

**Reuse-oriented Decentralized Wastewater  
Treatment based on Ecological Sanitation in fast  
growing Agglomerations**

**Dr.-Ing. Dissertation**  
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# 1. Introduction

## 1.1 Current dilemma in developing world

One of the most important demographic trends in the world today is urbanization with its particularly rapidly growing in developing countries. By this, the major challenge of 21<sup>st</sup> Century is the dramatic change in the spatial distribution of the population. The majority of urban growth is associated with the rapid expansion of smaller urban centers and peri-urban developments. Much of this growth is unplanned and informal. Keiner (2006) predicted that in the coming decades, almost the entire population growth in the world is likely to be in the urban population, primarily in Africa, Asia and Latin America.

In term of pace and magnitude, the contemporary growth of the urban population, and what might be called the „fast growing agglomerations“, is unprecedented. A few figures may illustrate the extraordinary fast transformation in demographic terms and settlement patterns. During the coming decades, almost the entire population growth in the world is likely to be in the urban population, primarily in Asia. According to the statistic of United Nation, between 2000 and 2025, the increase of the global urban population is estimated to be about 2 billion, or roughly 95% of the total population increase in the world. In one generation, the additional urban population is roughly equal to the combined populations of the two most populous countries of the world – China and India.

Urbanization and growth of megacities are not new phenomena. However, the trend of current urbanization in developing countries differs greatly from that in developed world. According to Varis (2006), the first difference is the rate of growth. The development of the megacities of the developed countries (e.g., New York and London) was a gradual process and experienced over a century. The second major difference is that as the megacities of the industrialized countries expanded, their economies were growing in the meanwhile. Therefore, their urban centers were economically able to provide with necessary water related services.

On the contrast, in developing countries, the cities are the most striking expression both of poverty concentration and environmental deterioration. These problems might be multiplied in the next decades, if appropriate action is not taken at all economic, environmental and social levels. In the current developing world, a crucial problem for the major urban stems from the fact that the rates of urbanization have generally far exceeded the capacities of the national and the local governments to soundly plan and manage the demographic transition processes efficiently, equitably and sustainably.

The population impacts in the fast agglomeration, which often occur in urban fringe, have great influence on the environmental approach and however have often received little attention due to the government's neglect. These informal areas which are literally mushrooming, are characterized deplorable living conditions and in the absence of a systematic policy for resource utilization and environmental care. Moreover, a troubling trend is that the most rapid growth of urban areas is taking place in the economically weakest countries and in the regions where water resource endowments are limited, technical and management capacities are comparatively poor. All these makes successful water management in fast agglomerations of the developing world a most challenging task.

Therefore, with the continuing fast growth rate of agglomeration, the provision of adequate amounts of safe water becomes increasingly expensive and complicated. Basically, provision of clean water and safe disposal of wastewater should remain basic necessities, for daily survival and for all economic activities. The increasing challenges with provision of clean water and wastewater disposal imply that huge investments are required for the water sector in the coming years. However, with a host of investment requirements for all the developmental sectors, there is an obviously considerable scarcity of essential investments in water supply and sanitation sectors, which require priority attention. Additionally, with the continuing high growth rates of the population and urban sprawl, the provision of adequate amounts of drinking water and safely disposal wastewater become increasingly complex and expensive.

As a matter of fact, many of cities in China generally fell progressively behind in constructing and managing sewage and wastewater treatment facilities due to insufficient financial support. In general, most of the infrastructure and facilities relating to water supply and wastewater disposal are invested by government. Those large-scaled centralized systems always demand tremendous investment because of the construction of deep-excavated sewage networks. Therefore, compared with the fast increasing demand caused by explosive population, the financial support from government was far insufficient. This has led to many surface water in China turned out to be open sewer, in another words, large amount of wastewater has been directly discharged to waterbody without any treatment.

The basic principles and rules for wastewater management should take consideration of the "*Belastung*" existed and involved in the wastewater. On the one hand, the contaminated material should be introduced to the wastewater as few as possible. On the other hand, the polluted material should be completely under control and eliminated. However, the naturally degradable material needs to be maintained in the closed loop of material flux (Tietz, 2006). Traditional methods and current practice overwhelming of centralized sewer system in the developed countries relating to water supply and sanitation are so-called "end-of-pipe" technologies and unable to satisfy the fast growing needs of developing countries, leading to a huge and pressing environmental problem.

*“Due to their linear character, the conventional end-of-pipe solutions have become increasingly questionable. They transferred and converted valuable resources into pollutants and at the same time, a relatively small amount of human faeces is allowed to use large amount fresh water for transportation medium and therefore polluted a huge amount of water. Additionally, flush-and-discharge system is prevailingly and universally regarded as the ideal option for urban areas, even in poor countries, where people cannot afford it, water and natural resource are scarce ..... (Winblad, 1996).”*

Taking all the inconsistencies into account, a centralized system obviously cannot be applied correctly for financial and structural reasons to solve the problems in developing countries especially where the urban population is increasing rapidly. From ecological point of view, traditional centralized systems are not toward sustainable development since huge fresh water are used as transportation medium, and the opportunities for nutrients recovery in the centralized approach are slim due to mix and dilution. Hence, it directly impairs soil fertility as the valuable nutrients and trace elements are not reintroduced into agriculture.

### **1.2 Objective**

Viewed from a global perspective, the development and implementation of new urban water management concepts are imperative. However, to solve the multitude and complexity of water-related problems resulted from urbanization, and to achieve sustainable development in fast growing mega- and middle-sized cities in developing world seems like an extremely ambitious task (Keiner, 2006). High public debts, inefficient resources allocation, poor governance, lack of investment capital, unreliable legislation and law system and inadequate management capacities have ensured that the needed infrastructures could not built on time, and the existing facilities could not be satisfactory with imperative demands.

Solving water-related problems should depend on introducing innovative technologies in the water sector and, particularly, on the types of sanitation that should be included in long-term development strategies. The current dilemma and problems turned out to provide great opportunities and more spaces for developing and implementing water management on decentralized approach that offer chances for wastewater reuse and resources recovery. Accordingly, future sustainable urban wastewater management should take a holistic approach and aim at low consumption of resources, long-lasting technology and advanced treatment requirement. This concept is aimed at overcoming the traditional “end-of-pipe” technology and replacing it by an overall resource management approach, which includes minimization of the material flux, recovery of valuable materials, environmentally and economically sound distribution and use of goods and serves.

The main purpose of this paper is to prove that a well-elaborated and planned decentralized approach based on the principle of reuse-oriented ecological sanitation can be economic, ecological and environmental sound solutions in developing countries, where constructing sewer system and conventional centralized treatment plants are usually not practical and affordable. The specific objectives of this paper are:

- To demonstrate and investigate the state-of-art technological options for decentralized wastewater treatment based on source control, namely the treatment options for greywater, yellow water, brown water, and rain water;
- To demonstrate the implementation of decentralized wastewater management in a semi-urban area of Beijing (Tianxiu Garden), particularly investigate the rainwater harvesting technology for households and drinking water saving potential by the retention of rainwater; quantify the potential savings of drinking water and evaluate the water quality improvement by greywater recycling in households;
- To demonstrate the implementation of decentralized wastewater management in an industrial park (TEDA in Tianjin), particularly investigate the formation of eco-industrial chain and present the regeneration and utilization of water resources in industrial park;
- To investigate the feasibility of implementation of decentralized wastewater management based on ecological sanitation in a peripheral area of Beijing (Yang Song Township), particularly create two scenarios for domestic wastewater management (with and without ecological sanitation), investigate the water- and nitrogen flow in different scenarios, and calculate the water- and nitrogen saving potential by ecological sanitation.

### **1.3 Overall methodology**

In order to achieve the above objectives, the overall methodology that consists of several processes is presented as follows in Table 1-1.



**Table 1-1** Overall methodology

Method	Instrument	Objective
<p><b><u>Section B (Chapter 4-6)</u></b> Explication of current technical options and management tools</p>	Theoretical and fundamental determination	To demonstrate and determine appropriate technological options and management for greywater, black water and storm water
<p><b><u>Section C (Chapter 7-9)</u></b> Verification, evaluation and review of assumed instruments in practice through three case studies i) from methodological view ii) from view of technological value to reach the overall objectives</p>	Practical implementation of the concept of EcoSan: water conservation and nutrient reuse	To demonstrate the application of EcoSan-principles & to come out with integrated strategies in small communities of both semi-urban area and township in Beijing, as well as in TEDA.
<p><b><u>Section D (Chapter 10)</u></b> Feasibility, hindrance &amp; perspective analysis through gained experiences</p>	Investigation and analysis the feasibility of implementation of decentralized management	To discuss the feasibility of decentralized wastewater management, presentation of existing problem and hindrances, as well as perspective in future

The reasons why these three case studies were selected for this paper are because these case-studies take place in a relatively high-density urban area (Tianxiu Garden) and in a fast growing agglomerations of urban fringe of Beijing (Yang Song Township), as well as in a fast growing industrial park (TEDA): i) Decentralized wastewater management based on ecological sanitation has been widely implemented in rural areas or urban fringe in many places worldwide, where the demand of agricultural reuse and fertilizer products are usually immense; ii) Comparing rural areas, the implementation of decentralized wastewater management in urban areas are rather rare. Urban areas with their rapid growing populations and high population densities are in particular need of closed-loop sanitation systems; iii) To demonstrate the implementation of decentralized wastewater management in an industrial park and to present the regeneration and utilization of water resources in industrial park, TEDA was selected.

## **1.4 Definitions and system boundaries**

### **1.4.1 Definitions**

Decentralized wastewater management may be defined as the collection, treatment, and disposal/reuse of wastewater from individual homes, clusters of homes, isolated communities, industries, or institutional facilities, as well as from portions of existing communities at or near the point of waste generation (Crites, 1998). Where treatment plants have been built to serve portions of a community, they have often been identified as satellite treatment plants, but are classified as decentralized plants. And the population density suitable for decentralized wastewater treatment is defined from different literal sources, e.g., small communities fewer than 10,000 people (EPA, 2002). And in this paper the population density is limited to 5,000 people for the application of decentralized wastewater treatment. In addition, decentralized sanitation and reuse systems encompass a radical shift away from currently systems of large-scaled wastewater treatment. In a decentralized sanitation and reuse systems, waste is concentrated instead of diluted and its products will be reused for soil replenished and energy production.

Ecological Sanitation, which is often named EcoSan (GTZ, 2005), is a promising alternative approach to overcoming the lack of sanitation and negative impacts of conventional systems avoid the disadvantages of conventional wastewater system. It does not favour a specific sanitation technology, but is rather a new philosophy in handling substances that have been seen simply as waste and wastewater for disposal. It marks a paradigm change from a linear to a circular flow of nutrients and to safe water resources, as well as takes economic, ecologic and social parameters into account. The basic principle of ecological sanitation is closing the loop, which enables the recovery of the organic material, macro and micro nutrients, water, and energy contained in household wastewater and organic waste reuse in agriculture through appropriate treatment.

### **1.4.2 System boundaries**

It is apparent that the issue of urban wastewater management today is much wider than previously anticipated. The choice of type of sanitation in urban area in future has become a central issue in a complex area of future human needs, and a fundamental part of the water management challenge, connecting several issues that have seldom been connected before. This integrated water management strategy means the application of a long-term policy for developing water resource uses in a sustainable and socially balanced manner.

#### **Population density**

Unlike conventional sewerage system that can be provided to the highly developed and densely populated commercial and residential centre, decentralized water management system might serve sparsely populated housing-neighbourhoods based on small community. Also, decentralized wastewater management implies that

there may be several smaller systems with smaller treatment plant. The basic spatial pre-requisition for decentralized wastewater management can be defined as follows:

- On-site system: individual home (EPA, 2002)
- Cluster system: 2~100 homes (EPA, 2002)
- Small communities: less than 5,000 people (Otterpohl, 2001)
- Small communities: fewer than 10,000 people (EPA, 2002)

Spychala (2004) also defined and indicated that small treatment plants (*Kleinanlagen*) is suitable for fewer than 1,000 people and daily wastewater effluent should be larger than 8 m<sup>3</sup>.

### **Suitable special areas for application**

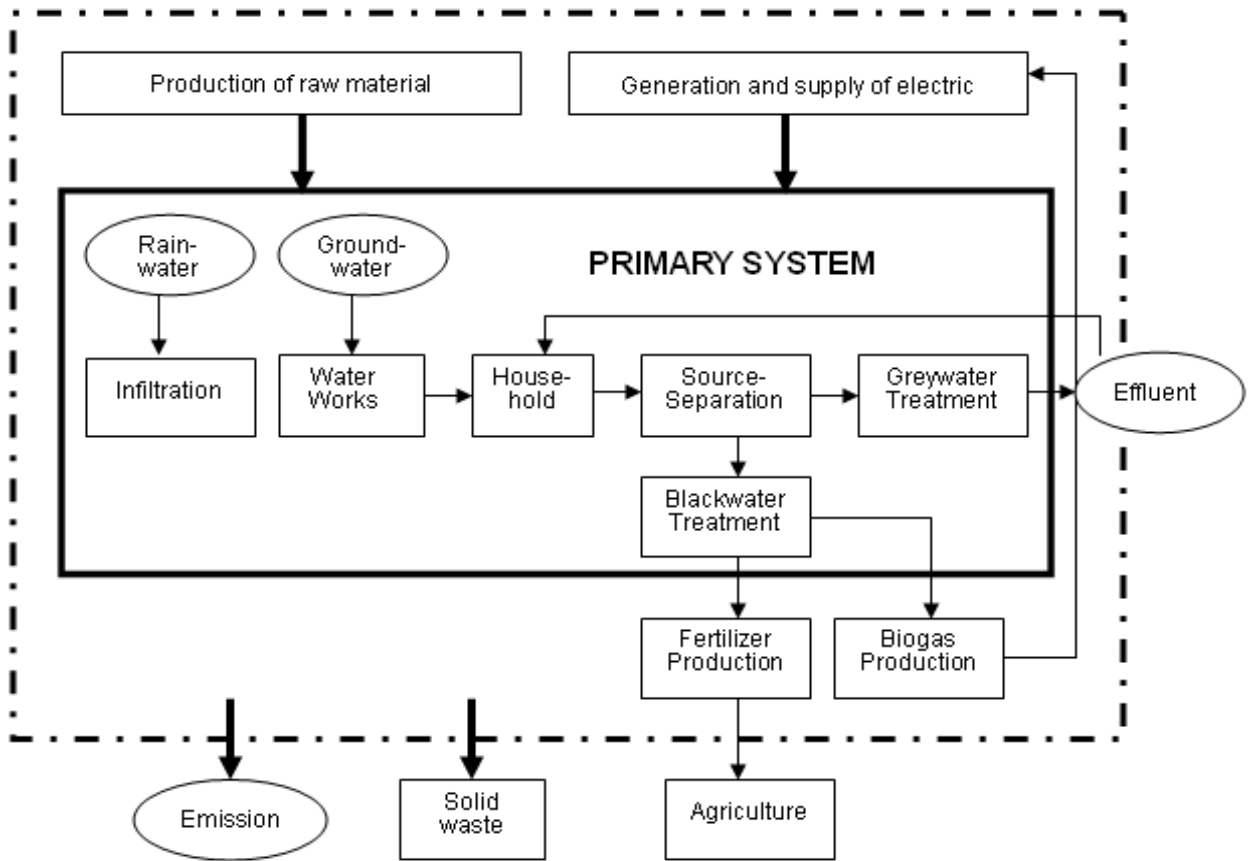
Decentralized wastewater treatment is not a new technology and was in the past decades prevailing in rural areas. However, decentralized system, which is based on ecological sanitation and focus on wastewater reuse and recycling, will increasingly be applied in many areas worldwide, especially interesting for mega-cities with growing structures, towns, semi-urban areas and urban peripheral areas, where population is dramatically increasing in developing countries.

### **Integrated water management**

Water is an essential element for human being, not only for food supply, but also for shaping living space. It is also a dispensable component for social production process and the supply of urban energy, recreation and leisure. Additionally, water is a significant factor that can affect to form the landscape structure, to secure warm supply and to keep balance of material flow - how the material can be consumed and converted. It also influences the way of energy allocation and saving (Voigt, 1997).

Therefore, nowadays the concept of decentralized wastewater management is far beyond traditional thinking and solution. It focuses not only on community-based wastewater collection, treatment, disposal and recycling, but also on rainwater harvesting and storage, groundwater protection and surface water conservation. The issues of managing urban water supply, wastewater and storm water can be viewed in an integrative manner by regarding urban areas as watersheds. Figure 1-1 presents the scope of a system for integrated water management.

When adapting decentralized management system, an overall and concerted consideration should be taken and an integrated water management strategy should be developed. Additionally, raw material flow, energy generation and resource management should be integrated into new decentralized water approach.



