	T – P (mg/L)	pH
WWTP of New District and Old District	100	30	30	15	1.0	6 - 9

Data Source: The Feasibility Research Paper of Wastewater Treatment Project of Huludao

II. Selection-criteria of wastewater treatment process

In general, the process for wastewater treatment ranged from “the activated sludge treatment”, “membrane bioreactor”, to chemical and physical treatment. In China, the activated sludge treatment is usually adopted as the conventional treatment process in order to reach the secondary treatment standard. This process is dominated to remove COD and SS. However, due to the severe eutrophication in recent years, the state and local environmental department enhanced the discharge standard for strictly control of nutrient discharge (N, P). Thus, treated water from the local treatment plant has to meet the higher requirements for nutrient discharge. With the enhanced discharge requirement of the three rivers, the innovative method of high-efficiently nutrient removal should be developed in the future, in order to reduce the total amount of nutrient discharge and decrease the environment contamination. Compared to other treatment processes, “the activated sludge treatment” was adopted for this project, since its stable treatment performance, high quality of effluent, low operation cost and high efficiency of treatment.

The constructed two wastewater treatment plants are small- to medium-scale plant. In order to achieve a high-efficient and stable operation, low energy consumption and full use of water resources, the selection-criteria of treatment process is as follows:

- According to the quantity and quality of influent and effluent, the treatment process with low energy consumption, low operation fees, small land equipment and small investment should be adopted.
- The layout of plant should consider the overall objectives both in short- and long-term, in order to reduce the investment and land requirement.
- The mechanic and electrical instrument used in the treatment process should be advanced, safe, reliable, high efficient, and economical.

- The treatment processes should be highly flexible and easy for upgrading, based on different quantity and quality of influent. Additionally, the nutrient removal rate should be high.
- The geographic and hydrological character should be taken into consideration when designing plant layout. The cold climate in northern China should also be considered when designing of activated sludge process.
- The pipeline systems are still combined systems in short-term. For a long-term development, the design of plant layout should be flexible for further upgrading.
- In order to reduce press for water supply of Huludao City, 75% of the treated wastewater will be reused. Wastewater recycling and reuse should be involved in the design of treatment process.

III. Description of treatment process

Based on the engineering characteristics, two treatment processes were compared for the treatment plants and the case in the New District will be taken for example.
Proposal 1: University of Cape Town (UCT) and Proposal 2: Sequencing Batch Reactor (SBR)

University of Cape Town (UCT) Process

The wastewater first enters the coarse grid to remove large particles, then is pumped to the fine grid and vortex-type grit chamber. Next, wastewater will flow into the first sedimentation basin in order to remove suspended solid and fine sand. Organic matters, $BOD_{5,}$ COD and nutrients will be removed in the UCT reaction basin. Last, treated water will enter the secondary sedimentation basin, then will be discharged into river after treatment.

In the UCT process (Gao, 2003) (see Fig. 6-12), the sludge from sedimentation basins and the biomass from the oxygen basin will be returned to the anaerobic area, so that NO_3^- could be transformed to NO_2^- and N_2 in the denitrification reaction. When the mixed wastewater flows from anaerobic zone to aerobic zone, phosphorus could be removed. If TKN and COD are properly loaded, the complete denitrification could occur and the removal rate of phosphorus could be improved. This UCT process could reach a maximum level of NO_3^- removal in the return sludge. Due to the design of return sludge, the operation fee might be increased. Chlorine will be added in the treated water for disinfection.

After treatment, approximate 2400 m^3/day treated water will be transported to the Zinc Factory used as cooling effect, and the rest of treated water will be discharged in to Cishan River. In winter, the removal rate of phosphorus might be limited. In order to reach good quality of effluent, Fe will be added in the secondary sedimentation basin so that phosphorus could be removed under coagulation.

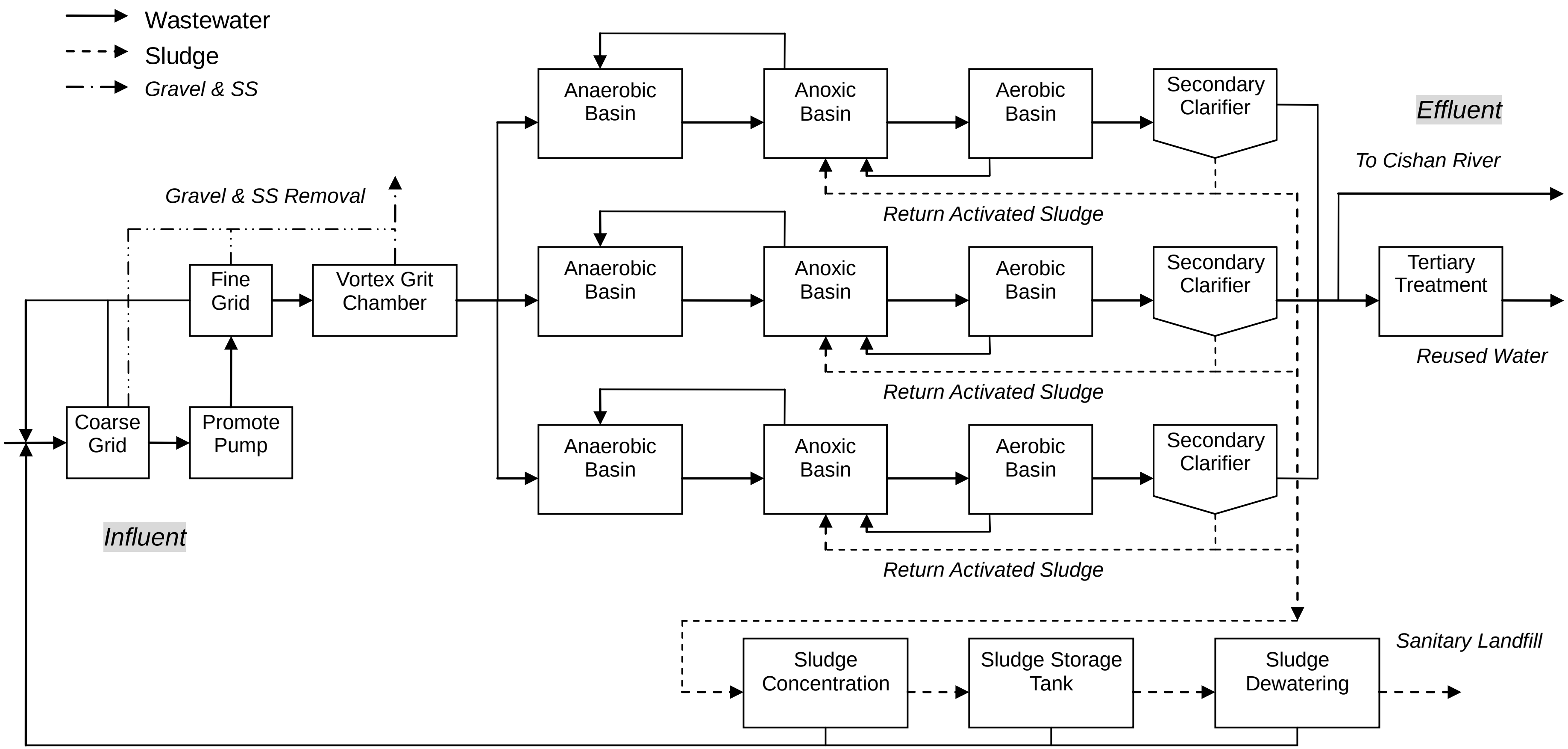

Figure 6-12: The UCT process flow diagram of the Proposal 1

SBR (Sequencing Batch Reactor) Process

Pre-equalization Basin: After primary treatment, the wastewater first flows into SBR Pre-equalization Tank (see Fig. 6-13) and then enters the corresponding SBR tank based on time-control systems (Wang, 2008). The reasons for setting up pre-equalization tank are as follows:

- It is aimed to adjust the outflow of primary sedimentation tank and the inflow of SBR reactor, and enable a stable and balanced influent of SBR reactor, as well as to reduce the negative impact brought by influent impulsion. In particular, in the medium- and small-scale wastewater treatment plant, the influent often fluctuates, thus the installation of pre-equalization tank is of great significance for both proper operation and reduction of project investment.

- In principle, all of the reaction processes are taken place in one unite – SBR tank. The time of influent filling and reaction can be adjusted by time-control so as to adapt the various influent conditions (e.g., quantity and quality). Also the pump inside SBR tank enables the balance between influent and effluent.

- The activated sludge from SBR tank could be pumped into Pre-equalization Tank, which could be considered as biological selection tank. The ability of biological degradation of organic matter in wastewater could be therefore enhanced due to high degree of biomass and the sludge bulge could be reduced.

Figure 6-13: The pre-equalization tank in Wastewater Treatment Plant of New District (16.01.2011)

In general, there are 5 steps for SBR process (See Fig. 6-14), detail description has been introduced in section 6.2.4. The figure 6-15 shows the plate-like aerators in SBR basin in Wastewater Treatment Plant of Old District.

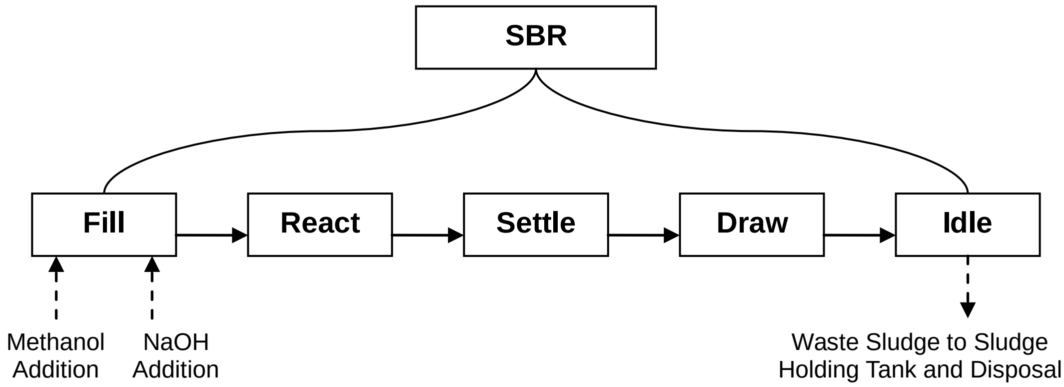

Figure 6-14: The general process of SBR

Figure 6-15: The plate-like aerators in SBR basin in Wastewater Treatment Plant of Old District

In the SBR process (see Fig. 6-19), Wastewater first enters into coarse and fine grid (see Fig. 6-16), as well as sedimentation basin (see Fig. 6-17), in order to remove suspended solid and sand. Then wastewater will enter SBR equalization basin (see Fig. 6-14) to mitigate the daily heavy loading. There are three SBR Basins (see Fig 6-18) working together and each SBR has its own cycle: fill, react, settle, draw and idle. The nutrient removal (N and P) will be carried out under the aeration condition. The settled sludge does not need to return back to the reaction and will be moved out regularly.

Chlorine will be added in the treated water for disinfection. After SBR treatment, approximate 2400 m^3/day treated water will be transported to the Zinc Plant used as cooling effect, and the rest of treated water will be discharged in to Cishan River. In winter, the removal rate of phosphorus might be limited. In order to reach good quality of effluent, Ferric Chloride will be added in the SBR basin so that phosphorus could be removed under coagulation.

Table 6-20 presents the comparison of quantity, operating power and space requirement of equipments between the Proposal 1 and Proposal 2. The related Data in Table 6-20 is oriented from the Feasibility Research Paper for Wastewater Treatment Project in Huludao City, which was draw up by the Institute of Municipal Engineering of Shanghai in 1999.

Figure 6-16: The coarse grid and promote pump station (16.01.2011)

Figure 6-17: The pump in vortex grit chamber (16.01.2011)

Figure 6-18: The SBR Basins in Wastewater treatment Plant (16.01.2011)