**Figure 1-1** Scope of a system for integrated water management

### Time span for implementation

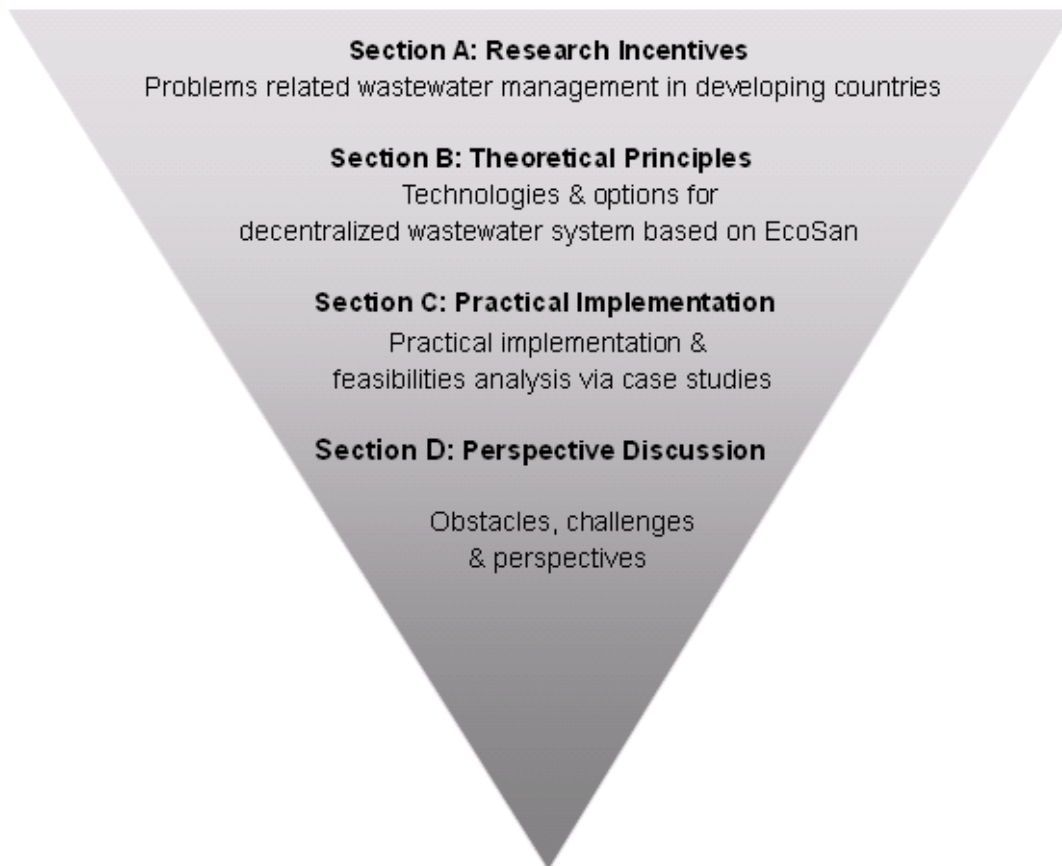
It appears unlikely at this point in time that the centralized water and wastewater systems will be replaced entirely by decentralized alternatives in the short- to mid-term. Especially in urban area, there are still great hindrances for the implementation:

- The feasibility of implementation largely depends on the individual situation of specific site, e.g., the life-span of existing centralized plant and the purification requirement of sewer system as well as initial investment;
- Limited available space with dense settlement is usually the characteristic of urban area. And the existing water supply and wastewater treatment infrastructure is dominated by large-scaled sewer and centralized plant, which is difficult to be re-constructed or upgraded to realize sustainable development based on source control of wastewater.

- In newly constructed settlements in urban fringe, there is hardly problem to implement alternative decentralized approach. However, for rebuilding of existing settlements with alternative system, e.g., separating-toilet, vacuum toilet or double sewer system, the expenditure is expecting to be significant larger due to inflexibility of existing infrastructure.

## 1.5 Structure design

The following Figure 1-2 presents the structure design for this paper.



**Figure 1-2** Structure design

**Section A** – *Research Incentive* involves the motivations of this paper and the existing current problems relating to wastewater management in developing countries.

- Chapter 2 gives a historic overview of the urban sprawl and population growth, and the emergence of mega-cities and the growth of middle-size large cities in developing countries. Subsequently, accompanied with imperative urbanization and uncontrolled urban sprawl, water-related environmental problems and challenges, the current hindrances and difficulties for problem-shooting are explicated in this chapter.

- Chapter 3 compares conventional centralized solution and decentralized wastewater management based on ecological sanitation, so as to illustrate why centralized wastewater management is not suitable for solving the current problem in developing countries. From economic and ecological points of view, there are more spaces and opportunities for implementing water management on decentralized approach that offer chances for maximum reuse and recovery of wastewater, and it seems to be a sustainable alternative since it takes resource management (soil, energy) and water management into an overall consideration.

**Section B – *Theoretical Foundations*** explicates the current technical solution and management option for decentralized wastewater management.

- Chapter 4 presents not only the analysis of greywater quality and quantity from household, worldwide experiences of water recycling and reuse, but also the guidelines and regulations for water recycling are specified. Furthermore, technological solutions and options for greywater management, ranging from natural treatment system to advanced efficiently mechanical-biological treatment system are illustrated;
- In chapter 5, brown water management by adopting different options is described, ranging from low-tech with low cost (composting in rural area) to high-tech with high cost (vacuum biogas in urban areas). At the same time, yellow water treatment is also discussed, e.g., the procedures of transportation and storage of urine, measures of reduction of nutrients' losses during urine-handling, as well as process of nutrient recovery are also presented in this chapter;
- In chapter 6, the necessity of a new rainwater management system is explained. Hence, the principle and foundation, e.g., the relationship between runoff evaporation and infiltration, site-survey are described. Furthermore, strategies for decentralized rainwater management (e.g., greened roof, rainwater infiltration, rainwater catchment and utilization) are illustrated.

**Section C – *Practical Analysis*** presents the practical implementation and analyses the feasibility of decentralized wastewater management in semi-urban areas, in industrial park and in urban fringe in China.

- Chapter 7 presents the first case study (Tianxiu Garden – 20 kilometres from city centre of Beijing) and demonstrate the implementation of decentralized wastewater water management in semi-urban area in Beijing. In the experimental practice in 2002, rainwater management designed by Geo Terra Company was to treat rainwater from the roofs of two resident-building by filter system and reuse it for toilet flushing, while the concept of greywater management was to recycle greywater from shower/basins and reuse it for toilet flushing after treatment by Rotating Biological Contactor (RBC). Moreover, the water- and cost saving potentials by the means of rainwater harvesting and greywater recycling has been analyzed.

- Chapter 8 presents the second case study (TEDA – Tianjin Technological and Economic Development Area), and demonstrate the formation of eco-industrial chain aiming to reuse the by-products or waste/wastewater of upstream enterprises as resource for the new production. Meanwhile, in order to create an integrated water management strategy with wastewater recycling and reclaim, a comprehensive discussion about integrated water management framework and its implementation at the industrial park level has been undertaken.
- Chapter 9 presents the third case study (Yang Song Township – 45 kilometres from city centre of Beijing). Two scenarios were designed to present decentralized wastewater management in peripheral area or urban fringe. Scenario 1 is designed as traditional centralized system, in which grey- and black water were combined together and discharged into surface water after treatment, while scenario 2 is designed as EcoSan system, in which yellow-, brown- and greywater were separated treated and reused. Water-flows and nitrogen mass balances of both scenarios were performed. Important results were that applying scenario 2 based on integrated water management is benefit of holistic development.

**Section D – *Perspective Discussion***, obstacles, challenges and perspectives of further development.

- In Chapter 10, the hindrances and obstacles of development for decentralized approach based on EcoSan are explicated. Meanwhile, the perspectives of further development of decentralized wastewater management are also involved.

## **2. The current situation and actual demands in China**

### **2.1 Characteristics of urban sprawl in developing world**

The urbanization and the formation of major urban metropolises are not new phenomena. For instance, cities such as London or New York started to grow significantly in the 19<sup>th</sup> century. However, the current emergence of urbanization in developing countries differs largely from that in developed countries.

#### **2.1.1 Extremely fast growth rate**

In the developed world, the development of earlier urban centres was a gradual process. For example, most of the population growth in cities (e.g. London and New York) was spread over nearly a century. Since it was a gradual development, the increase of population was thus manageable. Gradual growth rates also enabled these cities to progressively and effectively develop the necessary infrastructure and the capacities to manage their water supply and sewerage services.

In contrast, most of the urbanization in the large cities of the developing world (e.g., Mexico City, Jakarta), whose explosive growth generally took place in the last few decades. These major urban centres simply could not cope with the very high and continually increasing urbanization. They were not only unprepared to manage such explosive growths, but also they did not have the financial and management capacities to manage this change.

In China, according to official figures, in 1997, only 350 million people (30% of total population) were registered as part of the urban population, while about 70% were registered as rural. In 2030, China's population is expected to reach 2 billion (Feiner, 2005). Looking at present and future development trends and growth assumptions, we currently estimated that by 2030, China would reach the urbanization rates of semi-industrialized countries: approximately 30% rural and 70% urban. In this case, a gigantic number of 1.4 billion rural residents will have to readapt their livings in an urban way.

#### **2.1.2 Lack of necessary infrastructure**

In China, a currently crucial problem for the major urban centers stems from the fact that the rates of urbanization have generally far exceeded the capacities of the national and the local governments to soundly plan and manage the demographic transition processes efficiently, equitably and sustainably (Varis, 2006). Provision and maintenance of the needed infrastructure and services are particularly critical, as the accelerating urban growth rates have overwhelmed the limited management capacities and resources of the governments at all levels could handle.



In the past 19<sup>th</sup> century, as the urban centres of the developed countries expanded, their economies were improving concurrently as well. Accordingly, these centres were economically able to endow with financial resources so as to provide its citizens with appropriate water supply and sewerage services (Biswas, 2006). In stark contrast to the above, during the past few decades, economies of the developing world have not performed very well. Their population is growing so fast that local economics and infrastructures cannot keep up with it. Hence rapid growth can make it ever harder to improve urban conditions.

Varis (2006) indicated in many developing countries low-income cities dominate the challenge of local environment, especially in Asia the challenges are particular acute. Even though the percentage of those in Asia without adequate infrastructure for those life supporting needs are as almost same as those in Africa, the absolute number in Asia are over three times greater than in Africa and Latin America. Issues such as high public debts, poor governance and inefficient resource allocations have ensured that the investments needed to construct all types of new urban water and sanitation-related infrastructure and maintain the existing ones have not been forthcoming.

To a certain extent, many of cities in China generally fell progressively behind in constructing and managing sewage and wastewater treatment facilities due to insufficient financial support. In general, most of the infrastructure and facilities relating to water supply and wastewater disposal are invested by government. Tian & Liu (2006) estimated that China has invested over 47,180 million US\$ on the construction of wastewater treatment infrastructure since 1999. However, compared with the fast increasing demand and other industrial countries, it was far insufficient. According to the official statistic, the annual investment on wastewater infrastructure in other industrial countries accounts for 0.53%~0.88% of the local GDP, whereas the investment in China only accounts for 0.02%~0.03% of the local GDP.

### **2.2 Water-related environmental problems and challenges associated with urbanization**

Future imperative urbanization and uncontrolled urban sprawl will continuously increase the heavy burden on city infrastructures and environment until they collapse, if this situation is not addressed immediately. China is facing challenges not only in terms of overcoming widespread poverty, providing adequate infrastructure and service, and solving the problems associated with growing social inequality, but also in terms of severe inevitable environmental crisis. Unquestionably, unplanned and poorly managed urbanization processes have been an important source of social and environmental stress. The impacts of this poorly managed process have manifested in extensive air, water, and land and pollution, which will continue to have major impacts on human health of the urban dwellers of the developing world for many years to come.

### 2.2.1 Water scarcity

Although China is one of the countries with the richest oceans and lakes, it belongs to the countries with the lowest water resources (per capita) that are one fourth of the world average (Zhang & Mang, 2005). At present, most of the urban poor live in the areas without adequate access to clean water and sanitation. Moreover, half of the country's 600 cities suffered from water shortage and in one tenth cities the situation can be described as critical (Varis & Vakkilainen, 2006). The report of US commerce Department (2005) indicated there is currently annual water shortage of 40 billion cubic meters in China. Hence, as the capital of China, today Beijing is being listed among the world top ten cities suffering from lack of adequate water resources.

Varis (2006) also reported in the past few decades, for many of the developing world, ground water and surface water have already been developed. In most of the developing world like China, all the easily exploitable sources of water such as ground water and surface water, which are easy to be developed geographically, technologically and environmentally, have been over-exploited. And the remaining resources are more complex or too costly to bring to the urban areas. Hou (1998) revealed that the groundwater in North China is used at a rate much higher than that the aquifers are filled. This has caused level of groundwater to drop dramatically, in some places as much as 70 m.

This means that the water sources, which are easy to be developed geographically, technologically and environmentally, have been over-exploited. New sources of water, which could be developed cost-effectively for major urban areas of the developing world, are mostly not available. There are simply no new sources of water that could be used economically and environmentally in an acceptable manner, which can quench the continually increasing urban thirst. The rest resources are more complex to handle to the end-users. Accordingly, the costs of bringing this new water to the urban areas are becoming very high, especially compared to the cost of the earlier, or even the present, generation of water projects.

### 2.2.2 Wastewater treatment

Besides water availability, the quality of water is also a severe problem for Chinese. Biswas (2006) implied that in the coming decades, the major water problem that developing countries are facing is not likely to be physical water scarcity, but continued deterioration of water quality. Wastewater is produced in urban area, irrespective of whether it is used or not. Equally, it is essential that wastewater be treated adequately in order to reduce environmental and health hazards for the people. At present, existing unsatisfactory wastewater disposal practices can be observed in both rural and urban areas in China.

In the absence of adequate water quality management and the absence of necessary infrastructures, the local situation is deteriorating steadily. According to the report of US Commerce Department (2005), the official municipal wastewater treatment rate was 39.9 percent at the end of 2002, which is far from adequate given Chinese's serious water pollution. It has been reported by Zhang & Mang (2005) only one fifth of industrial wastewater is treated to some extent before being discharged in a waterway and the water quality of the rivers is low - only 25% of the water after treatment achieve drinking water standard.

In China wastewater treatment and disposal facilities exist usually only in the large cities, on the remote urban fringe or in some peri-urban areas, there is often no hygienic means and an even greater number lack adequate infrastructure of disposing of total wastewater. According to the statistic of US Commerce Department (2005), in counties, towns, and extensive rural areas of China, wastewater treatment rates were significantly lower and even less 20%. It is a common practice to discharge a large amount of untreated sewage directly into water bodies or put onto agricultural land causing significant water contamination and health risk. Consequently, millions of rural residents have no access to proper drainage systems, and it is mainly the low-income urban and rural dwellers, which are affected by the lack of sanitation infrastructure. Even if they do have, very few sewage-treatment facilities work well.

### **3. Centralized versus decentralized wastewater management**

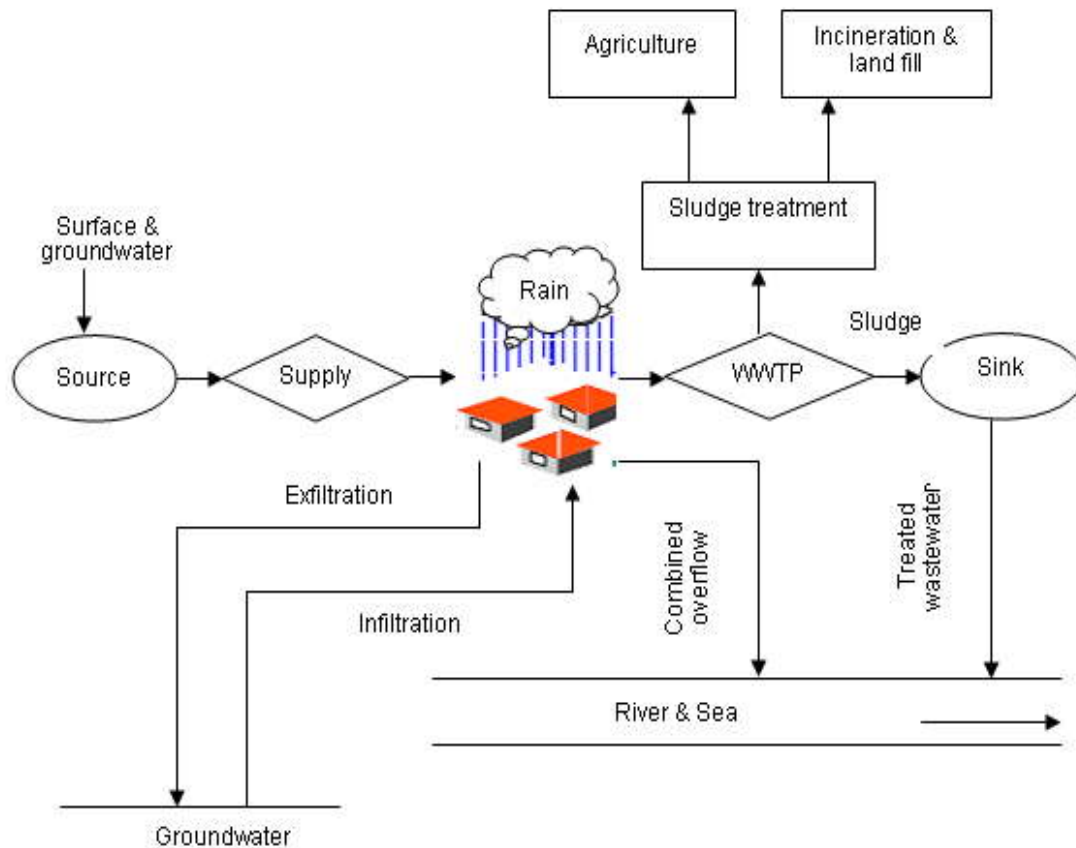
#### **3.1 Conventional centralized wastewater management**

##### **3.1.1 Introduction**

The current concept of wastewater collection, treatment and discharge is based on centralized sewer systems, which were installed in municipal areas to remove all kinds of mixing polluted liquid streams from the household. And this traditional concept is so-called “end-of-pipe” technology, as transport of sewage out of the city only shifted the problem instead of solving it at the beginning. In order to limit environmental pollution and to reduce the public health risks in waste and wastewater, wastewater and other waste from household are conveyed far away from residential sites as quickly as possible. To a large degree, conventional centralized sewage system could solve the problems of sanitation very efficiently. This is now regarded as the standard approach in industrial wastewater treatment. Figure 3-1 demonstrates the schematic concept of centralized wastewater system.

##### **3.1.2 Inherent deficiency of conventional centralized urban wastewater management with regard to sustainability**

Theoretically, the water-related problems in the developing world should also be solved by implementation of centralized system that has been prevailed in the industrialized countries during last century. However, urban planning is quite different depending on the context. Urban problem, urban development instruments and policies differ considerably from western to eastern. The transfer of technology, knowledge, and experience from developed country to developing country is extremely superficial when this is taken into consideration. Table 3-1 presents the inherent deficiency of conventional centralized wastewater management.



**Figure3-1** Schematic concept of centralized wastewater system (Adapted from Gajurel, 2003) (WWTP: Wastewater Treatment Plant)

#### **Extremely expensive infrastructure for developing world**

In fact centralized wastewater management is a very costly part of the infrastructure. Globally, investments ignoring operation and maintenance usually cost more than \$30 billion annually. By the year 2025, it could be \$75 billion annually (Esrey et al., 2001). Hence, it is well known that the investments for the pipelines to collect and transport wastewater are approximate 70%~90% of the total wastewater system (Wilderer & Peter, 2002; Winblad, 2002). Its elaborate systems of pipes, pumps and treatment plants, as well as its institutional and managerial requirements are unaffordable in much of Asia, Africa, and Latin America (Winblad, 2002).

Huge investments are required not only for installation but also for maintenance. According to Wilderer (2001), countries with an average annual per capita gross national product (GNP) of below US\$ 1,000 not only lack the resources to construct treatment plants, but also cannot maintain them. Moreover, as the lifetime of a sewer is only in the order of 50~70 years, these investments have to be made again and again. Therefore, even in the developed countries, based on the principle of “economic scale”, conventional centralized systems are simply too expensive for small communities to build.

**Table 3-1 Inherent deficiency of conventional centralized management**

<b>Drawbacks of conventional centralized system</b>	<b>Explanation</b>
<i>Extremely expensive cost of infrastructure</i>	Huge cost investment in installation, operation and maintenance of sewage network systems and treatment plants.
<i>Overflows and leakage in combined sewer systems</i>	Due to rainwater, overflows and leakage in wet weather lead to contamination of groundwater and surface water.
<i>Unaffordable energy consumption</i>	The energy consumption for operating the traditional centralized plants is unaffordable for developing world.
<i>Streams combination and dilution</i>	Waste of large amount of valuable fresh water in transportation and loss of opportunity of reusing nutrients for agriculture.
<i>Technology concern</i>	Ever-expanding sequence and complex of treatment steps significantly increase the cost of building and operation treatment plants and often require advanced skills.
<i>Contamination of downstream</i>	The nutrients and pollutants in treated wastewater have potential to lead contamination and eutrophication of receiving water in downstream during discharging.
<i>Negative impact of sludge disposal</i>	Traditional sludge treatment including incineration & landfill might result in harmful substances entering ecological system and affecting environment.
<i>Lack of flexibility</i>	Existing conventional system is inflexible to be reconstructed or updated to meet new demand, if community is under development and facing change.

**High and unaffordable energy consumption**

In conventional centralized plants, most of equipments are manufactured by man, and energy consumption for operation would be expensive since its energy sources depend on electric- and waterpower, or other energies largely depended on fossil fuel. It has been estimated that in the traditional centralized plants the energy demand, which includes degradation of organic matters, removal of nitrogen and phosphorus, and sludge treatment, is approximately 400 kJ/capita\*day (Jönsson, 1997; Zhang, 2007).

China is the second largest energy consumer after the United States and consumption of coal – its dominant fuel - is the highest in the world (Yang, 2006). Ma (1997) indicated that this is the main reason that environmental engineering cannot be universally applied in China where energy sources are poor or expensive. Also, it has been proved many projects with centralized treatment plants in developing countries did not function well as it intended or failed completely because too often the energy consumption is not affordable (Behrendt et al., 2006; Müllegger et al., 2003) .

#### **Abuse of fresh water as transportation medium**

Even if sufficient investments and energy could be made to ensure that conventional centralized sanitation systems, the problem with the current centralized technologies is they lack sustainability. Potable water, a limiting and determined factor for economic development, is often misused to transport human waste instead of being considered as valuable resource (Winblad, 2002; Otterphl, 2000; Esrey, 2001).

The current dominant centralized wastewater system in developed countries, which is essentially based on flush-and-discharge toilet and pipeline system, is mostly dependent on a high flow of fresh water. Therefore, most sewers that are heavy-user of precious potable water supplies, especially in water-poor areas, have resulted directly in ground water exploitation. Otterpohl (2000) pointed out that in some urban areas of mega-cities in developed countries, flushing toilet accounts for 20%~40% of the total water daily consumption in household. In Germany for instance, the daily drinking water demand for various household activities is 130 liter/person. And one third is used for daily toilet flushing (Wilderer & Peter, 2002).

Moreover, in the current urban wastewater management system, the streams from toilets, kitchen, washing machine, showers, office building, various enterprises, and rainwater are usually combine together, and diluted usually by using large amount of fresh water. Christ (2003) implied combination and dilution are regarded as the major reasons for the complexity of modern wastewater treatment plant, ever-expanding large-scale pipeline system, and for the high operation and maintenance costs.

#### **Loss of nutrients recycling for agriculture due to dilution**

Further problems greatly concern the agriculture sector. The important reason for choosing other solutions than water-born sanitation is that it does not facilitate the reuse of nutrients and organic residuals present in excreta. And a sustainable sanitation system must deliver the possibility of the safe reuse of nutrients in food production. The valuable organic material, nutrients and trace elements contained in human excrement are usually regarded as hazardous waste pollutants and most of them are either destroyed in the treatment process or enter the water cycle causing the eutrophication of lakes and rivers. Langergraber & Muellegger (2005) indicated even sewage sludge is used in agriculture, only a very small fraction of the nutrients are reintroduced into the living soil layers.

Otterpohl et al. (1997) claimed that the current mineral reserves for phosphorus will only last for 100 to 150 years at current levels of consumption. The relatively inexpensive phosphorous used today will almost certainly cease to exist in the next 50 years. Stenström & Jenssen (2007) implied the production of 1 kg mineral nitrogen fertilizer requires 10.5 kWh of energy. Panesar & Werner (2006) also indicated that farmers around the world require 135 Mio tons of mineral fertilizer annually for crop production, while at the same time conventional sanitation dumps 50 Mio tons of fertilizer equivalents with a market value of around 15 billion US\$ annually into our water bodies.

Therefore, the conventional end-of-pipe technology does not correspond to the basic criteria of sustainability - on the one hand, nutrients are eliminated in conventional treatment processes; on the other hand, production of these nutrients needs a relatively high amount of primary energy. Thus there is an urgent necessity to develop strategies of sustainable management that could control both water and nutrient flows in urban area, in order to achieve the objective of cost reduction, handling efficiency, food production increasing, environmental integrity and social benefits.

#### **Technological concern**

The historical development of wastewater treatment technology has led to an ever-expanding sequence of treatment steps, and a significant increase of the cost for building and operating treatment plants. Moreover, operating treatment plants often requires advanced skills and knowledge.

At the beginning, sedimentation would be sufficient. However, it could lead to severe impacts on ecology in the receiving waters and therefore biological wastewater treatment was then developed. Biological treatment was firstly aimed at the biodegradation of the organic matter. Soon, it became obvious that high concentration of ammonia caused oxygen depletion in the receiving water. Thus, nitrification process based on the oxidation of ammonia to nitrogen was introduced. Still, the water quality in rivers deteriorated due to eutrophication. Denitrification and phosphorus removal technologies were added as further treatment steps. Disinfection technology to lower the concentration of bacteria and viruses is considered as an additional step in order to keep the quality of the receiving waters at highest level.

Chris (2003) implied another critical technological concern is terminal product generated by the treatment approach currently applied. The traditional processes are focused on conversion of the wastewater constituents into inorganic products such as carbon dioxide (CO<sub>2</sub>) and water (H<sub>2</sub>O). However, it would be economically and ecologically far more advantageous to focus treatment process on the production of substance, e.g., methane (CH<sub>4</sub>), fertilizer, energy CHP (cogeneration of heat and power).



#### **Overflows in combined sewer system during wet weather**

In the centralized wastewater system, most existing sewer systems are combined systems, which were designed to discharge both wastewater and rainwater to a receiving water body as fast as possible. These combined systems have brought inevitably environmental problems particularly during heavy storm. The emergency overflow and caused by heavy rain in summer time has drawn worldwide attention. It is not economically feasible to transport all this storm water to a wastewater treatment plant during wet weather.

During dry weather conditions, the flow is only a fraction of the maximum flow during storm-events. In the temperate climate of central and northern Europe, the peak flows can easily be up to a many times higher than that in dry weather. Heip et al. (2001) indicated during rain events sewage discharges increase by factors of 8-12 above dry weather flows due to influx of storm water into sewer system. Hence, the elimination of sewer overflows during wet weather by using centralized approaches is expensive.

When rainwater flows over the streets, water that falls during rainstorms mixes with pollution, which can include toxic particles from motor oil, and other garbage. Nearly all the rain that fall on the sidewalks, rooftops and streets goes into combined sewer pipes. Although the amount of rainfall is highly variable from season to season, traditional storm water systems must be built to accommodate the periods of heaviest rainfall. This means the system is expensive to build and have more capacity than needed most of the time, even though uncommonly large storm can still overload it.

Consequently, storm water during wet weather conditions is a threat to the conservation of groundwater, since over-load rainwater in the combined sewers might overflow into groundwater. Diluted wastewater enters into the environment without any treatment. Moreover, the contaminant loading is also fluctuating because of the diluting effect of storm water and may reach the amount of polluting load in the treated water leaving the treatment plant. As a result more pollution load could enter the surface water by combined sewer overflow during heavy rains. In addition, no wastewater treatment process is flexible enough to treat such fluctuating flows.

#### **Leakage in sewer system**

Leaking sewer pipes are a substantial worldwide. A study concluded the leakage of wastewater from sewer pipes amounted to 10% percent of average daily wastewater flow, or five million gallons per day (Heip, et al. 2001). In some areas, leaking sewers may be a greater source of ground water and surface water contamination across the country than are septic systems. Since combined systems have potential to emit raw wastewater, leaking of sewers can cause high risks of contamination of the environment and lead to exfiltration of wastewater into the groundwater or infiltration of groundwater into the sewers. This is generally regarded as a substantial problem existed in conventional sewerage system.

There are many factors could result in leakage in pipeline system underground. Heip, et al. (2001) indicated that under anaerobic conditions in sewers, hydrogen sulphide ( $H_2S$ ) will be formed and then oxidised again with the formation of sulphuric acid, which will damage concrete, which is the most commonly used material for sewers. He reported that the leakage problems in the developing world are even worse due to lack of financial support for operation and maintenance.

#### **Contamination of downstream**

As a matter of fact, the conventional sanitary system has a potential to transfer a domestic health problem into the entire settlement or catchment. Therefore, it is obvious that if wastewater is not properly treated, organic or inorganic nutrients and pollutants will lead to the contamination and eutrophication in receiving water body in downstream during discharging. Consequently, the downstream water users have to install expensive clarifying equipment to cover their demand for drinking water from surface water. Severe problems without adequate treatment in some developing countries would accelerate the deteriorating conditions in water downstream.

The emissions of treated wastewater might be large even if the sewage is treated by an advanced and well functioning centralized sewage treatment plant. Such a plant might reduce the nitrogen emissions by 50%, the phosphorus emissions by 95% and  $BOD_5$  emissions by 95%. Even so, for nitrogen-, phosphorus and  $BOD_5$  emission would be 6 g/capita\*day, 0.08 g/capita\*day and 1 g/capita\*day (Jönsson, 1997). If the population density is high and the recipient is small, these emissions will also lead to the eutrophication in receiving water bodies. Since the key factor in the centralized treatment concept is “control”, violation of quality standards may have serious consequences.

Further concern is the discharge of hormones and medicament residues (e.g., antibiotics) has also potential to contaminate water bodies in downstream and resulted in a negative effect on the provision of drinking water (Rakelmann, 2003). Micro pollutants are becoming an increasing concern, e.g. residues of drugs enter the wastewater via human excrements. It is most probable that these substances are not accumulated in the sewage sludge. Due to high dilution with fresh water in the transportation, an elimination of micro-pollutants in the “end-of-pipe” wastewater process is not possible or at least has a very poor efficiency. As a consequence the number of resistant bacteria increases.

#### **Negative impact of sludge disposal**

Even after treatment, the sewage sludge from central municipal treatment plants are often loaded with harmful materials (Wilderer, 2001). The sludge often contains heavy metals such as Cadmium (Cd) that accumulate in the human body during the lifetime and can potentially cause kidney disease in long-term. Sludge also contains many other compounds such as drugs, and substances similar to hormones, dioxins, and might cause inheritable genetic changes of organisms.

All the compounds mentioned above and other persistent hazardous substances found in sewerage sludge will, sooner or later, enter surface water bodies and ground water. Traditional sludge treatment including incineration and deposition might result in air pollution and thus an expensive post treatment is required. It can also lead to potentially harmful substances or hazardous by-products entering ecological systems, and later, human bodies. In the long-term, these substances may also enter agricultural products. If wastewater sludge is deposited in a landfill, it may continue to affect the environment for decades through the loss of the nutrients and the production of methane (CH<sub>4</sub>) from the anaerobic degradation of organic matter. Also, Kujawa-Roeveld (2001) concluded the problems related to landfill are lack of space, the uncontrolled emission of greenhouse gases and the possibility of groundwater or soil contamination due to leakage.

#### **Lack of flexibility**

Lack of flexibility is another drawback of conventional centralized system. Usually the wastewater treatment system was planned according to the status and requirement of that time. With fast development, when the community becomes larger and there are new demand and requirements for wastewater management, it is difficult to reconstruct or update the existing system, since the conventional system is dominated by large-scale pipeline system and the hydraulic capacity is limited.

Moreover, with the tendency of urban population shrinking particular in developed countries, it is obvious the centralized wastewater system seems not to be compatible with the changing settlement structure. This is also consequence of earlier urban planning methods – wastewater planning always runs after urban- or regional planning. In future, the decentralized wastewater approach should be integrated into urban planning in initial stage and as early as possible.