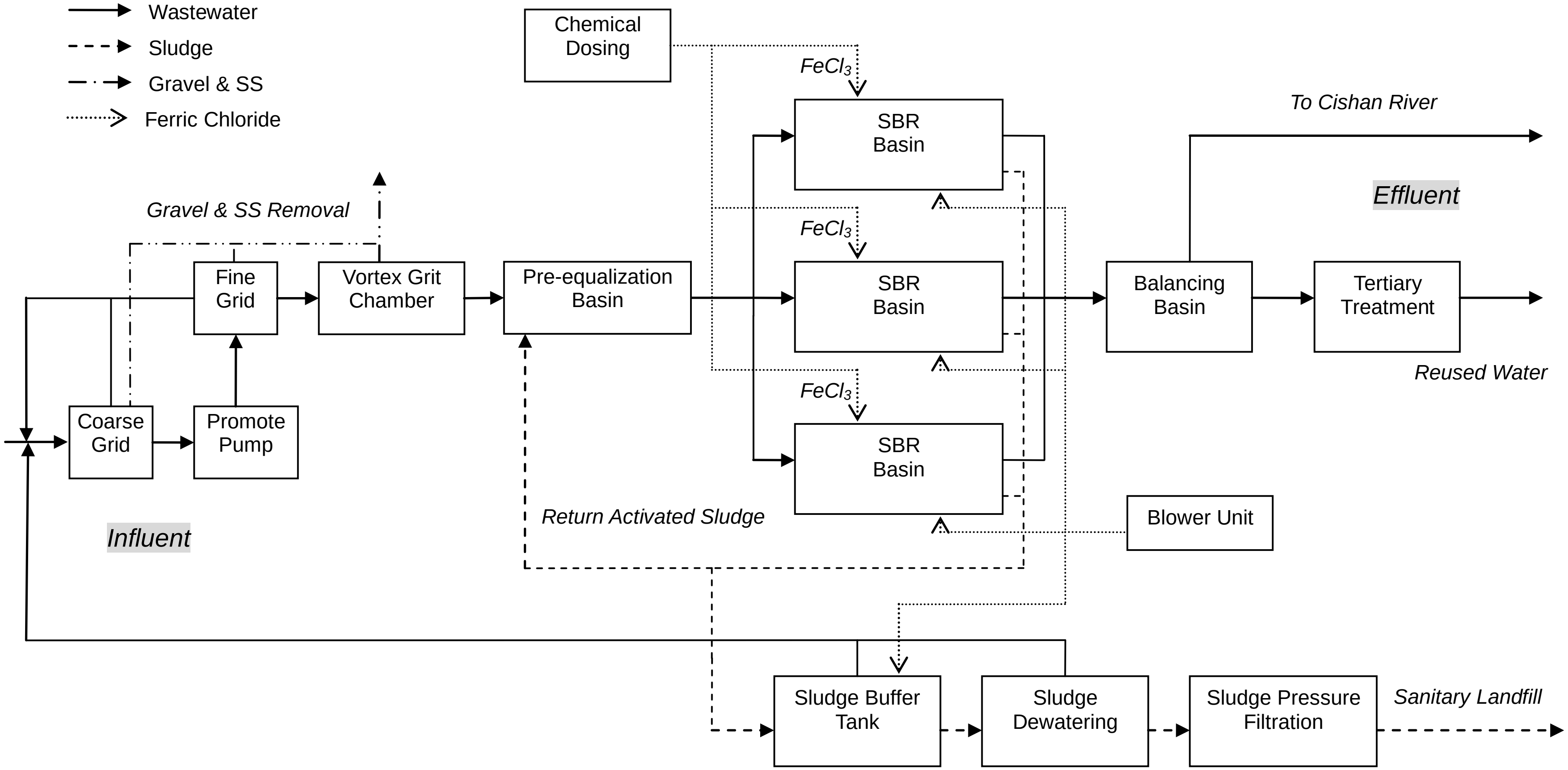

Figure 6-19: The SBR process flow diagram of the Proposal 2

Table 6-20: The comparison of quantity, operating power and space requirement of equipments, between the Proposal 1 and Proposal 2

	Proposal 1			Proposal 2		
	Quantity	Operating Power	Space Requirement	Quantity	Operating Power	Space Requirement
Promote Pump Station	1		150 m^2	1		150 m^2
- Coarse Grid	2	2 * 2.2 kW		2	2 * 2.2 kW	
- Submersible Sewage Pump	4	4 * 30 kW		4	4 * 30 kW	
Grid Chamber	4		75 m^2	4		75 m^2
- Fine Grid	2	2 * 2.2 kW		2	2 * 2.2 kW	
- Blower	2	2 * 11 kW		2	2 * 11 kW	
- Grit Lifting Pump	4	4 * 2.2 kW		4	4 * 2.2 kW	
UCT Reaction Basin	2		3 086 m^2			
- Reflux Pump (Anoxic Basin to Anaerobic Basin)	6	6 * 11 kW				
- Reflux Pump (Aerobic Basin to Anoxic Basin)	6	6 * 22 kW				
- Stirrer	12	6 * 4.5 kW 6 * 6.0 kW				
SBR Pre-equalization Basin				1		280 m^2
- Stirrer				2	2 * 5 kW	
SBR Reaction Basin				3		3 600 m^2

- Excess Sludge Pump				3	3 * 2.5 kW	
Blower Station	1		189 m^2	1		189 m^2
- Roots Blower	3	3 * 45 kW		5	5 * 45 kW	
- Ventilator	3	3 * 75 kW		3	3 * 75 kW	
Secondary Sedimentation Tank	2		2 512 m^2			
- Sludge Scraper	2	2 * 1.5 kW				
Sludge Pump Station	1		32 m^2			
- Return Sludge Pump	3	3 * 1.1 kW				
- Excess Sludge Pump	2	2 * 2.2 kW				
Sludge Sump	2		560 m^2	2		560 m^2
Sludge Dewatering Station	1		432 m^2	1		432 m^2
- Pump for Adding the Sludge	2	2 * 7.5 kW		2	2 * 7.5 kW	
- Belt Filter Press	2	2 * 3.0 kW		2	2 * 3.0 kW	
Chlorination Station	1		286 m^2	1		286 m^2
- Chlorination Plant	1	10 kW		1	10 kW	
Total Space Requirement		7 322 m^2			5 572 m^2	
Total Operating Power		649.5 kW			455.5 kW	

Data Source: Huludao Municipal Wastewater Treatment Co., Ltd.

Based on above presented Table 6-20 and the Feasibility Research Paper for Wastewater Treatment Project in Huludao City, an overall comparison between Proposal 1 and Proposal 2 are established as follows (see Table 6-21).

Table 6-21: The overall comparison between Proposal 1 and Proposal 2

	Proposal 1	**Proposal 2**
Technological Characteristic	In UCT Process, anaerobic & aerobic reactions take place in different units, high efficiency in biological process. Secondary sedimentation basin and pumps between units are required, thus the operation cost will be high.	In SBR Process, the influent flow & organic load are flexible. The SBR operation circle can be adjusted according to influent changes. Secondary sedimentation tank and sludge return are not necessary. Thus, the operation cost will be low.
Operation	The number of equipment units is more than that in SBR Process. Operating requirements are relatively high, and also difficult to manage.	The number of equipment units is less than UCT's. It is simple and easy to operate, due to automatic control.
Operating Power of Equipments	649.5 kW	455.5KW
Space Requirement	7 322 m^2	5 572 m^2 Beneficial to heat preservation
Investment	The investment for both equipments and projects are high.	Relatively low
Cost for Electricity	Relatively high (e.g., 1 182 600 kWh/year for Blowers in Proposal 1)	Relatively low (e.g., 886 950 kWh/year for Blowers in Proposal 2)

After comparing with two proposals, Proposal 2 was selected, due to the preeminent advantages of SBR - small land requirement, low operation cost, flexible operation, and low investment.