## **3.2 Decentralized wastewater management based on ecological sanitation**

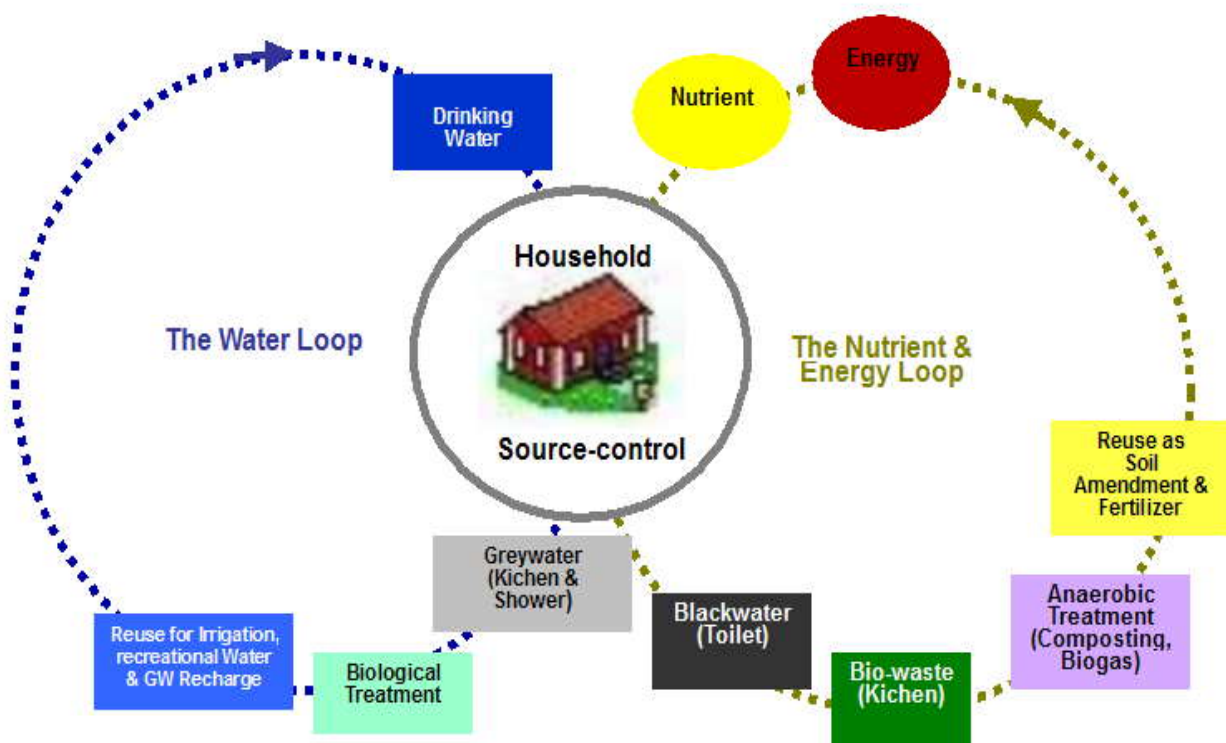
### **3.2.1 The principle of ecological sanitation**

According to Langergraber (2005), the basic motivation behind the need to reshape the management of nutrients and streams of organic residual in the society may be found in “basic system conditions for sustainable development” for water and sanitation management, formulated in the Agenda 21:

- The withdrawal of finite natural resources should be minimised.
- The release of non-biodegradable substances to the environment must be stopped.
- Physical conditions for circular flows of matter should be maintained.
- The withdrawal of renewable resources should not exceed the pace of their regeneration.

Ecological Sanitation is a promising alternative approach to avoid the disadvantages of conventional wastewater system. It is different from conventional approaches: a closed-loop sanitation, in which water from household and the valuable nutrients from human excreta (urine and faeces) are considered valuable resources to restore for soil fertility and to increase food production (Winblad, 2004; Otterpohl, 1997; Esrey et al., 2001; Langergraber, 2005). It is a sustainable system, which are based on an overview of material flows as part of an ecologically and economically wastewater management system tailored to the needs of the users and to the respective local conditions (Panesar & Werner, 2006). It does not favour a specific sanitation technology, but is rather a new philosophy in handling substances that have been seen simply as waste and wastewater for disposal.

Moreover, ecological sanitation is an alternative to overcoming the lack of sanitation and negative impacts of conventional systems (Jessen, 2004). It marks a paradigm change from a linear to a circular flow of nutrients and to safe water resources, as well as takes economic, ecologic and social parameters into account, but not by promoting a single new technology - only new sanitation principles and concepts (Esrey, 2001). The basic principle of ecological sanitation is closing the loop, which enables the recovery of the organic material, macro and micro nutrients, water, and energy contained in household wastewater and organic waste reuse in agriculture through appropriate treatment. These are the reasons why ecological sanitation may be more appropriate in developing countries than conventional systems. Figure 3-2 presents the basic principle of ecological sanitation.



**Figure 3-2** Circular flow in an Eco-San system (Adapted from Stenström & Jessen, 2007)

### 3.2.2 Source control – the basic step toward sustainable development

The change in the sanitation management paradigm from flush-and-discharge to recycling urine and faeces has gained increasing attention in Europe (Otterpohl, 2000; Otterpohl et al. 1997; Strauss, 2000). The fundamental and optimal strategy of innovative and integrated water concepts is based on the principal of separating different flows of domestic wastewater according to their characteristics to optimise the potential for reuse. Source control and separating should be the basic step toward sustainable development. To find sustainable and technically useful solution, it is necessary to look at the water and material flows in detail. The below Table 3-2 shows the very different characteristics of domestic wastewater flows with reference to their volumes and loads per capita per year.

**Table 3-2** Typical characteristics of the main components of household wastewater (Otterpohl, et al., 2002; Gajurel, et al., 2003; Langergraber, 2005)

		Greywater	Urine	Faeces
Volume (litre/capita*year)		25,000~100,000	500	5
<b>Yearly loads (kg/capita*year)</b>				
Nitrogen	~ 4~5	~3%	~ 87%	~ 10%
Phosphorus	~ 0.45	~10%	~ 50%	~ 40%
Potassium	~ 1.8	~34%	~ 54%	~ 12%
COD	~ 30	~41%	~ 12%	~ 47%

Household wastewater is generated as a result of household activities. Each activity produces wastewater of different characteristics. Wastewater from washing, cooking, bathing/showering, cleaning dishes, preparation of food – called *greywater*, which contains low nutrients, but has very large volume compared to wastewater from defecation and urination. Wastewater from urination – called *yellow water*, which contains most of nutrients whereas *brown water* – wastewater from defecation, which contains most of pathogens causing disease as well as nutrients and organic matter.

The yearly consumption of water per person is about 50 m<sup>3</sup>, while only 0.5 m<sup>3</sup> of urine and faeces are produced (Behrendt et al., 2006). The composition of greywater varies greatly and reflects the lifestyle of residents and the choice of household chemicals for laundry. While the water consumption in water-scarce area is about 20~30 litres per person per day, a person in a richer area many generate several hundreds of liters a day. Generally, in traditional sewer systems greywater constitutes 70% of the wastewater volume flow (Müllegger, 2003).

Also, greywater may contain more than 50% of the organic matter and a substantial amount of bacterial and viruses (Jenssen & Vråle, 2003). Thus it can be

expected to contain far lower densities of pathogens than effluent water from an advanced wastewater treatment plant. Treated greywater can thus be expected to have a much better hygiene quality than any kind of mixed wastewater. Based on measured coprostanol, the faecal contamination to the greywater was estimated as 0.04 g/capita\*day, while normal faecal load in mixed wastewater from households is about 150 g/capita\*day (Ridderstople, 2004).

Furthermore, only 10% of nitrogen, 26% of the phosphorus and 21% of the potassium is found in the greywater (Jenssen & Vråle, 2003). Therefore, separation of urine and faeces leads up an approximate reduction of 90% nitrogen as well as 80% phosphorus in the remaining wastewater. Comparing with municipal wastewater, greywater contains fewer nutrients and nutrients removal becomes a minor issue. In some greywater high concentration of phosphorous, which comes from washing and dish-washing powder, can be found (Ridderstople, 2004). If people use only P-free detergents, the phosphorus content of the greywater should be reduced.

Yellow water (human urine) normally does not contain pathogens. Most of the nutrients in household wastewater come from human urine, approximately 80% of nitrogen and more than 50% of phosphorous and potassium. Phosphorus is equally distributed between urine and faeces. However, urine only contributes 1% of the volume of household wastewater (Vinnerås, 2002).

Brown water (human faecal excreta) are the main source of pathogenic organism and therefore responsible for the major hygienic hazard. Excreta are a rich source of plant nutrients such as nitrogen, phosphorus and potassium, and of organic matter. Each day, human excrete in the order of 30 g of carbon (90g of organic matter), 10-12 g of nitrogen, 2 g of phosphorus and 3 g of potassium. Most of the organic matter is contained in the faeces and can be submitted to decomposition processes (Strauss, 2000). Excreta are not only a fertilizer. Its organic matter content, which serves as a soil conditioner and humus replenisher, is an asset not shared by chemical fertiliser.

#### **3.2.3 Decentralized wastewater management**

Proper decisions on where to connect houses to a sewerage system and where to build on-site facilities or small decentralized plants are the key issue for the economics of the whole wastewater infrastructure (Langergraber, 2005). Good regional planning can avoid the deadlock of very expensive pipeline systems that usually cost approximately 80% of total investment, which could serve the environment in highly efficient decentralized treatment and collection system.

For a sustainable development in China, the absence of infrastructure creates a demand for small-scaled wastewater treatment and improved sanitation facilities. Limited investment should be expected in decentralized naturally based infrastructure and urban wastewater systems that promote the recovery and reuse of wastewater resources, rather than in traditional centralized systems that are costly intensive and technologically complex. Providing access to sufficient quantities of safe water and

the facilities for a sanitary disposal of excreta, as well as recycling valuable nutrients in the wastewater as fertilizer in a cost-effective and energy-saving way are of significant importance to solve multifold water-relating problems.

Decentralized wastewater management may be defined as the collection, treatment, and disposal/reuse of wastewater from individual homes, clusters of homes, isolated communities, industries, or institutional facilities, as well as from portions of existing communities at or near the point of waste generation (Crites, 1998). Where treatment plants have been built to serve portions of a community, they have often been identified as satellite treatment plants, but are classified as decentralized plants. Centralized wastewater management, on the other hand, consists of conventional wastewater collection system, centralized treatment plants, and disposal/reuse of the treated effluent, usually far from the point of origin.

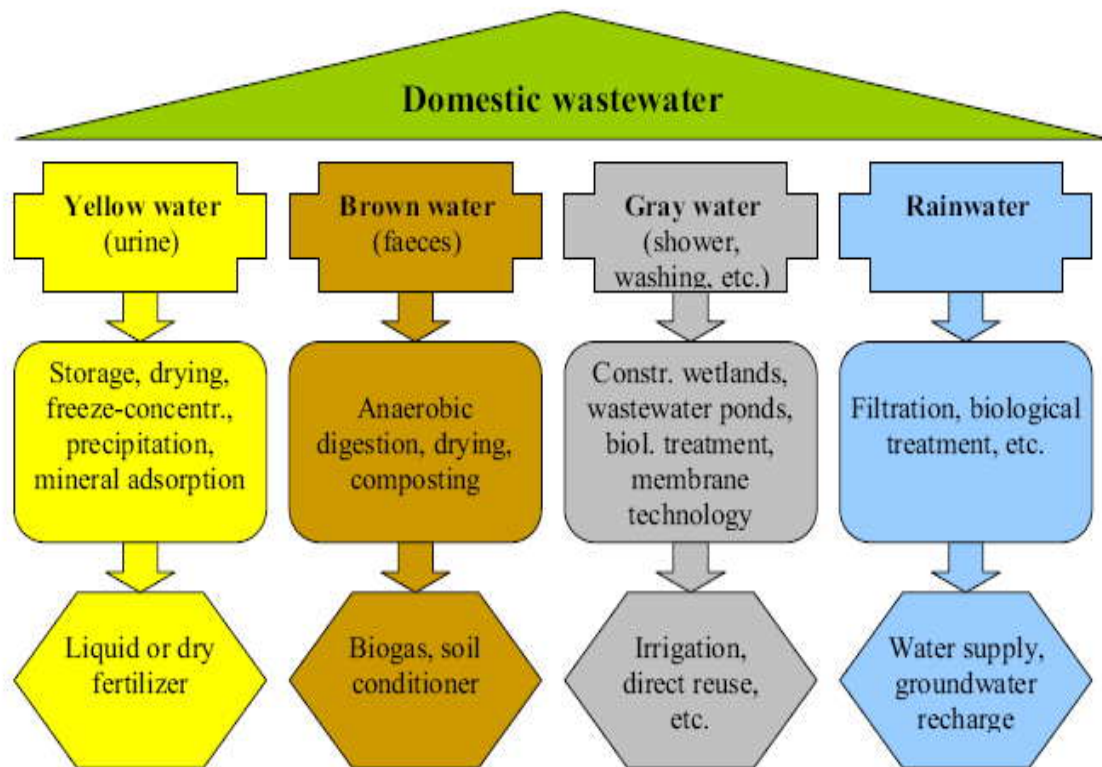
Decentralized wastewater systems, often called „septic“ or „onsite“ systems, derive their name from their location – they treat wastewater close to the source, typically providing treatment on the property of individual homes or businesses (Crites, 1998). Decentralized systems also include systems serving clusters of individual homes, large capacity septic systems, and small collection and treatment systems. These systems similarly treat wastewater close to the source, typically using small pipes for collecting small volumes of domestic wastewater, unlike centralized urban wastewater treatment systems that pipe large amounts of wastewater many miles through sewers prior to reaching the treatment facility.

Whilst centralized systems are necessary in densely populated urban areas, precedence is normally given to appropriate decentralized facilities in semi-urban areas. The essential advantage of such non-centralized systems is their flexibility and they can adapt easily to the local conditions of the urban area as well as grow with community as its population increases. The reduction of size and length of sewers can also contribute to the investment and maintenance cost. Also, neighbourhoods can become involved in the construction and operation of their own sanitation systems, thus mitigate the burden on the governmental finance and increasing the system suitability.

#### **3.2.4 Decentralized wastewater management based on ecological sanitation**

In view of the individual types of wastewater that are very varied, it becomes obvious that it cannot be rational for technical and economical reasons to mix the flows and combined flow. The new goal of urban wastewater management is not only the safe disposal of human residuals, but also safe reuse of nutrients from sanitary systems and organic parts of solid wastes in agriculture without a harmful accumulation of toxic substances in soil, surface water bodies and groundwater.

Figure 3-3 shows typical decentralized wastewater treatment based on source separation.



**Figure 3-3** Decentralized wastewater treatment based on source separation (Jenssen & Vråle, 2003)

Panesar & Werner (2006) claimed as ecological sanitation does not prescribe a particular technical solution, but rather tailors sanitary system to fit the needs of social, economic and environmental sustainability in a given context, a wide range of technologies are being used in ecological sanitation systems and reuse-oriented decentralized wastewater systems. Many of these have proven to be a viable alternative to conventional centralized system.

These range from quite simple low-tech systems to complicated high-tech solutions. On the low tech side, the use of system components such as urine diversion dehydration toilets or composting toilet is common. For such systems, faeces and urine are most often collected and treated on site. High-tech components can include the use of vacuum technology to collect either black or brown water centrally with reduced water consumption, struvite precipitation for the recovery of nutrients, and membrane technology for the recycling high-quality water for irrigation and domestic purposes. Hence, these technologies can also be combined with other treatment technologies such as constructed wetlands and ponds for greywater treatment, anaerobic digesters or humification for sludge treatment to optimally address the treatment and resource recovery needs in a particular area. Such flexibility in the choice of system technologies makes ecological sanitation suitable for various situations.



## 4. Greywater management

### 4.1 Greywater quality and quantity from household

The household greywater, which is generated from different sources, e.g., kitchen, shower, bath, and washing machine, usually vary significantly in characters. Figure 4-1 summarized the characteristic of greywater from different countries. Figure 4-2 gives an example of the greywater consumption of Germany in 1983 and 1994. And a declined tendency of greywater consumption in Germany can be recognized in Figure 4-2.

**Table 4-1** Characteristic of Greywater from different countries

Parameter	Germany <sup>1</sup>		USA <sup>2</sup>	Sweden <sup>2</sup>	Australia <sup>2</sup>
	a	b			
BOD <sub>5</sub> (mg/l)	280~360	150~250	162	196	159
COD (mg/l)	500~600	250~430	366	-	-
Turbidity (NTU)	-	-	-	-	113
Total Coliform (CFU/ml)	1000~1,000,000	1,000~100,000	240,000	36,000	-
Fecal Coliform (CFU/100ml)	100~100,000	1,000~100,000	-	-	-
Total N (mg/l)	8~18	-	-	6.5	11.6
Total P (mg/l)	2.5~4.5	-	-	7.8	-
pH	-	-	6.8	-	7.3

Explanation

1: Nolde, (1996)

a: Household greywater with water-saving facilities

b: Household greywater with water-saving facilities, excluding water from kitchen

2: Li, (2004)

**Table 4-2** Greywater consumption in Germany (Litre/day\*capita) (Li, 2004)

Different types of using greywater	Consumption (in 1983)	Consumption (1994)	Consumption range
Dish-washing	8	4	4~6
Washing machine	16	19	20~40
Personal hygiene	8	10	10~15
Bath	40	20	20~40
House cleaning	3	3	3~10
Total	75	56	57~111

## **4.2 Guidelines and regulations for water recycling**

Obviously, the implementation of wastewater reclamation, recycling and reuse can promote the preservation of limited water resources in connection of watershed protection. In the planning and implementation of water reclamation and reuse, the intended water reuse application requires the quality of the water produced, and the method of water distribution and application (Asano, 1998).

The greywater, which will be reused for different objectives, should fulfil specific requirements with respect to hygiene and other aspects and it must be constrained with the limited value of microbiological and physical-chemical parameters. These values are regarded as guidelines for single parameter or group parameters.

However, only a few countries have well-established guidelines for water reclamation and reuse, and the value of reclaimed water has been fully recognized (Sakgot, 2001). In these countries, where laws and regulations exist, mandate water reuse under certain conditions. In 1992, the U.S. EPA (Environmental Protection Agency) constituted “Guideline for Water Reuse” – the regulations regarding wastewater reuse, which was formulated based on previous existing regulations of 1990 (U.S. EPA, 1992).