IV. Design of wastewater tertiary treatment process for water recycling

Huludao City is located arid area and domestic water supply mainly from surface water and ground water. Industrial water supply is transported from Wujintang Reservoir which is 50 km far away from city (HUPB, 2008). Therefore, the transportation cost is huge and industrial enterprises are facing severe potable water scarcity and unevenly distribution.

Municipal wastewater is a valuable resource and easy to exploitation due to stable wastewater quantity, especially for those cities in severe water shortage. Comparing with long-distance transportation of potable water from far reservoir, wastewater recycling is relatively cost-effective and can mitigate city water scarcity. Therefore, the local government suggested that after tertiary treatment the wastewater in New District could be recycled and reused as industrial raw water for thermoelectric plant in Zinc Enterprise.

The demand of industrial raw water from thermoelectric plant in Zinc Enterprise is 720 m^3 per hour (HCC, 2008). Considering other different uses of treated wastewater in the enterprise and wastewater treatment plant, the designed quantity of treated wastewater in New District is 750 m^3 per hour (HCC, 2008).

Table 6-22 presents the industrial water consumption of Thermoelectric Plant. The related data were provided by Thermoelectric Plant of Huludao Zinc Plant to Huludao Construction Committee in 1997 (HCC, 2008).

Table 6-22: The industrial water consumption and water quality requirement of Thermoelectric Plant

Application Purpose	Water Quality Requirement	Water Flow	Remark
Raw Water for softening and demineralization of Steam Boiler (4 Steam Boilers, Design Pressure 5.5 MPa)	To accord with the *Entering Water Quality Standards for demineralization and softening Equipment* (GBJ109-87) and Water Quality Requirement for Raw Water of Steam Boiler by Thermoelectric Plant	150 m^3/hr	Source of Raw Water: Surface Water from Wujintang Reservoir
Raw Water for softening and demineralization of Steam Boiler (Several Waste Heat Boilers, Design Pressure 1.5 – 2.6 MPa)	To accord with the *Entering Water Quality Standards for demineralization and softening Equipment (GBJ109-87)* and Water Quality Requirement for Raw Water of Steam Boiler by Thermoelectric Plant	360 m^3/hr	Source of Raw Water: Surface Water from Wujintang Reservoir
Make-up Water of Industrial Circulating Cooling Water System (Anode Protection for Sulfuric Acid Plant)	To accord with the *Make-up Water Standards for Industrial Circulating Cooling Water System* and Water Quality Requirement for Make-up Water of Industrial Circulating Cooling Water System by Thermoelectric Plant	210 m^3/hr	Source of Raw Water: Surface Water from Wujintang Reservoir

Source: Huludao Construction Committee

The influent quality of tertiary treatment is considered as the discharge standards of secondary treatment (see Table 6-9).

The effluent quality of tertiary treatment should reach the standards of raw water quality in Zinc Enterprise (these standards is provided by Zinc Enterprise, see Table 6-23). According to the standards of surface water from Wujintang Reservoir, which has been provided raw water for the thermoelectric plant (see Table 6-24), the effluent quality standards of tertiary treatment in New District could be concluded in Table 6-25.

Table 6-23: The raw water quality standards of Huludao Zinc Plant

	Standard / Code	Unit
Color	≯ 15	
Turbidity	≯ 5	
pH	6.5 – 8.5	
Total Hardness	≯ 250	Mg/l
Cl^-	≯ 100	Mg/l
Fe	≯ 0.3	Mg/l
Cu	≯ 1.0	Mg/l
Zn	≯ 1.0	Mg/l
Volatile Phenols	≯ 0.002	Mg/l
Linear Alklybezene Sulfonates	≯ 0.3	Mg/l
Cyanide	≯ 0.05	Mg/l
Fluoride	≯ 1.0	Mg/l
As	≯ 0.04	Mg/l
Se	≯ 0.01	Mg/l
Hg	≯ 0.001	Mg/l
Cd	≯ 0.001	Mg/l
Pb	≯ 0.1	Mg/l
Bacteria Count	≯ 100/ml	
Escherichia Coli	≯ 3/1	

Source: Huludao Zinc Plant

Table 6-24: The surface water quality in Wujintang Reservoir

	Indication		Indication	Unit
Total Solids	283.2	DO	2.40	Mg/l
Dissolved Solids	281.4	Na	18.0	Mg/l
SS	1.8	Ca	50.0	Mg/l
Alkalinity	0.05 – 2.75	Mg	18.6	Mg/l
Carbonate	3.0	Fe	0.03	Mg/l
Bicarbonate	161.65	Al	0.61	Mg/l
Total Hardness	4.05	Cu	0.01	Mg/l
Temporary Hardness	2.75	NH_3	0.05	Mg/l
Permanent Hardness	1.30	Cl^-	16.0	Mg/l
K	4.36	SO_4^{2-}	65.66	Mg/l
Silicate	4.82	Dissolvable Silica	3.93	Mg/l
Silicate (Colloid)	0.89	Nitrate Radical	35.0	Mg/l
pH	8.34			
Electrical Conductivity	820			ms

Source: Huludao Environmental Protection Bureau

Table 6-25: Effluent quality standards of tertiary treatment in Wastewater Treatment Plant of New District

	Standard	**Unit**
Color	≯ 15	
Turbidity	≯ 5	
pH	6.5 – 8.5	
Total Hardness	≯ 250	Mg/l
Cl^-	≯ 100	Mg/l
Fe	≯ 0.3	Mg/l
Cu	≯ 1.0	Mg/l
Zn	≯ 1.0	Mg/l
Volatile Phenols	≯ 0.002	Mg/l
Linear Alklybezene Sulfonates	≯ 0.3	Mg/l
Cyanide	≯ 0.05	Mg/l
Fluoride	≯ 1.0	Mg/l
As	≯ 0.04	Mg/l
Se	≯ 0.01	Mg/l
Hg	≯ 0.001	Mg/l
Cd	≯ 0.001	Mg/l
Mu	≯ 0.1	Mg/l
Pb	≯ 0.1	Mg/l
SS	≯ 1.8	Mg/l
BOD_5	3	Mg/l
COD_{cr}	≯ 15	Mg/l

Source: Huludao Municipal Wastewater Treatment Co., Ltd.

V. *Feasibility analysis of wastewater recycling in WWPT of New District*

A. Technological aspect

- The domestic wastewater accounts for 80-85% of total amount of wastewater in New District, while industrial wastewater accounts for 15-20% of total amount (HEPB, 2008). Therefore, the influent is dominated by domestic wastewater. After tertiary treatment, the effluent quality of treated wastewater is near tap water and could reach the required standard for tertiary treatment which was presented in Table 6-25.
- Based on the technological practices of treated water reuse in other countries and the experience of demonstrated project of Wastewater Treatment Plant in Dalian City, effluent quality (for recycling and reclaim) is guaranteed.
- The quality and quantity of treated wastewater from secondary treatment process are stable. This is a reliable prerequisite for further treatment (tertiary treatment processes) and recycling & reclaim.