In addition, various countries, e.g., Israel, South Africa, have also established regulations or guidelines. Today, regulations for using reclaimed water for irrigation are being prepared in Spain, Italy and Greece (Salgot, 2001). Guidelines that even are not enforceable can be used in the development of a reuse program.

### **4.2.1 Guidelines for household reuse**

In Germany, there is no legal minimum quality requirement of the recycling water for household reuse (Li, 2004). In other countries, according to WHO (World Health Organisation), different requirements of recycling water for household use have been established. In Table 4-3 threshold value for different parameters in different countries are summarized.

**Table 4-3** Summary of water quality requirement from different countries for household reuse (US. EPA ,1992; Asano, 1998; WHO,1998)

Parameter	Value				
	WHO	Australia	Japan		U.S.EPA
			Toilet Flushing	Garden Irrigation	
Fecal Coliform	-	<1 in 100 ml	-	-	0/100 ml
Total Coliform	<200	<10 in 100 ml	<10,000 in 100 ml	Not detectable	-
Viruses	-	<2 in 50 ml	-	-	-
Parasite	-	<1 in 50 ml	-	-	-
Turbidity	-	< 2 NTU; or < 5 NTU in 95% of samples	Acceptable	Acceptable	≤ 2 NTU
pH	-	6.5~8.0 (permitted) 7.0~7.5 (desired range)	5.8~8.6	5.8~8.6	6~9
Colour	-	< 15 TCN	Acceptable	Acceptable	-
Cl <sub>2</sub>	-	-	> 0	> 0.4 mg/l	≥ 1 mg/l
BOD <sub>5</sub>	-	-	-	-	≤ 10 mg/l

**Table 4-4** Standard for community wastewater reuse in Germany (Schütze, 2005; BGBl. Abwasserverordnung, 2002; Krekeler, 2002)

Treatment scale based on population-density	BOD <sub>5</sub> (mg/l)	COD (mg/l)	Ammonium (NH <sub>4</sub> <sup>-</sup> ) (mg/l)	Total N (mg/l)	Total P (mg/l)
<50 (Hamburg)	20	90	10	25	-
50~150 (Hamburg)	15	75	10	18	-
<1,000	40	150	-	-	-
1,000~5,000	25	110	-	-	-
5,000~10,000	20	90	10	-	-
10,000~100,000	20	90	10	18	2
>100,000	15	75	10	13	1

In Germany, since 1976 after the establishment of “Novelle des Wasserhaushaltsgesetzes (WHG)”, the minimum standard requirement for wastewater reclamation was set up (Li, 2004). This requirement was based on the technique statue, which means to reduce emission in wastewater based on the technologically and economically available processes.

Also, in Germany, the decomposition capacities of treatment plants have to comply with its dimension, measured as connected inhabitants. The larger the plant is, the higher the decomposition capacity must possess (Krekeler, 2002). Hence, wastewater generated from different scales of community and thus the standards for reusing are not completely same. Table 4-4 presents the minimum standard for community wastewater reuse in Germany.

The important requirements of EU-Guideline for quality of bath water are presented below in Table 4-5.

**Table 4-5** EU-Guideline for the bath water quality (Li, 2004)

Parameter	Required Value
Total Coliform	10,000 / 100 ml
Fecal Coliform	2,000 / 100 ml
Salmonellae	0 / 1 L
pH value	6~9
Colour	No abnormal changes of colour
Mineral oil	No visible film on the surface of water
Odour	No odour
Phenol	< 0.05 mg
Intestine Viruses	0
Transparence	1 m in visible deepness

### 4.2.2 Guidelines for groundwater recharging

The groundwater recharging by using treated wastewater could be realized via different ways. The treated wastewater infiltrate through unsaturated zone, until reaching groundwater level and move to the nearest well. The soil treatment processes consist of chemical or biological adsorption, transformation and so on. The methods of groundwater recharging include surface infiltration and direct injection. The surface water infiltration makes full use of the infiltration-capacity of soil. And the direct injection usually requires higher treated water quality demand than infiltration. For the surface infiltration, the requirement depends largely on the site condition.

Currently there are several commended criteria for groundwater recharging. Only in USA, the legal foundation of the indirect reuse of treated water in community level has been established. The law of "Guidelines for Water Reuse" set up by U.S.EPA has been formulated and carried out by several states, e.g., California, Florida, Washington, Texas, Oregon and Arizona (Li, 2004). In states with no specific regulations or guidelines on water reclamation, programs may be permitted on a case-by-case basis.

Reclaimed water can be used to replenish groundwater by direct injection and rapid infiltration (Metcalf, 2003):

➤ *Surface spreading*

It is the simplest, oldest and most widely used for groundwater recharge. The reclaimed water is percolated from spreading basin through an unsaturated groundwater zone, where total suspended solids in reclaimed water can be removed. Infiltration basins constructed on highly permeable soils, however, large land surface may be required for percolation.

➤ *Direct injections*

It is practiced where groundwater is deep or where hydrogeological conditions do not allow surface spreading of reclaimed water. Also, the lack of available land for surface spreading makes direct injection is only option for groundwater recharge. And it is an effective method to create fresh water barrier against seawater intrusion in coastal region. However, this process can be costly and injected water may not be fully recovered.

Table 4-6 shows the criteria for groundwater recharging in the state California (1992) (Asano, 1998). The implementation of the rules is dependent mainly on recharging technique (infiltration or injection), and soil infiltration technologies (category I ~ III), minimum distance to groundwater aquifer, infiltration rate, distance to the nearest well for drinking water exploitation. Table 4-7 presents the requirements of wastewater water reuse as groundwater recharging by using different recharging methods.

**Table 4-6** Recommended criteria for groundwater recharging by wastewater recycling in California, USA (1992) (Asano, 1998)

Requirement	Category			
	Infiltration of soil surface			Direct injection
Treatment grade	I	II	III	IV
Pre-treatment and biological process	X	X	X	X
Filtration	X	X	-	X
Removal of organic matter	X	-	-	X
Desinfection	X	X	X	X
Max. Percentage of discharged wastewater in well extraction	50%	20%	20%	50%
Distance (m) to groundwater with infiltration rate/speed				
50 mm/min	1	1	2	N.A.
80 mm/min	2	2	5	N.A.
Detention time in subsurface (month)	6	6	12	12
Horizontal distance (m)	50	50	100	100

**Table 4-7** Requirements of wastewater water reuse as groundwater recharging by using different recharging methods (Asano, 1998)

Infiltration or injection in non-drinkingwater-aquifer	Depend on site condition and reuse objective
Indirect reuse as drinking water through infiltration in groundwater aquifer	Depend on individual site condition. The demand of drinking water quality should be desirable after infiltration through vadose zone
Indirect reuse as drinking water through direct injection in groundwater aquifer	Minimum requirement: pH=6.5~8.5 Turbidity $\leq$ 2NTU Fecal Coliform: 0/100 ml Cl <sub>2</sub> $\geq$ 1mg/l fulfil requirement of drinking water quality

### 4.2.3 Guideline for portable water generation

The highest water quality requirement should be drinking water. The general requirements for drinking water quality can be formulated as follows:

- Drinking water should be free of pathogens and viruses, which have potential to cause disease and health impairment.
- Drinking water, wherever it come from rivers, lakes, reservoirs, springs, or groundwater wells, should be served to meet health-based standard to protect against contaminants that may be found in drinking water. Therefore, it should be basically clean, cool, no colours and odours, and safe to be used.
- The soluble substances in drinking water should be kept in limited amount. The content of certain substances, e.g., Fe, Mn, organic related matters, should be remained as few as possible.
- Drinking water should preferably not bring about corrosion.

Table 4-9 presents the guideline of WHO for drinking water standard.

### 4.2.4 Guideline for surface water discharging

In many countries and areas of the world, wastewater after treatment discharging to surface belongs to the simplest way. Typical treated effluent standards for surface discharging applied in many countries and comparison with irrigation standard are given in the following Table 4-8.

**Table 4-8** Standard for surface water discharging (Krekeler, 2002)

Parameter	Discharge in surface water		Discharge in sensitive water	Reuse for irrigation
	High quality	Low quality		
BOD [m/l]	20	50	10	100
TSS [mg/l]	20	50	10	<50
Kjeldahl-N [mg/l]	10	-	5	-
Total N [mg/l]	-	-	10	-
Total P [mg/l]	1	-	0.1	-
Faecal Coliforms [No./100ml]	-	-	-	< 1,000
Nematode eggs/l	-	-	-	< 1
Total Dissolved Solids [mg/l]	-	-	-	< 500

**Table 4-9** WHO Guidelines for drinking water (1998) – requirements for physical parameters and substance (WHO, 1998)

Parameters	Chemical Symbol	WHO	TrinkwV2001
<b>Microbiological parameters</b>			
E. Coli	-	0/100 ml	0/100 ml
Total Coliform	-	0/100 ml	0/100 ml
<b>Physical parameters</b>			
Colour	-	15 TCU	0.5 pro m
Odour	-	-	-
Temperature	-	-	-
Turbidity	-	5 NTU	1 NTU
<b>Chemical - anorganic matters (mg/l)</b>			
Aluminium	Al	0.2	0.2
Ammonia	NH <sub>4</sub> <sup>+</sup>	1.5	0.5
Arsenic	As	0.01	0.01
Cadmium	Cd	0.003	0.005
Chloride	Cl	250	250
Chromium	Cr	0.05	0.05
Copper	Cu	1	2
Iron	Fe	0.3	0.2
Fluoride	F	1.5	1.5
Lead	Pb	0.01	0.01
Manganese	Mn	0.1	0.05~0.2
Silver	Hg	0.001	0.001
Nickel	Ni	0.02	0.02
Selenium	Se	0.01	0.01
Zinc	Zn	3	-
Nitrate	NO <sub>3</sub> <sup>-</sup>	50	50
Nitrite	NO <sub>2</sub> <sup>-</sup>	0.2	0.5
<b>Chemical - organic matters</b>			
Toluene	-	24~170 (µg/l)	-
Xylene	-	20~1800 (µg/l)	-
Styrol	-	4~2600 (µg/l)	-
1.2- dichlorobenzene	-	1~10 (µg/l)	-
1.4- dichlorobenzene	-	0.3~30 (µg/l)	-
Benzene	-	0.01(mg/l)	0.001(mg/l)
Trichloroethene	-	2 (mg/l)	0.01(mg/l)
Dichlormethane	-	0.07 (mg/l)	0.05 (mg/l)



### **4.3 Criteria of technology options**

Compared with mixed wastewater, greywater is harmless from an environmental and hygienic point of view, thus the requirements for the treatment of greywater are lower than for the treatment of municipal wastewater since nutrient removal is not essential. Therefore only COD removal is required (Otterpohl, 2000; Gajurel, 2003; Jenssen & Vråle, 2003). However, up to date it should be stressed that there is still little knowledge and experience of greywater treatment in urban areas and in different climate. Also, most experiences are from cold climate regions (Ridderstolpe, 2004).

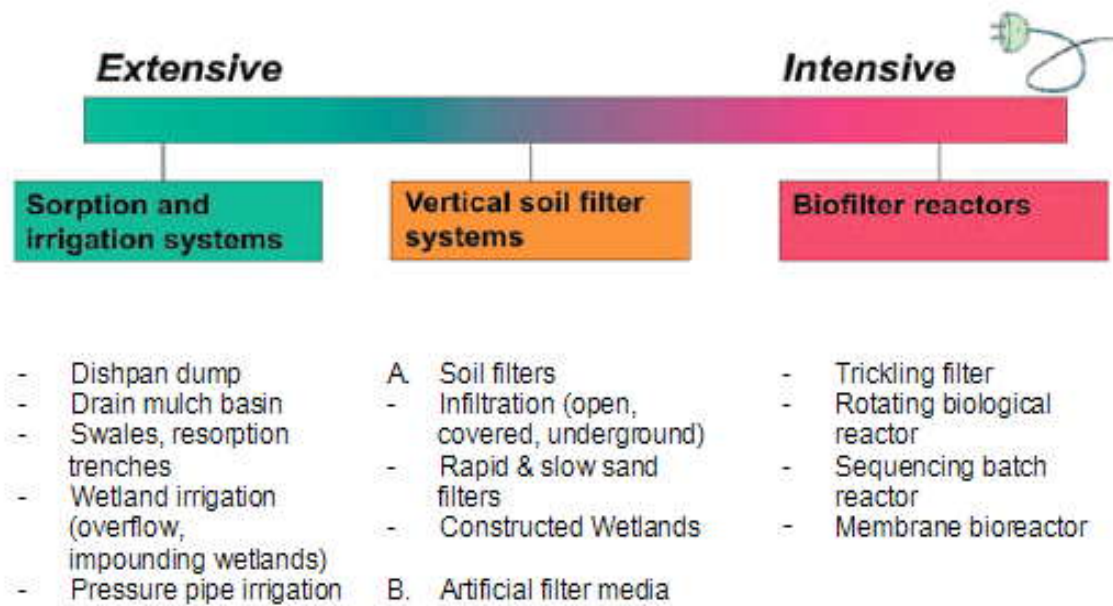
#### **4.3.1 Discharge and reuse**

A number of technologies can be applied for greywater treatment varying in both complexity and performance. These systems range from systems for single household (e.g., using disinfected untreated greywater for toilet flushing), to physical treatment systems (e.g., sandfilters or membranes), biological treatment options (e.g., rotating biological contactors and membrane bioreactors), and natural treatment systems (e.g., constructed wetlands and infiltration systems). Wherever natural conditions allow, soil infiltration is a cost-effective option for greywater treatment (Jenssen & Vråle, 2003). Also, the experience has shown that especially rotating biological contactor and constructed wetlands are most suitable for greywater treatment when reuse is considered (Lange & Otterpohl, 2000).

The extent of greywater treatment will depend largely on the final discharge and use of the water. If discharged to the sea, no treatment or a simply primary treatment is required, and if discharged to the lakes or rivers, a secondary treatment step is often needed (Jenssen & Vråle, 2003). A further treatment that is aimed to reduce levels of organic pollutants and heavy metals is especially important when greywater is used for groundwater recharge and for irrigation (Ridderstolpe, 2004; Jenssen & Vråle, 2003). For in-house reuse and drinking water, a sophisticated tertiary treatment may be necessary.

#### **4.3.2 Energy consumption**

In the greywater treatment processes, the aerobic biofilm technologies dominated the treatment (Li, 2004; Otterpohl, 2001) and ranged from extensive to intensive application. Distinctive differences of energy consumption vary from different applications. In Figure 4-1, the extensive treatment processes in the left are close to ecological engineering and self-sustaining in an ecosystem is basic foundation. Thus the energy used for running the treatment processes is inexpensive as it is provided by solar. The disadvantage is they need large land areas. On the right side, the intensive applications are found. These systems are compact but need artificial energy (e.g., electricity) to work. The systems in the middle need a minimum of artificial added energy and produce no or very little sludge. These systems use soil as filter media and are often found to be the optimized solutions for greywater treatment.



**Figure 4-1** Technological options for greywater treatment  
(Adapted from Ridderstolpe, 2004)

### 4.3.3. Low-tech versus High-tech

The basic treatment methods and technologies may be divided into two categories: “low-tech” and “high-tech” concepts. The term of “low-tech” does not at all indicate that such concepts have low efficiency or performance. Instead, such plants are low in energy and technology consumption, both in the construction and operation phases. In general, such concepts make use of nature-based treatment. Common technologies relating to “low-tech” are ponds and lagoons, and various soil infiltration systems. Brattebo (1995) implied that during recent years, new classes of low-tech concept have drawn renewed interesting, i.e., the class of modern water hyacinth systems, the reed beds systems with or without post-treatment in ponds or constructed wetlands.

“High-tech” concepts represent the contrary to “low-tech” systems, because the plants may be quite complicated both in the use of construction materials, equipment and control regulators, and very often also in total costs. There are several classes of “high-tech” concepts, based on mechanical-biological schemes, mechanical-chemical schemes, and mechanical-biological-chemical schemes. There is no doubt that the present international focus is on improving various mechanical-biological schemes, with little or without chemical added.