B. Economical aspect

The Wujintang Reservoir is 50 km from Zinc Enterprise. Such a long distance made the construction of pipeline system very costly. It is not convenient for overall management and it leads to unevenly distribution for both industrial and domestic water supply. The wastewater from treatment plant in New District can be regarded as valuable resources. Comparing to the withdraw of surface water from the Wujintang Reservoir, recycling of wastewater in constructed plant nearby is cost-effective due to the cost reduction of pipeline construction.

The treated wastewater could be recycled and reused not only as raw water for the thermoelectric plant, but also as water supply for the daily consumption of wastewater treatment plant (e.g., as washing water in the sludge dewatering plant), or for miscellaneous uses inside industrial plant (e.g., landscaping, car-washing, sweeping). Therefore, the potable water saving potential is great through recycling wastewater. Meanwhile the operation cost is diminished.

As a demonstration project of new water resource exploitation in Huludao City, this wastewater recycling project is of great significance for mitigating the severe scarcity of natural water resource in the city, reasonable distribution and use natural water resource, and project investment reduction, as well as improvement of economical benefits.

C. The technological design for wastewater recycling in New District

According to the practical experiences of wastewater recycling and reusing project from overseas, and the requirement for the quality and quantity of recycled water (see Table 6-25), the following technological option is adopted (see Fig. 6-20).

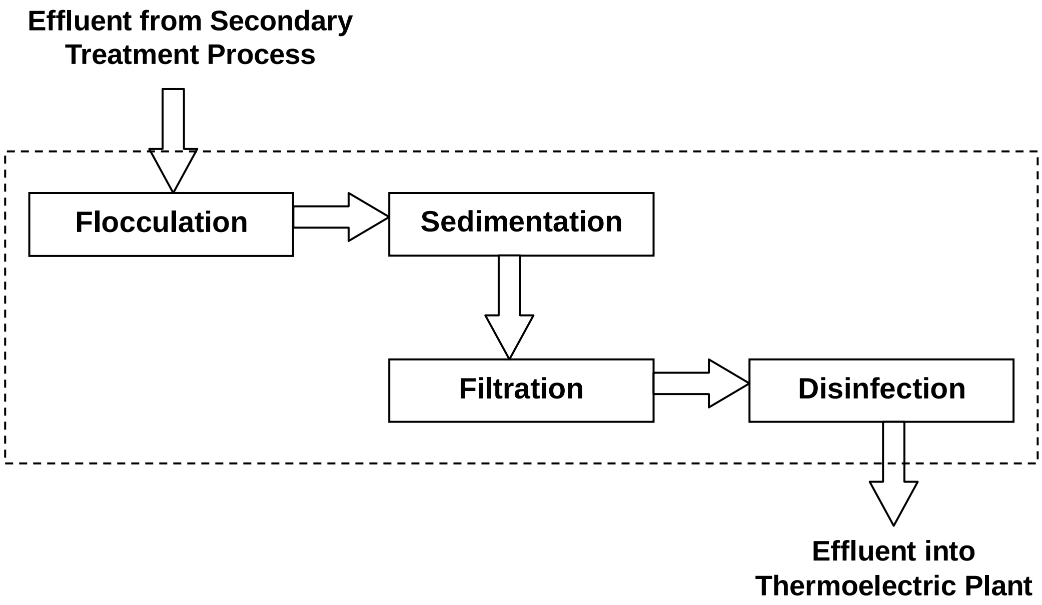

Figure 6-20: The process flow diagram of wastewater recycling and reusing system

D. Technological explanation

(1) The process of flocculation is aimed to form aggregates or flocs from finely divided particles and from chemically destabilized particles, in order to remove suspended solid matter and organic colloid and enhance turbidity in wastewater. Flocculation is a transport step that brings about the collisions between the destabilized particles needed to form larger particles that can be removed readily by settling or filtration. In addition, other inorganic matter such as T-P and emulsified oil could also be removed through chemical reaction. Basically, there are two steps in the process of flocculation, namely mix and react. Firstly flocculation typically follows rapid mixing where chemicals (e.g., Al2(SO4)3) have been added to destabilize the particles and stabilizing particles. The stabilized particles and suspended solid are under coagulation, in order to form larger particles that can be removed readily by settling or filtration.

(2) Flocculent particle settling can be obtained by using an inclined plate or tube and is aimed to separate particles and water. They are based on the theory that settling depends on the settling area rather than detention time. Although they are used predominantly in water-treatment application, plate and tube settlers are used in wastewater treatment for primary, secondary and tertiary sedimentation.

(3) Filtration is aimed to improve the removal rate of Total Phosphorus (TP), COD, BOD, heavy metal, bacteria, virus and other organic matters.
(4) Disinfection refers to the partial destruction of disease-causing organisms. The most common disinfectants are the oxidizing chemicals and chlorine is the one used most universally. Also Ozone is a highly effective disinfectant and its use is increasing even though it leaves no residual.

VI. Sludge treatment process

According to the proposal 2, the sludge production after dewatering is 4 500 kg/day. There are still large amount of organic matter and virus existing. The secondary sludge treatment is necessary, in order to:

- reduce organic matter to reach sludge-stabilization,
- reduce sludge volume and
- recycle useful material in the sludge.

The Sludge Retention Time (SRT) in SBR is 8 days. In order to reach sludge further stabilization, the sludge from SBR requires another 12 days' retention. The sludge retention basin is injected with aeration, and through belt filter press the sludge is mechanical compressed and thickened. Then they would be transported to outside of the city. Finally, the sludge would be buried with other city garbage.

6.4.4 Operating performance and costs

I. Operating performance

The construction of wastewater treatment system in the New District was started in May 2001 and finished in August 2003 (Wang, 2008). It consisted of several parts (Wang, 2008): i) 30 000 m^3/d treatment plant; ii) 12 km sewage nets; iii) promoting pump station in Seashore; iv) 50 m^3/h underground entire treatment plant in Haodun and 100 m^3/h underground entire treatment plant in Chaotun. After total commissioning, the results indicated that the quality of effluent conformed to the requirements of design. At the present time, flow of treated water in the plant is reached 30,000 m^3/d and load rate 100%. An expansion programme is under way.

The wastewater recycling and reuse system was initiated at the same time with the main project. It was designed to be able to treat wastewater up to maximum 24 000 m^3/d. Ever since commissioning, the wastewater recycling and reuse system has been able to supply with 10 000 m^3 treated water for Zinc Plant per day (Wang, 2008).