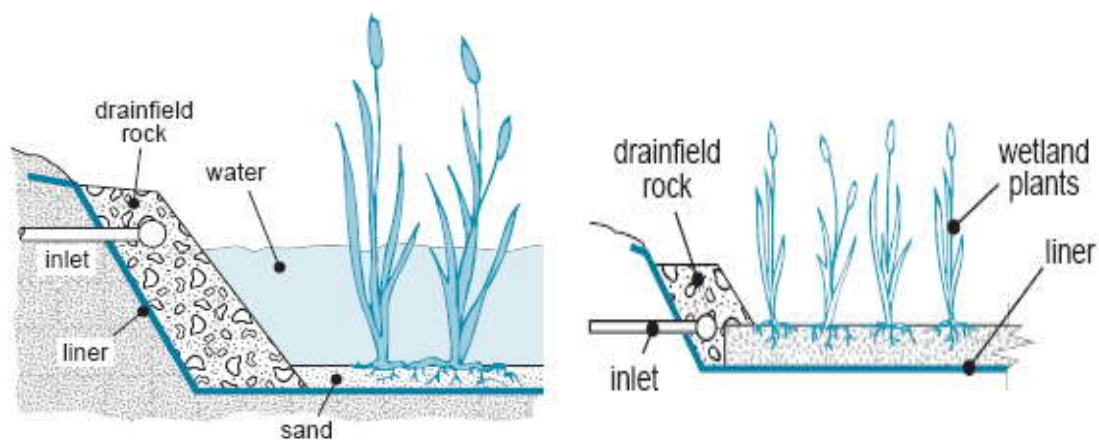
## 4.4 Technological solutions and options

### 4.4.1 Natural system - Constructed wetlands (CWs)

Historically, constructed wetlands have been used worldwide for over 30 years, in both warm and cold climates (EPA, 2002; Axler, 1998). The design and construction of wetlands has been regarded as one of the most important applications of ecological engineering since it is ecologically based “green machines” - the use of plants (Mitsch, 1997). As ecological engineering is solar-based ecosystem, investing in ecological engineering is usually less costly. Also, wetland technology offers a comparative advantage over conventional, mechanized treatment system because the level of self-sufficiency, ecological balance and economic viability is greater. Additionally its uncomplicated technology and minimal operation and maintenance requirements have been proved increasing attractive and its relatively low investment has great potential to mitigate the insufficient investment for infrastructure construction in China.

CWs receive primary effluent (e.g., from septic tank) and treat it to secondary effluent standards, and better, in contrast to enhancement systems or polishing wetlands, which receive secondary effluent and treat it further prior to discharge to the environment (EPA, 2002). A constructed wetland treats wastewater by a variety of physical, chemical and biological processes. Typically, solids are removed through physical filtration, settling and decomposition. Organic matter is reduced and consumed by bacteria and other microbes (biodegradation), both aerobically and anaerobically. Phosphorus removal is largely due to chemical adsorption - essentially an ion exchange, to plant litter and to the gravel substrate (Axler, 1998).

Constructed wetlands range broadly in size, from very large-scale municipal systems to smaller systems for individual, single-family residences (EPA, 2002). Since CWs require large land areas, they are not appropriate for some applications such as large urban areas with large wastewater flows. They are especially well suited for wastewater treatment in small communities, where inexpensive land is available and skilled-operators hard to find and keep.



**Figure 4-2** FWS constructed wetland (left) (Gustafson, 2001)

**Figure 4-3** SSF constructed wetlands (right) (Gustafson, 2001)

In general, two types of constructed wetlands systems are most commonly designed and used: the Free Water Surface (FWS), the Subsurface Flow (SSF) systems (see Figure 4-2 and Figure 4-3). Particularly the application of wetland systems is dominated by SSF systems because of its small land requirement and effective purification performance at high application rates, as well as lower water evaporation (Lüderitz et al., 2001). The plant species most frequently used in wetland systems are *Scirpus sp.* (bulrush), *Typha sp.* (cattail), and *Phragmites communis* (reeds) (Gersberg Et al., 1986).

#### **Free water surface constructed wetlands (FWS)**

Free water surface (FWS) constructed wetlands closely resemble natural wetlands in appearance and function, with a combination of open-water areas, emergent vegetation, varying water depths, and other typical wetland features. FWS wetland is a combination of emergent aquatic plants (e.g., reeds), floating plants (e.g., duckweed), and submergent aquatic plant (sago pondweed) (Davis, 1999).

Free water surface wetlands are usually more economical for treating large volumes of wastewater, and are better suited for large community systems in milder climates (Krekeler, 2002). The advantages of FWS are that their capital and operating costs are low, and their construction, operation and maintenance are uncomplicated. The main disadvantage is that they generally require larger land area than other system. They also have fewer odour problems and are less prone to freezing in winter.

#### **Subsurface flow constructed wetland (SSF)**

A SSF is not an actual wetland because it does not have soils. Emergent wetland plants are rooted in gravel, but wastewater flows through the gravel and not over the surface. This system is also shallow and contains sufficiently large gravel to permit long-term subsurface flow without clogging. Basically, the water level is maintained below the surface of the gravel substrate. Treatment processes are a mixture of aerobic, with oxygen supplied to micro-sites largely by plant roots, and anaerobic within the pore water in the rock media.

The primary mechanisms for BOD<sub>5</sub> and TSS removal are flocculation, settling, and filtration of suspended and large colloidal particles. SSF systems are effective for TSS and BOD<sub>5</sub> because of relatively low velocities and a high amount of media surface area (EPA, 2002; Davis, 1999). They typically do better at TSS removal, because TSS removal is completely physical mechanism, while BOD<sub>5</sub> removal is more complex. Larger biodegradable particles that have been quickly removed by physical mechanisms will be degraded over time and be converted into particles in the soluble and small colloidal size range.

SSF systems have been used for secondary treatment (30 mg/l of BOD<sub>5</sub> and TSS) or effluent enhancement for variety of wastewater, e.g. primary and septic tank effluents; pond effluent; and effluents from activated sludge, RBC, and trickling filter systems that don't consistently meet secondary standards (EPA, 2002). Additionally, the SSF is most commonly used for small flows and is often used for individual homes, small clusters of houses, or resorts (Gustafson, 2001). Because of the hydraulic constraints imposed by the substrate, SSF wetlands are best suited to wastewater with relatively low solids concentrations and under relatively uniform flow conditions.

The advantages of SSF wetlands are greater cold tolerance and greater assimilation potential per unit of land area than in FWS systems. In terms of treating the same volume of wastewater, SSF wetlands require smaller land than FWS wetlands. Comparing FWS systems, the disadvantages of SSF wetlands are that they are more expensive to construct, primarily because of the cost of media (e.g., sand, gravel) (EPA, 2002; Davis, 1999). Because of cost, SSF wetlands are often used for small flows. Hence, SSF wetlands may be more difficult to regulate than FWS wetlands, and maintenance and repair cost are generally higher than for FWS wetlands (Davis, 1999).

CWs have been used internationally with good results, but performance levels decrease in cold climates during winter. A properly operating constructed wetland should produce an effluent with less than 30 mg/l BOD<sub>5</sub> and less than 25 mg/l TSS (Gustafson, 2001). Fecal Coliform bacteria were generally reduced by 96~99% in winter to > 99% during snow-free season (Axler, 1998). According to Müllegger, (2003), using horizontal SSF wetlands systems, a good removal efficiency for organic matter (>90%) and pathogens (up to a factor of 100) can be achieved. If nitrification is required, the SSF wetlands with vertical flow and intermittent loading can be used.

Selecting an appropriate location for construction of CWs should consider the land use and access, the availability of the land, site topography, soils, the environmental resources of the site and adjoining land. The specific area demand for wetland systems was usually regarded as main barrier and is still a matter of discussion. However, the surface area by the wetland systems treating greywater needs only 1~2 m<sup>2</sup>/capita (Otterpohl, 2002; Jenssen & Vråle, 2003; Li, 2004), whereas the recommended surface area for the systems treating combined wastewater is normally in the range from 7 to 9 m<sup>2</sup>/capita (Jenssen & Vråle, 2003). The space required for a horizontal filter plant treating combined black and grey water is on the basis of  $\geq 5$  m<sup>2</sup>/capita (Tietz, 2006; Krekeler, 2002) and the total area must be greater than 20 m<sup>2</sup>. Vertical filter plants only require  $\geq 2.5$  m<sup>2</sup>/capita and the total area of the plant must be greater than 10 m<sup>2</sup> (Krekeler, 2002).

## 4.4.2 Mechanical-biological treatment plants

### 4.4.2.1 Rotating biological contactor (RBC)

The rotating biological contactor (RBC) (see Figure 4-4) has been on the small wastewater treatment plant (WWTP) market for a long time, and this has been one of the most common categories for package plants (Brattebo, 1995). Although the general rising interest for Sequencing Batch Reactor (SBR) and other modern small WWTP systems have led to a decreasing demand for RBC concepts, the RBCs are still considered attractive due to low energy consumption and simple and stable operation, and the systems as such have not changed very much during the last decade.

A rotating biological contactor (RBC) conceptually operates on a similar principle to the trickling - aerobic attached-growth process with a high rate of recalculation, but has a rotating bed of attached bacteria, which is immersed in a tank of wastewater. These disks are submerged (40%~80% percent) and rotated in a tank containing the wastewater to be treated (Crites, 1998). The settled sewage from the primary settlement tank enters the secondary treatment stage. The secondary treatment plant consists of slowly rotating discs driven by a small motor. For larger plants, final settlement takes place in a conical shaped upward flow clarifier. A sludge pump returns the sludge to the primary settlement tank.

Wastewater flows through the medium by simple gravity. The discs rapidly develop a microbial community in the form of a film and this film is responsible for BOD<sub>5</sub> removal. The microorganisms responsible for treatment become attached to the disks and rotate into and out of the wastewater. Biomass continuously sloughs from the disks, and some suspended biomass develops within the wastewater channels through which the disks rotate, making the addition of a secondary clarifier necessary. The rotation of the disks exposes the attached biomass to air and wastewater. The oxygen necessary for the conversion of the organic matter is obtained by adsorption from the air.

The major advantage of an RBC is low energy consumption, easy operation and low land-requirement. The only energy-consuming component is the drive of the biological contactor. There is a single motor driving the shaft continuously in a RBC. The typical single RBC is for 1,000 PE and has a 1.5 KW motor. Based on 15c/kWhr the annual power consumption costs €1,600 (Molloy, 2006). This energy can also alternatively be solar energy. It may be suitable for many applications in developing countries, and within northern Europe and the USA it has found application in rural areas. It is particularly suitable process for small communities (EPA, 2000). The space requirement for installation is relatively small, therefore the investment cost including mechanical preliminary treatment lies far below the cost for 1 m<sup>3</sup> of sewer (Huber, 2002).

#### 4.4.2.2 Sequencing batch reactor (SBR)

The Sequencing Batch Reactor (SBR) is a fill-and-draw activated sludge system and has been used all over the world since 1920s (Al-Rekabi, 2007). Interest in SBRs was revived in the late 1950s and early 1960s. SBR package plants have found application as onsite systems in some European countries and USA (EPA, 1999).

##### Processes flow

SBR is uniquely suitable for wastewater treatment applications characterized by low or intermittent flow conditions. The unit process of the SBR and conventional activated sludge systems are the same. The difference between the two technologies is that the SBR performs equalization, biological treatment and secondary clarification in single tank or basins (using a timed control sequence), whereas conventional facilities rely on multiple basins (EPA, 1999). A typical process flow schematic for a municipal wastewater treatment plant using an SBR is shown in Figure 4-5.

##### ➤ 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 desired 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 basin.

##### ➤ React

The basin is aerated and air is bubbled through the liquid. Biological oxidation takes place similar to the aeration basin in the conventional activated sludge process. 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.



**Figure 4-4** Schematic of RBC (Huber, 2002)

➤ **Settle**

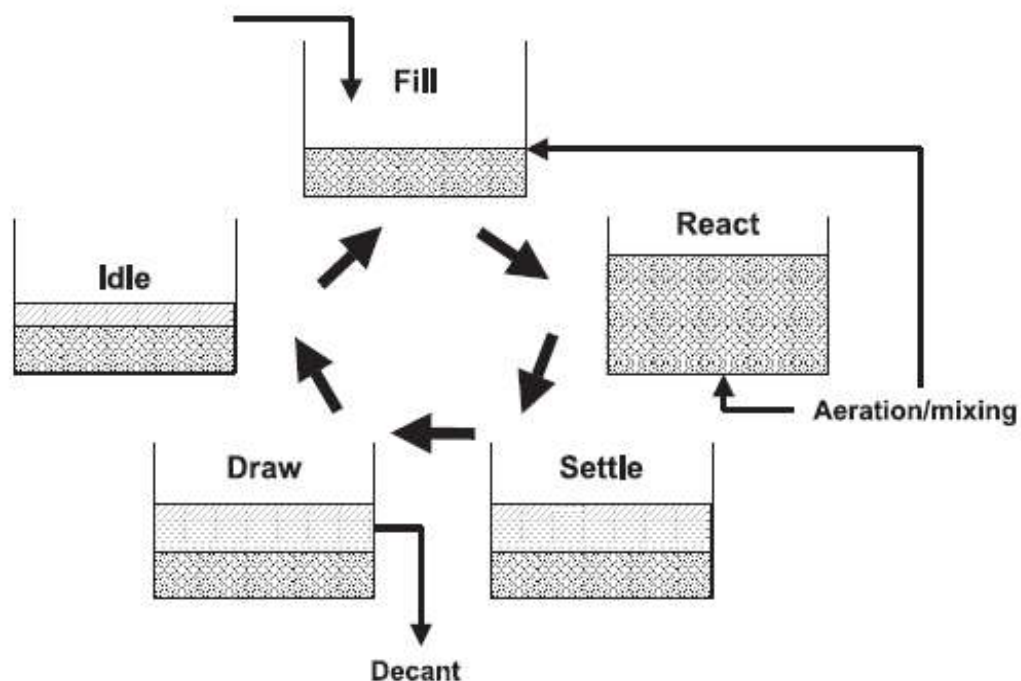
Solids separation takes place under quiescent conditions (i.g., without inflow or outflow) in a tank. This major advantage in the clarification process results from the fact that the entire aeration tank serves as the clarifier during the period when no flow enters the tank. All of the biomass remains 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.

➤ **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 prevent floating matter from being discharged. The biomass settles, and the floating matter is removed.

➤ **Idle**

During this time, excess biomass is wasted and sludge is removed from the bottom of the basin using pumps. With SBRs there is no need to install return activated sludge pumps and also primary sludge pumps, like those associated with conventional activated sludge systems.



**Figure 4-5** A typical SBR process flow schematic (EPA, 1999)



### **Advantages and applications**

Construction of SBR can typically require a smaller footprint than conventional activated sludge systems because the SBR often eliminates the need for primary clarifiers. Hence, the SBR never requires secondary clarifiers (EPA, 1999). In addition, the efficiency of the SBR process stands with the reliable removal of clarified water during the sedimentation phase and prevention of activated sludge removal during the reaction phase.

Another important advantage of the SBR technology compared to the continuous process system is that the duration of individual phases can be varied from cycle to cycle by simple modification of the control program (Huber, 2004). The variation of the phase and cycle duration allows reacting different quality, concentration and load of wastewater contents in the plant inlet. Such a flexible operation ensures economical treatment, especially for influents the amount and concentration of which frequently varies.

In the conventional activated sludge process, a limited amount of flexibility can be implemented by adjusting the rate of return activated sludge and waste activated sludge or through varying the rate of air introduction in the aeration basin. The SBR process is automated through the use of a control system, which automatically coordinates equipment operation through various phases of the SBR cycle. This feature offers a high degree of flexibility allowing adaptation of the process cycle to meet the changing influent conditions. Table 4-10 illustrate the differences between conventional sludge process and SBR process.

In addition, cycles within the SBR system can be easily modified for nutrient removal in the future if it becomes necessary. Al-Rekabi (2007) indicated this technology is particularly appropriate where there are highly variable hydraulic and organic loads, and they are normally used to achieve a higher degree of treatment than a continuous-flow, suspended-growth aerobic system unit by eliminating impacts caused by influent flow fluctuations. Additional disinfection is required to meet effluent fecal coliform requirements. Older wastewater treatment facilities can be retrofitted to an SBR because the basins are already present.

SBRs are high-tech reactors requiring electricity, pumps, sensors and aeration equipment. A very large number of small-scale treatment plants are currently being constructed according to the SBR method. The size of SBRs corresponds to 0.3~0.5 m<sup>3</sup>/capita. An eight - person reactor takes up less than 10 m<sup>2</sup>. SBR must be serviced three times a year and controlled daily (Krekeler, 2002).