The Wastewater Treatment Plant of New District started the sludge cultivation in April 2003. The treatment condition remained stable since July 2003. Through constant adjustment of technological parameter in 2004, e.g., improvement of devices for wastewater aeration, the effluent quality could reach secondary class of "The Overall Discharge Standard for Wasted Gas and Water in Liaoning Province" (DB21-59-89). In 2004, the total amount of treated wastewater was 5,840,000 m^3 in new district, and daily treatment amount was 16,000 m^3. The amount of treated water for supply as industrial cooling water was up to 3,650,000 m^3, while the discharged wastewater into Cishan River is up to 2,190,000 m^3 in 2004. The degradation of COD was 641 tons, SS 465 tons, TN 141 tons and TP 13 tons (Wang, 2008). The table 6-26 presents the treatment performance from July to December in 2004.

Table 6-26: The operating results of Wastewater Treatment Plant of New District from July to December in 2004

	COD_{cr} (mg/L)		BOD_5 (mg/L)		SS (mg/L)		NH_3-N (mg/L)		TP (mg/L)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
Jul.	102.0	48.0	-	-	63.1	32.0	23.0	13.5	2.8	0.9
Aug.	95.1	49.1	32.1	12.2	72.0	27.0	27.2	13.7	2.7	0.9
Sept.	81.0	41.7	26.3	10.6	73.6	24.0	28.2	14.1	2.4	1.0
Oct.	127.0	65.7	47.8	23.1	69.0	33.0	35.4	14.8	2.7	1.1
Nov.	215.0	72.4	40.0	19.0	191.0	24.2	28.6	14.7	1.9	1.0
Dec.	178.0	93.7	41.8	26.8	75.1	35.9	34.5	16.3	3.1	1.0
Average	133.0	61.8	47.0	18.4	90.6	29.4	29.5	14.5	2.6	1.0
Removal Rate	54%		61%		68%		51%		61%	

Data Source: Huludao Municipal Wastewater Treatment Co., Ltd.

From the above Table 6-26, the effluent quality of COD, BOD_5, NH_3-N, SS, and TP could reach the national standard**.** The treatment rate of wastewater could reach 100%, and the major polluted matter can be removed from wastewater and removal rate can reach the national standard. The experiment showed that SBR process is an appropriate approach for urban wastewater treatment.

However the Wastewater Treatment Plants of New District of Huludao City adopted the Standard A of First Class in the "Discharge Standard for Municipal Wastewater

Treatment" (GB 18918-2002), in which the highest permitted value for discharge is: COD 50 mg/L, BOD_5 10 mg/L, SS 10 mg/L, TN 5 mg/L, TP 1.0 mg/L, pH 6~9, Escherichia Coli 1000/L. Through the strengthening of technological control including the enhancement of SBR process, the effluent from wastewater treatment plant in new district could reach the required standard: COD 50 mg/L, BOD_5 10 mg/L, TP1 mg/L, and 10 mg/L. Due to the short design time for adjustment, small capacity of equalization tank, low ratio of COD/NH_3-N, nitrification and denitrification effects were not obvious, which led to the unsatisfactory removal rate of ammonia nitrogen (see Table 6-27 and Fig. 6-21).

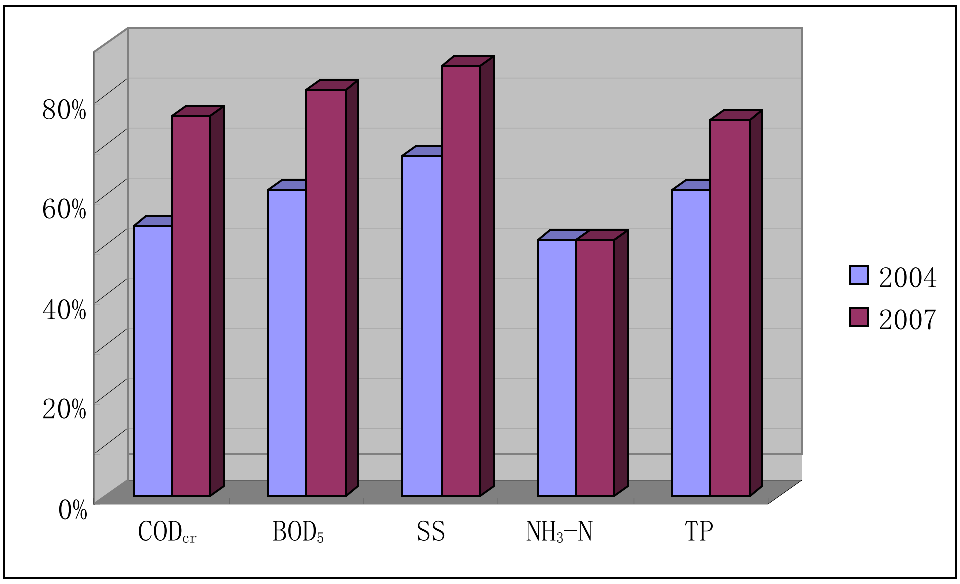

Figure 6-21: Comparison of removal rate of COD, BOD, SS, NH_3-N and TP of 2004 and 2007

Table 6-27: The operating results of Wastewater Treatment Plant of New District from March to August in 2007

	COD_{cr} (mg/L)		BOD_5 (mg/L)		SS (mg/L)		NH_3-N (mg/L)		TP (mg/L)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
Mar.	220.0	＜50.0	58.5	10.0	65.1	10.0	24.0	13.5	3.0	0.9
Apr.	205.0	＜50.0	55.2	9.8	70.2	10.0	27.5	14.7	2.8	0.8
May	210.0	＜50.0	56.1	10.0	71.6	9.9	29.6	14.5	2.6	1.0
Jun.	208.0	＜50.0	48.6	9.6	69.0	9.8	36.5	14.6	2.8	1.0
Jul.	210.0	＜50.0	50.3	9.7	75.1	10.0	28.9	14.9	2.9	0.3
Aug.	195.0	＜50.0	47.8	9.5	76.2	9.9	32.5	15.3	3.3	0.3
Average	208.0	＜50.0	52.8	9.8	71.2	9.9	29.8	14.6	2.9	0.7
Removal Rate	76%		81%		86%		51%		75%	

Data Source: Huludao Municipal Wastewater Treatment Co., Ltd.

II. Operating costs

The table 6-28 shows the yearly operating cost and unit cost per cubic meter of WWTP of New District.

Table 6-28: The yearly operating cost and unit cost per cubic meter of WWTP of New District

Content of Accounts		RMB (Yuan)	
Yearly Energy Cost		163.99	
Chemical Agent Cost		40.08	
Salaries or Wages of Personnel		36.00	
Depreciation on Fixed Assets		311.89	
Maintenance Funds		131.95	
Selling expenses of Deferred and intangible assets		0.69	
Ordinary Maintenance of Equipments		29.99	
Other Operating Cost		107.19	
Interest Expense		5.21	
Yearly Operating Cost		509.20	
Yearly Total Cost	Variable Cost	316.47	826.99
	Fixed Cost	510.52	
Unit Cost of Wastewater Treatment (per m^3)		0.76 RMB/m^3	
Variable Unit Cost (per m^3)		0.29 RMB/m^3	

Data Source: Huludao Municipal Wastewater Treatment Co., Ltd.

From above Table, the unit cost of wastewater treatment was counted out 0.76 Yuan per cubic meter. The price of treated wastewater that is sold to Zinc Plant is 1 Yuan per cubic meter (Wang, 2008).

6.4.5 Result analysis on the case study 2

The SBR process is reliable and mature for urban wastewater treatment. The removal rate of contaminant e.g., TN, TP and COD was relatively high. The sludge bulge did not occur in SBR process as often as in other process, and the Sludge Retention Time was relatively long. The continuous influent loading could be realized by alternate operation of multi-tanks. The operation became easy and convenient by the adoption of decentralized control system (PLC on-site operation) and remote central monitoring. Since several processes (fill, react, draw, idle) take place in one unit, the anaerobic basins, secondary sedimentation basins and the sludge-scraping devices are no longer necessary. Therefore, the investment and operation cost as well as space-requirement are reduced. The aeration devices adopted timing control by frequency conversion to achieve intermittent aeration. The aeration time lasts 3-4 hours for one circle, thus 8-12 hours of aeration time can be saved per day. Therefore, the operation time of aeration devices is reduced and electronic power is saved.

Although there are many advantages in SBR processes for wastewater treatment, some technological drawbacks during operation cannot be ignored.

- The amount of wastewater discharge in new district of Huludao City could only be reached half of the amount that has been designed and expected. Due to low COD loading (150 mg/l), the rate of sludge proliferation was relatively slow and thus the sludge concentration was low, which directly influence the removal rate of contaminant. Up to 2007, with the rapid development of new district and increase of population, the operation performance became better gradually.

- The quality of facilities (e.g., aeration devices, discharge valve) plays an important role and directly influences the treatment capacity and effect.

- Due to the low ratio of COD/NH^3-N and the capacity of pre-equalization tank is limited, thus the Retention of Hydraulic Time is only 2 hours. Consequently, the time for anaerobic digestion is not enough and thus it is difficult for denitrification take place. The removal rate of TN was therefore not satisfactory. In order to solve this problem, the wastewater recycling trial has been undertaken by the supply of service water for Zinc Plant in Huludao City from 2004 (10,000 m^3/day) (Wang, 2008). After secondary treatment, the effluent would be led to the tertiary treatment in order to reach the standard of service water for boiler supply and softening water for electrical plant. Currently a wastewater recycling facility that could treat 50,000 m^3 wastewater per day is under construction in the Zinc Plant of Huludao City. All of the secondary treated wastewater could be recycled and reused after the tertiary treatment. In addition, since the amount of sludge production is relatively small in SBR process and the age of sludge is large, as well as the clarified liquid is returned back to reaction tank, the removal rate of TP is not satisfactory. One of the solutions is to add chemical TP removal process in the pre-equalization tank for sludge infiltration treatment.

- In wintertime, the temperature of SBR reactor is low (10℃) (Wang, 2008) and the sludge is not active enough during operating, thus the treatment performance is not acceptable. This problem could be solved by maintaining continuous influent and increasing aeration.

The application of SBR process for municipal wastewater treatment could result in low investment- and operation cost. The wastewater treatment plant in new district of Huludao City was designed to treat 30,000 m^3 wastewater per day and the actual treatment amount is 20,000 m^3 per day (in 2007). Since the actual treatment amount is lower than that has been designed, the wastewater treatment cost is relatively high (0.76 Yuan/m^3). The secondary treated wastewater from SBR processes would be reused as cooling water for Zinc Plant in Huludao City and the supplied service water is 10,000 m^3 per day. After tertiary treatment, the quality of secondary treated wastewater could reach the standard for service water, e.g. boiler supply and softening water. Therefore, all the secondary treated wastewater could be recycled and reused. The potable water resource could be conserved and the fresh water consumption can be reduced. Meanwhile, the operation cost is reduced.

A brief explanation of judgment and proposal presents as follows.

- There are many advantages in the application of SBR processes for municipal wastewater treatment, such as flexible operation, high automatization and good treatment performance.
- The investment and operation cost are relatively low due to short aeration time.
- The removal rate of TN, TP and organic matter is relatively high.
- However, there are still some drawbacks during SBR processes, e.g. high demand for the quality of key devices, low sludge concentration and long Sludge Retention Time due to low temperature in the reaction basin in wintertime, thus DAT-IAT technology are recommended in wintertime.
- It will be more cost-effective when the wastewater treatment capacity can reach 10,000 m^3 per day.
- The secondary treated wastewater from SBR processes could be recycled and reused according to different requirement of end-users. After tertiary treatment, treated wastewater could be reused as industrial cooling water for the thermoelectric plant. Therefore, the potable water resources could be conserved and wastewater could be reused as “new” resource. Meanwhile, the operation cost is reduced.

Chapter 7. Conclusions and Recommendations

With 1.3 billion population, China is the largest country in the world and it is estimated the population could reach 1.6 billion by the year 2050 (UN, 2007). China has become one of the world’s major economic powers with the greatest potential. Along with the implementation of national urbanization and modernization strategy in China, the urban scale and quantity are increasing systematically. The conflict between environment and development is becoming ever more prominent. Relative shortage of resources, a fragile ecological environment and insufficient environmental capacity are becoming critical problems hindering China's development.

Currently, a number of cities are on the serious condition of water shortage and wasting in China. It is an important means for development of economy and society to achieve the sustainable utilization of water resources. Building a sustainable management and development system of urban water resources has conclusive sense for supporting the urban economic and social development. Through the theoretical and practical analysis, this dissertation put forward the framework of sustainable development (SD) of water management and economic circulation model within various scales for China’s small and medium-sized cities. The research focused on the following aspects.