**Table 4-10** Comparison of activated sludge process and SBR (Adapted from Li, 2004)

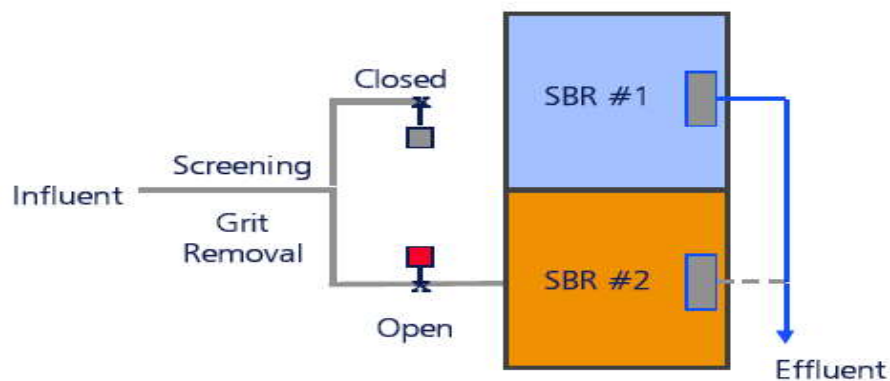
Characters	Conventional activated sludge process	SBR
<b>Loading</b>	Continuously	Intermittent
<b>Basin requirement</b>	Primary clarification, aeration, nitrification and secondary clarification take place in different basins.	All processes take places in one basin
<b>Space requirement</b>	Large	Small
<b>Performance affected by hydraulic loading</b>	Depend on the type and concentration of influent of wastewater	No influence
<b>Biological activity</b>	Continuously low	Higher than conventional activated sludge process in average, though is low at end
<b>Substrate concentration in basin</b>	Relatively small change in whole process	High concentration at the beginning and very low concentration at end of cycle
<b>Sludge generated by hydraulic loading</b>	High influence	No influence
<b>Demand of returning activated sludge</b>	Necessary	No need
<b>Flexibility for different loading situation</b>	Low	Very flexible

### Conventional and innovative SBR process

Although conventional SBR system has many advantages, it does have some drawbacks:

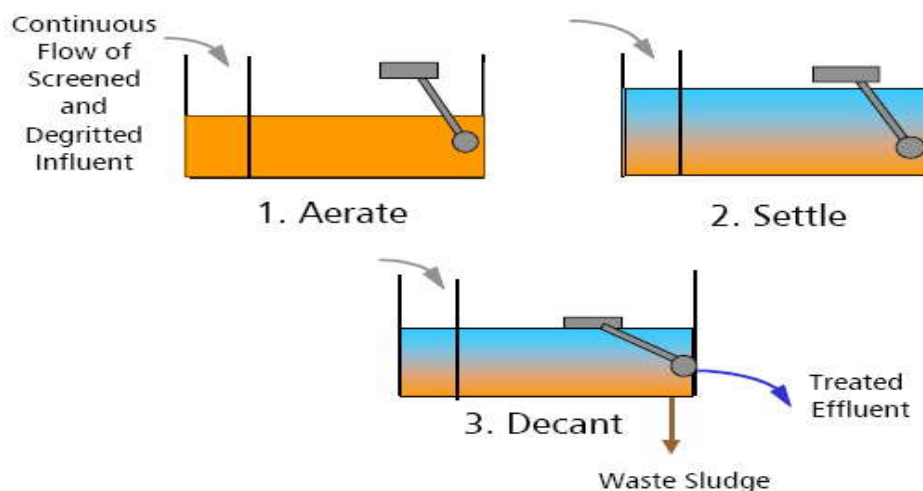
- It must be designed with a minimum of two reactors (see Figure 4-6). These configurations are required to allow continuous acceptance and treatment of the influent. During the react, settle and decent phases of the cycle, flow is diverted to other basins.

- For most municipal treatment facilities, flow and loading to a plant vary frequently. With a conventional SBR system, this results in unequal mass and hydraulic loadings of receiving flow during daily flow variation to each reactor in multi-reactor facilities. The variation in loadings causes differences in the biomass and oxygen demand of the individual reactors.
- Since the influent volume is various and changed from time to time, the basin can be full before the fill-time and cause over-flow, or the basin can be half-empty and negatively affected activated sludge process.



**Figure 4-6** Flow-based conventional SBR process (ITT, 2006)

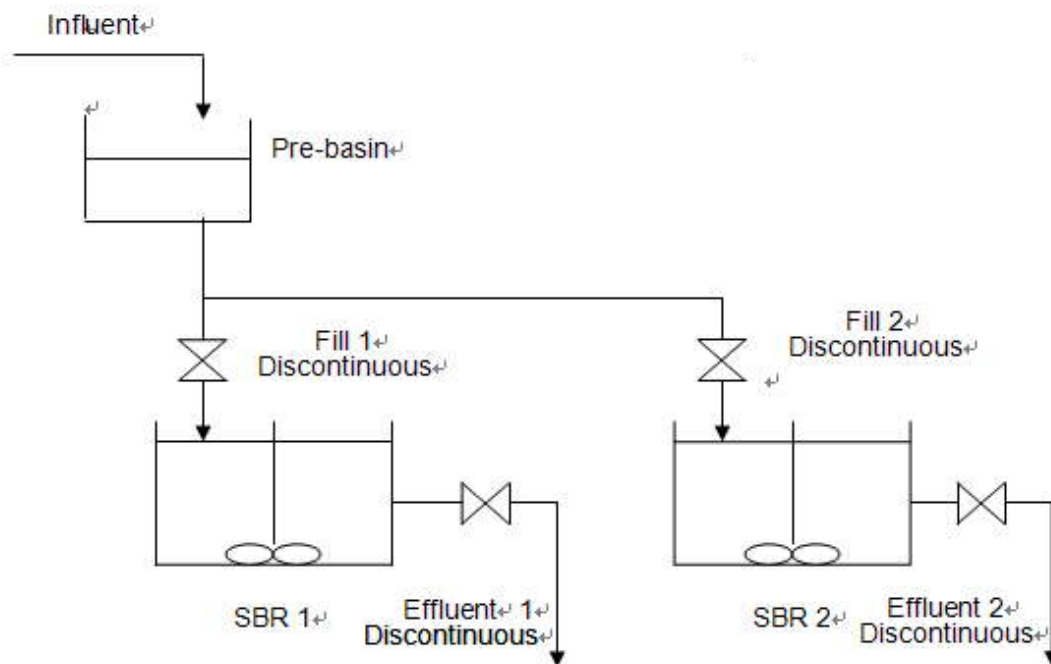
Figure 4-7 illustrates an innovative SBR process, in which influent is receiving continuously during all phases of the cycle: aerate, settle and decant. This allows the SBR process to be controlled on a time, rather than flow basis and ensures equal loading and flow to all basins. Use of time-based control system facilitates simple changes to the process control program. The duration of each cycle and segment of each operating cycle are the same among all basins in a time-based system. Therefore, changes to the process can be made simply by changing the duration of individual segment. In a flow-based conventional SBR, cycle times and individual segments of each cycle may be different among basins due to flow variations.



**Figure 4-7** Time-based innovative SBR process (ITT, 2006)

Ideally, a true batch reaction SBR should operate under continuous flow only under emergency situations (Al-Rekabi, 2007). Plants designed as continuous-inflow systems have been shown poor operational conditions during peak flows. Some of the major problems typically exist in forms of overflows, washouts, poor effluent, and permit violations.

Another alternative option designed with discontinuous-inflow was given by Li (2004) (see Figure 4-8). In the new concept, a pre-basin should be prepared. With the alternative option, the process (including biological clarify, sedimentation, effluent removal) will not depend on the influent volume, which is changed frequently time by time. Through quick fill of wastewater, the concentration of organic matter can reach maximal level, and provide optimal pre-condition for digestion in activated sludge process. The following biological P-elimination, denitrification and nitrification, will be not dependent on the hydraulic loading of wastewater influent.



**Figure 4-8** Alternative option designed with discontinuous-inflow of SBR (Li, 2004)

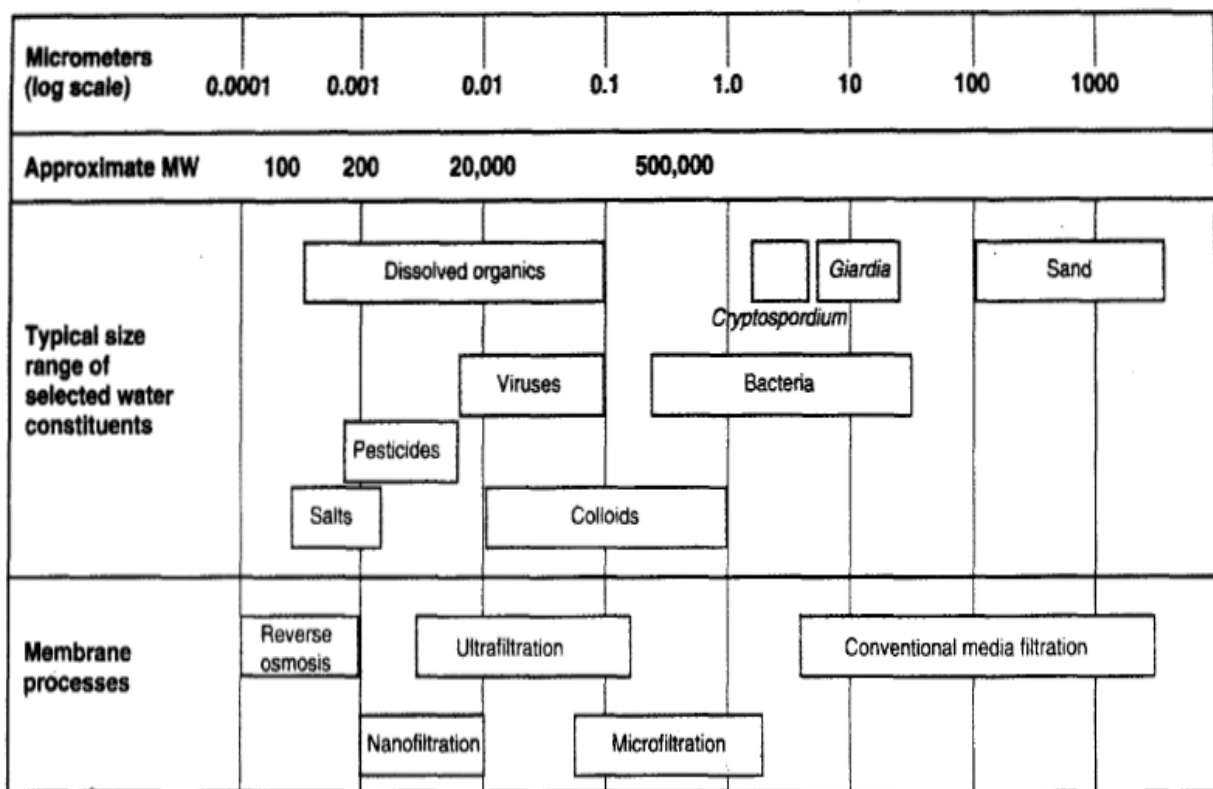
#### 4.4.2.3 Membrane Bioreactor (MBR)

Membranes found their place in wastewater treatment in the early 1990s (Cheryan, 1998). Although wastewater treatment using membranes is the newest form, it is increasingly becoming the most popular method and open up opportunities for decentralized treatment, since they encourage water reuse and has been successfully applied at a variety of relatively small plants.

### Review of membrane technology

The primary role of a membrane is to act as a selective barrier. It should permit passage of certain components and retain certain other components of a mixture. With the help of Microfiltration (MF) and Ultrafiltration (UF), it is possible to keep back all particles, bacteria, and even viruses. Nanofiltration (NF) and Reverse Osmosis (RO) even allow keeping back dissolved substances such as salts and emerging contaminants. Nanofiltration (NF) and Reverse Osmosis (RO) treatment permits wastewater treatment plants (WWTPs) to produce recycled water more suitable for irrigation and for recharge or for possible indirect potable reuse. For this purpose, however, the pressure must be very high, which causes high-energy costs. In municipal wastewater treatment, the application of membrane technology is limited up to now to MF and UF plants, which are operated at low pressure (Cheryan, 1998).

Membranes are commonly used for the removal of dissolved solids, colour and hardness in drinking water. In wastewater reclamation and reuse, water quality requirements may call for reductions in suspended solids, total dissolved solids, and selected constituents such as nitrates, chlorides, and natural and synthetic organic compounds. It is a viable method of achieving desired effluent quality levels at reasonable costs. Figure 4-9 compares the size of the constituents found in wastewater and the operation size range for different membrane.

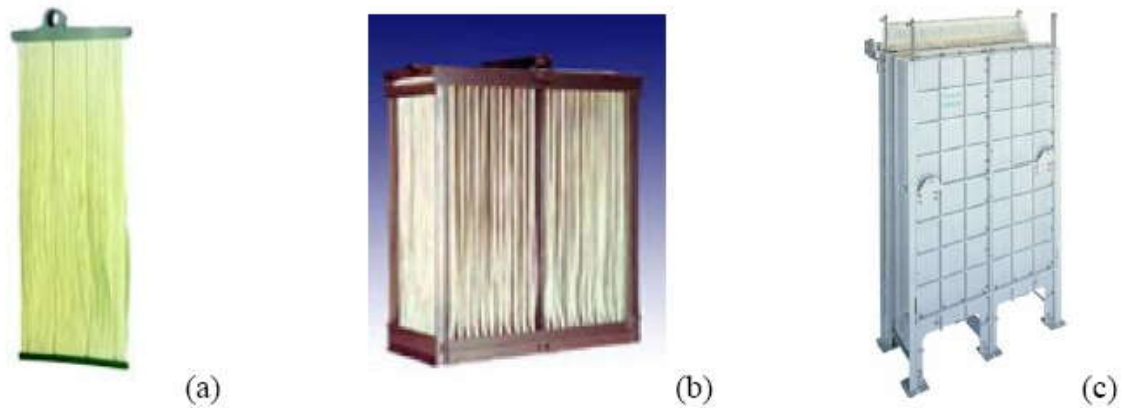


Note: MW = Molecular Weight

Conventional media filtration is shown for comparison only

**Figure 4-9** Comparison of the size of the constituents found in wastewater and the operation size range for different membrane (EPRI, 1997)

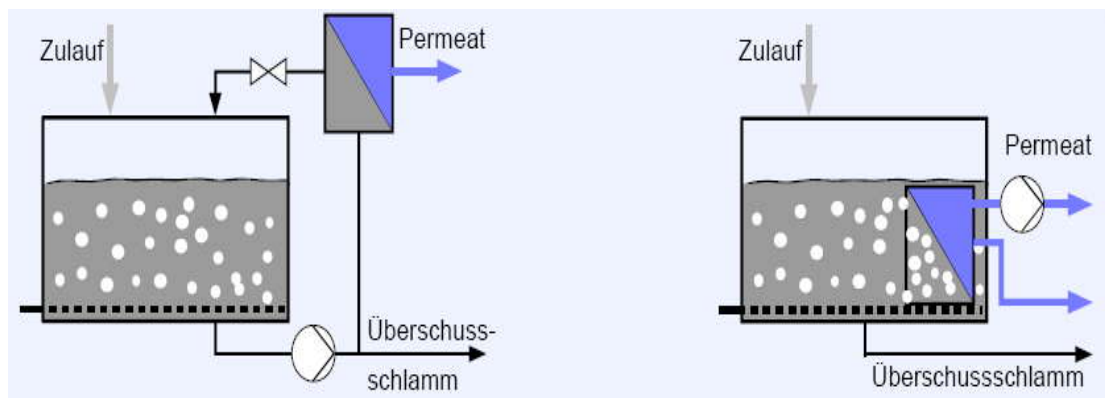
Several configuration types of membranes have used for MBR application. These include plate, frame, rotary disk and hollow fibre. Examples of hollow fibre membranes as modules, or cassettes and a plate are presented in Figure 4-10.



**Figure 4-10** Examples of hollow fibre membranes as a module (a), as a cassette (b) and as plate membrane (c) (Larsson, 2004)

### The types and processes of membrane bioreactor (MBR)

Research on membrane bioreactors (MBR) started 30 years ago. The technology first entered the Japanese market and today is commonly used worldwide (Wallis-Lage, 2003). Basically there are two configurations of MBRs: the external systems that are located outside the bioreactor, and the immersed fibre systems that are designed within bioreactor. In the case of an external system, feed enters the bioreactor where it comes in contact with biomass. The mixture is then pumped around in a recirculation loop containing a membrane unit where permeate is discharged and retentate is returned to the tank. The concept of immersed membranes was conceived in the late 1980s in Japan and Canada (Bernal, 2002). The immersed system differs in that there is no recirculation loop since the separation occurs within the bioreactor itself.

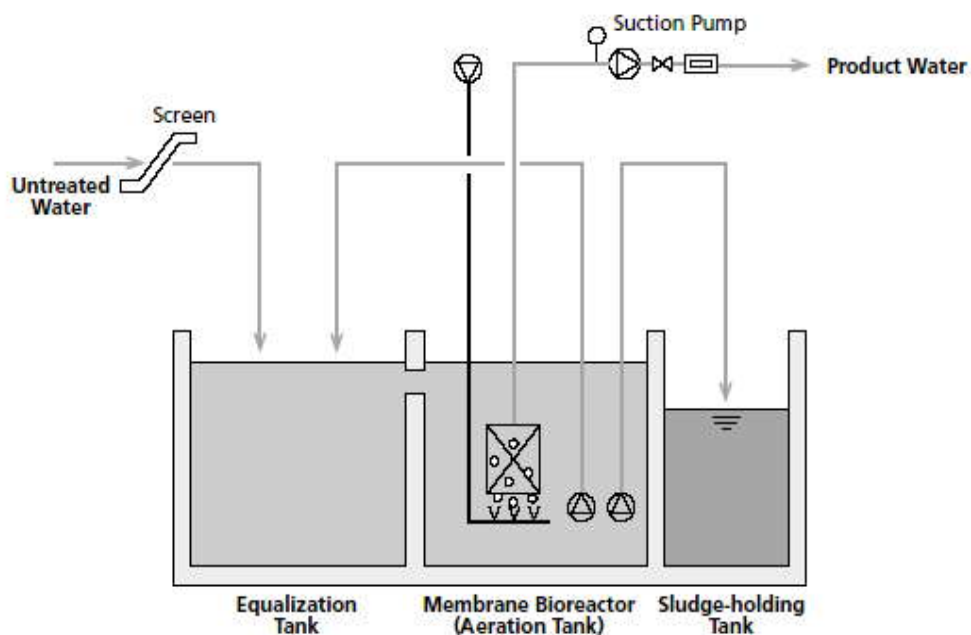


**Figure 4-11** MBR Configuration: external (left) and submerged (right) (Kraume, 2004)

Figure 4-12 shows a basic flow sheet of a typical submerged MBR process. Effluent is passed through a screen to remove solids. An equalization tank is typically included to handle variation in flows so that the MBR can be sized to treat the average daily flow rather than the peak daily flow. The membranes are submerged in the aeration tank. Filtrate is drawn through the membranes using a suction pump. Biomass is removed using a sludge pump as needed. Air blowers supply air for the biological process, to scour the membranes and to uniformly distribute suspended solids throughout the aeration tank.