- Based on the analysis of the urbanization’s impact on such water environmental factors as hydrology, water quantity, water quality, groundwater, and hydrophilicity, put forward the objective system, support system and evaluation system of sustainable development of urban water management in SMSCs.
- Based on the analysis of the relationship between flood control and urban socio-economic development, put forward the SD strategy for urban flood control as well as the construction of *Flood Prevention and Security City*. Urban flood control and management should coordinate with river basin flood control and construction of urban infrastructure, to guarantee and support urban socio-economic development, especially development of SMSCs.
- Based on the analysis of the economic instruments for water pollution prevention and control, put forward the SD strategy for prevention and control of urban water environment as well as the construction of *Eco-city*. Pollution charge, tradable water pollution right and evaluation of water resource value in national economic accounting are the important approaches to marketization and industrialization of wastewater treatment.
- Based on the analysis of the relationship between water supply and water demand, put forward the SD strategy for urban water resource utilization as well as the construction of *Water-saving City*. City construction and industrial distribution should consider the carrying capacity of urban water resources. Improvement of urban water saving depends on reform of water price system and market.

- Based on the analysis of the concept and contents of water culture, put forward the principles of construction and repair of urban water culture. Ecological restoration and water landscape restoration should coordinate with urban water culture.
- Based on the analysis of the regulation mechanism of water market and management, put forward the direction and contents of the reform of urban water market and management for the SD of SMSCs.
- Based on the integrated analysis of the SD of urban water management of SMSCs, put forward two models of circular economy –small and large scope recycling of urban water, and discussed the relevant practical case studies. MBR technology has been introduced in the case study of the wastewater treatment and recycling system of the DJD Hotel (small scope recycling of urban water); SBR technology has been introduced in case study of the wastewater treatment and recycling system of the Huludao City (large scope recycling of urban water).

The rapid development of SMSCs becomes an important part of China's urbanization. From 1980 to 2000, the population of large cities increased 97 percent from 5.473 million to 11.323 million; the population of SMSCs increased 220 percent from 3.315 million to 10.611 million. By the end of 2000, the city population of china reached 4.32 billion, of which population of SMSCs accounted for 74 percent (Lue, 2003).

SMSCs can be divided into two categories, namely SMSCs around large cities and relative independent SMSCs away from large cities. The first type should be seen as an integral part of the metropolitan area, the other is the center of administration, service, logistics and economy in rural area.

- The role of SMSCs in metropolitan area

  Metropolis and large cities concentrated various industries and functions. On one side, they are more attractive. On the other side, overpopulated and over industrialized development resulted in many serious urban problems, such as traffic problem, air pollution and housing problem. To reduce the risks and damages, a part of housing function and industrial agglomeration have to be spread to the surrounding space of large city. Then they formed a metropolitan area with the cooperative and complementary functions. Therefore, SMSCs are an important part in metropolitan area.

- The role of relatively independent SMSCs

  Relatively independent SMSCs are far away from metropolis or large cities. They are the center of administration in local area, and provide education, health caring, and other service for themselves and their surrounding space. The development of these cities depends on whether competitive industries exist. The competitive industry may be the tourism, mining industry, or manufacturing industry, etc. Under the regulation and control of the China's traditional planning economic system, the development of most of these cities has been driven by single competitive industry, especially mining industry or manufacturing industry. The exhausted resource and the diminished activity of main industry have seriously hindered the development of the relatively independent SMSCs. Changing the singular industrial structure became an urgent problem, which need to be solved under the condition of the sustainable development of society, economy and environment. Another problem of these cities is about urban service functions. Usually, the situation of providing service is not satisfied for their surrounding area. It focuses on the social service, business service, and education service, as well as public health service.

As an important part of the system of cities and towns, SMSCs have their own features and development advantages compared with large cities and rural areas.

- Compared with large cities

  As the development of small cities started later, they can take lessons from the development experience of large cities to exploit their advantages and achieve the great-leap-forward development. Due to the constraints of a variety of factors, the extent of the damage to the environment is relatively smaller, and available resources are relatively more. Therefore, implementation of urban sustainable development can form relatively stable urban ecosystem, to achieve harmonic common development of the society, economy, environment and resources.

- Compared with rural area

  Medium and small cities provide much more comfortable living conditions (including water, electricity, sanitation, shops, health care, education and entertainment services, etc) and a wide range of employment opportunities. From the view of economy, value, taxes, consumer demand created by SMSCs are higher than by rural areas. Because of high employment density, the concentration of capital and technology, as well as sufficient floating population, SMSCs become the reliable power source of economic growth.

In the construction and development process of SMSCs, there still are many deficiencies. For example, urban planning is relatively lagging; urban construction cannot meet the needs of development; lack of general study of the integrated utilization of urban resources such as water, land, infrastructure, which however constrain the sustainable development of cities.

The small and medium-sized cities are very important for further urbanization in China. The healthy development of these cities is significant foundation to promote the regional and economic development, and the key factors towards sustainable development of state. Water-related issues have severely hindered China’s socio-economic development. Therefore, the recommendations are given as follows.

- SMSCs should develop and improve the rational and integrate SD system of urban water, to guide, evaluate and manage water-related affairs.
- SMSCs should implement and improve the reform of institution and policy, to build a reasonable management system of urban water.

- SMSCs should implement and improve the reform of water price system, investment and financing system, to build a sound water market.
- SMSCs should implement and improve the policy of circular economy in urban water sector, and select suitable technology and process according to their own actual conditions. Water recycling and reuse is related to water resources utilization, water pollution control, water environmental and ecosystem protection, etc., and can bring huge economic, social and environmental benefits to SMSCs.
- SMSCs should pay great attention to strengthening the public participation and environmental education, to create a reasonable decision making system and a good supervising mechanism.

The sound sustainability of urban water system strongly necessitates balance and maintenance based on resilience of urban water system. One of the severe deficiencies of spatial planning is reflected by the harmful impacts of urban land use due to over-expansion on urban water systems. Therefore, urban water-related planning and design require considering spatial concepts and methods for urban water system in spatial planning. Under their own conditions,

- SMSCs should pay attention to reduction of the impervious area in catchment areas, within watersheds or catchment areas, protection of existing surface water bodies and wetlands as important elements for urban spatial structures, and involvement of buffer zones or riparian corridors in urban green structures (Da, 2010).
- SMSCs should pay attention to transformation of the attitudes in their institutions for improving the communication of visions, strategies and targets.
- SMSCs should pay attention to cooperation between urban water management and spatial planning at strategy level and implementation level.

The basic purpose of sustainable utilization of water resources is to satisfy the water demand of human society and ecological system, and to protect water quality for human health. Under the pressure of increasing population, accelerating urbanization and developing economy, the conflict between social and ecological water demand is more and more outstanding. In order to solve the problems of fresh water shortage and water environmental pollution, a fundamental aspect is the implementation of water recycling based on circular economic theory.

Along with the rapid growth of population and urbanization, the conflict between environmental protection and economic development is becoming more serious. Sustainable development and utilization of water resource is a significant foundation to realize the sustainable development of human society, because water is the source of life.

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