Like other treatment plants, The MBR uses microorganisms to treat the wastewater. In typical treatment plants, the organisms are separated from the water using gravity in large tanks. In an MBR, the membranes (either MF or UF) filter the biological mixture, keeping the organisms in the process and allowing water to flow through the membranes. This has a distinct advantage because more organisms can be used in the process, 3 to 5 times more than in a conventional treatment plant (Cheryan, 1998). Additionally, in a conventional wastewater treatment plant, the secondary clarifier limits the solids concentration in the aeration tank. The MBR replaces secondary clarification in a conventional wastewater treatment plant. The result is the ability to treat the same amount of wastewater in a smaller space.

This system is a typical design of a membrane enhanced activated sludge process. The key feature in this process is the use of membranes as an integral part of the bioreactor, avoiding the need for both primary and final settlement stages. The membranes are submerged in the aeration tank and the treated effluent is separated from the mixed liquor by negative pressure (suction). The membrane is used to separate the biomass from the effluent exiting the process.



**Figure 4-12** Typical submerged MBR process (Bernal, 2002)

### Opportunities for membrane utilization

Membrane provide a number of significant benefits and have become cost-effective for many water recycling and water reuse applications, replacing conventional processes while benefiting new construction, upgrades, and retrofits of existing facilities. This technology is particular needed for site where effluent of consistent quality with low BOD<sub>5</sub> and TSS for reuse or discharge, for sites where space is limited, for sites where there is a need to increase the capacity of an existing system, or to reduce operating requirement. The below Table 4-11 gives a summary of advantages and disadvantages with MBR application.

#### ➤ High treatment efficiency

Membrane technology provides a viable means to aid in water recycling efforts and can increase reuse water quality by removing new constituents such as pharmaceutical compounds. In particular, it may be useful in situations where a traditional sedimentation or concentration process is inadequate to provide the desired effluent. Also, with the rising demands on small community to deliver effluents to higher standards and more reliable quality, there is a need to develop and deliver processes that will meet requirements more cost effectively. With its versatile separation capability, membrane technology is making an impact on a number of wastewater treatment areas.

**Table 4-11** Advantages and disadvantages with MBR

Advantages	Disadvantages
Small footprint	High Membrane costs
Complete solids removal	High capital cost
Complete pathogenic organisms removal	Membrane complexity
Removal, clarification & nitrification in a single unit	Membrane fouling
Low (zero) sludge production	Operation and maintenance
Sludge bulking is not a problem	Aeration limitations
Effluent disinfection, barrier against pathogens	-
High MLSS (15,000-20,000 mg/l)	-
No primary or secondary settlement requirement	-
High sludge age, low sludge production rate	-
Ideal technology for existing system upgrading	-
Easy modification or upgrading of existing works	-
Tertiary quality effluent for reuse/recycling	-



Bade (2005) claimed that one of the most important advantages of the use membrane is the disinfection of wastewater. Strict microbiological limit values are one of the main legal obstacles for wastewater reuse. In terms of high quality effluent in MBR process, typical TSS are less than 2 mg/l and BOD less than 10 mg/l, since bacteria can usually not pass membranes with a pore-size of 0.45  $\mu\text{m}$ , which is fulfilled by all commercially used membranes (Bernal, 2002). Hence, the MBR filtrate can be directly treated by RO without any need for additional pre-treatment.

Also in the processes of combined greywater and blackwater treatment, nitrification, denitrification and chemical phosphorous removal have been accomplished successfully with MBR. Cheryan (1998) claimed because the membranes retain all biomass in the system, long Solid Retention Time (SRT) and high Mixed Liquor Suspended Solids (MLSS) concentration can be achieved. This benefits the bacteria with low growth-rate, as nitrifying bacteria. Long SRT prevent nitrifying bacteria from being washed out from the bioreactor, improving the nitrifying capability.

➤ **Smaller footprint for space saving**

In the MBR processes, the membranes prevent from the need for both primary and secondary clarification (settlement) tanks in a conventional wastewater treatment plant, thereby resulting in considerable saving in space and is suitable for the area where the land is limited (Bernal, 2002; Cheryan, 1998; Larsson, 2004). Because the membrane replaces the clarification process, the cost and the settling problems associated with secondary clarifiers are eliminated. In an MBR, the membranes create a solid barrier and therefore the process is not subject to gravity settling solids limitations, as in conventional clarifiers.

Furthermore, membrane processes can particular accept influents with a much higher solids concentration than conventional settlement equipment. Solid concentration may be in line with the upstream aeration tanks, which permits a reduction in the volume of the tanks compared to conventional clarification systems, resulting in a significantly smaller footprint for the overall process. Additionally, the high level of MLSS effectively achieves nitrification and denitrification without the need for extended aeration.

Additionally, membranes have been increasingly used to upgrade on-site wastewater treatment that includes water reclamation. By maintaining a much higher density of microbes, the treatment capacity is greatly increased, resulting in a much smaller footprint compared to gravity settling units. Cheryan (1998) indicated the advantage with low sludge production can be explained by the ability to operate the MBR at high SRT. This creates a condition of substrate limitations and results in low food to microorganism ratio. It also allows operation at high SRT without requiring large aeration volumes, because the MLSS in the system is high. Due to this, MBR creates a small footprint, less space than conventional treatment facilities.

## 5 Black water management

### 5.1 Brown water with organic bio-waste

New approaches of wastewater management are assumed that sanitation system should be conceived enable the recycling of organic matter and nutrients contained in human excreta. A change in the sanitation management paradigm from flush-and-discharge to recycling of urine and faeces is gaining attention. As a consequence, treatment strategies and technological options for faecal sludge and solid waste will have to be developed which allow the optimum recycling of nutrients and organic matter to agriculture application.

Brown water (faeces) is of major concern with respect to health risks. Basically there are two options for faeces handling: 1) since the concentration of organic material can be converted to biogas, treatment and reuse of the faeces and organic wastes (or the filter residues – the solids from black water) seem to be attractive. Faeces can be used for fertilizer production after removal of pathogenic germs in a biogas plant and converting organic carbon into methane gas (CH<sub>4</sub>); 2) Another option can be used in rural areas - smaller amount of faeces and organic waste can be composted, which is a considerably easier technical process compared to biogas technology (Christ, 2004; Otterpohl 2001; Winblad, 2002).

In general, faeces treatment procedures occur usually in two steps (Winblad, 2004):

➤ *Primary processing*

The purpose of primary processing is to reduce the volume and weight of faecal material to facilitate storage, transport and further (secondary) treatment. Primary processing takes place in chambers below the toilet. Here the faeces are kept for a certain period. During this containment the number of pathogens will be reduced as result of storage time (6~12 months), composition, dehydration (ventilation and the addition of dry material) and increase pH (additional of ash, lime) as well as the presence of other organisms.

➤ *Secondary processing*

The purpose of secondary processing is to make human faeces safe enough to return to the soil. Secondary processing takes place either on-site (in the garden), or off-site (at an eco-station). This step includes further treatment by high temperature composting or pH increase by addition of urea or lime as well as longer storage time. If a completely sterile end product is required the secondary processing could be carbonization or incineration.

## 5.1.1 Dehydration

### 5.1.1.1 The process and application of dehydration

Dehydration is a way of destroying pathogenic organisms. It does this by depriving them of the moisture they need to survive. In this process, there is little breakdown of organic material. And urine diversion is essential based on dehydration (GTZ, 2005; Easrey et al, 1998). In a dehydrating system, urine is directed away from faeces to keep the processing chamber contents dry and volume of material small. This also makes it possible for us to use the urine separately as a fertilizer.

In a dehydration toilet, the excreta are dried with the help of sun, natural evaporation and ventilation (Calvert, 2004). The toilet requires no flushing water. The faeces are collected in a chamber below the toilet where they are safely kept out the environment for a period of 6~12 months are dried (GTZ, 2005; Easrey et al, 1998). High temperature in the chamber, together with sufficient ventilation is the most important mechanisms in the drying process. The ventilation also reduces odors due to air currents, which flow towards the vent pipe out of the chamber.

Additionally, absorbents such as lime, ash, or dry soil should be added to the chamber to absorb excess moisture, make the pile less compact and make it less unsightly for the next user. Moreover, depending on the additive, the pH may also be increased due to this addition, and hence enhance bacterial pathogen die-off.

After six months, faeces are removed from the dehydrating toilets as a sanitized powder. The dry product from the dehydration process is not compost but rather a kind of mulch, which is rich in carbon and fibrous material, phosphorous and potassium. This dry material is usually given a secondary treatment before being dug into the ground where the material comes into contact with the living soil. The contents are further stored, used as a soil conditioner, buried or composted (in home composting or at local composting center). Further storage, sun drying, alkaline treatment or high-temperature composting may be recommended to further decrease health risks of utilization of the dehydrated faeces (GTZ GmbH, 2005).

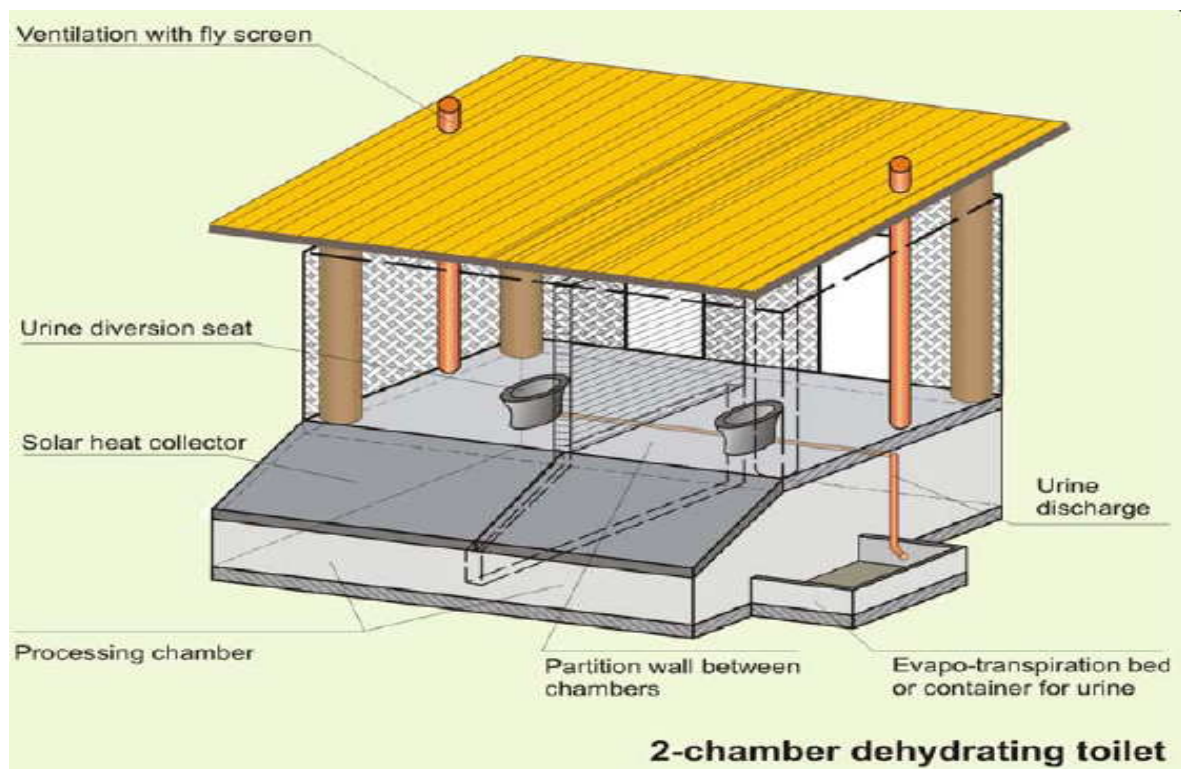
Dehydration toilets can be placed outside the house and attached even inside to house. Therefore, the option of dehydration toilets are suitable both for rural and densely populated urban areas. Dehydration toilets are increasing popular in the developing world. They can be successfully used in various climatic conditions and are most advantageous in arid climates where water is scarce and faeces can be effectively dried.

### 5.1.1.2 Double-chamber dehydration toilets with urine-diversion

Many alternative ways of constructing dehydration toilets exist. Generally double-chamber toilets with urine diversion have shown the most successful results and the highest popularity (Easrey et al, 1998). A double-chamber dehydration toilet (see Figure 5-1) can transform infectious faeces into a safe product, if storage times are respected and if alkaline materials are added. In this type of toilets, faeces are collected in two vaults beneath the toilet seat, where they are dried. A ventilation pipe connected to the vault helps reduce odors and enhances the drying process. Urine drains away and collects in a container behind the toilet, or in a larger storage tank.

The first chamber can be used for at least six months. When it is full the vault is sealed. All openings are tightly closed, e.g. with lime or clay. The other chamber now comes into use instead. When the second vault is nearly full, the first vault has to be emptied. The dehydrated faeces, now odorless, can be used as a soil conditioner. Further storage or composting with other organic materials is recommended to increase hygienic safety.

Dehydrating toilet can be installed in yard/garden just like an old fashioned latrine. They can also be installed in house. Unlike composting toilets that are usually purchased as ready-made plastic toilets, dehydrating toilet usually come in the form of brick-built or wooden structures constructed by owners on site (Krekeler, 2002).



**Figure 5-1** Double chamber dehydrating toilet (Krekeler, 2002)

## 5.1.2 Composting – low-tech for rural areas

### 5.1.2.1 The composting process

Decomposition (composting) is the biological decomposition of the organic matter (e.g. carbohydrates, sugars, proteins, fats, cellulose, mineral matter etc.) under controlled aerobic condition. In a composting toilet, faeces (or plus urine) are deposited in a processing chamber along with organic household and garden refuse and agents (e.g. straw, wood, twigs, etc.).

It is a complex natural biological process in which various organic substances are mineralised and break down the solid into humus. Additionally, temperature, airflow, moisture, pH value, C-N ratio, carbon materials and other factors are controlled to varying degrees to promote optimal conditions for decomposition (GTZ, 2005). After certain retention time (normally 6-8 months) the partly decomposed material can be moved to garden compost or an eco-station for secondary processing through high temperature composting.

In the process of decomposition, the air enters the chamber from the outside. Near the surface of the pile the process may be aerobic while in the interior it is often anaerobic. Under aerobic conditions, decomposition is rapid and odour-free. Additionally, since many microorganisms are killed by temperature 65°C (Krekeler, 2002), high-temperature aerobic composting (>60°C) will effectively destroy most pathogenic organisms. However in such process temperatures are in practice difficult to reach in a composting toilet, since the volume of material is too small (Gajurel, 2003). To raise the temperature for faster decomposition and faster die-off of pathogens, there should be a large input of carbon-rich material such as weeds, wood and kitchen waste to ensure a good supply of oxygen to the inside of the pile. Thus lower temperature can achieve acceptable pathogen kill if the material is retained long enough (8-12 months).

In a composting toilet, the best result in terms of pathogen destruction with a moisture content of 50%-60% (Gajurel, 2003; Krekeler, 2002). At higher moisture content condition, the material become soggy and compact, and the organisms are deprived of oxygen. At low moisture content, on the other hand, slow down the activity of the microorganisms, as they are starved for water. Additionally, microorganisms feed on organic matter containing, among other nutrients, carbon and nitrogen. Carbon is used for energy and nitrogen is for body-building. The optimum C:N ratio is with the range of 15:1 to 30:1 (Gajurel, 2003).

Every year the Earth is losing 25 billion tonnes of topsoil because of erosion (Calvert, 2004). Chemical fertilizer, although increase plant growth, cannot replace topsoil. Topsoil contains humus formed from decayed plant and animal matter is rich carbon compounds and microorganisms necessary for healthy plant growth, which are not found in chemical fertilizer. The additional of humus is therefore necessary to

maintain and renew the topsoil. With the loss of topsoil comes the loss of human food security.

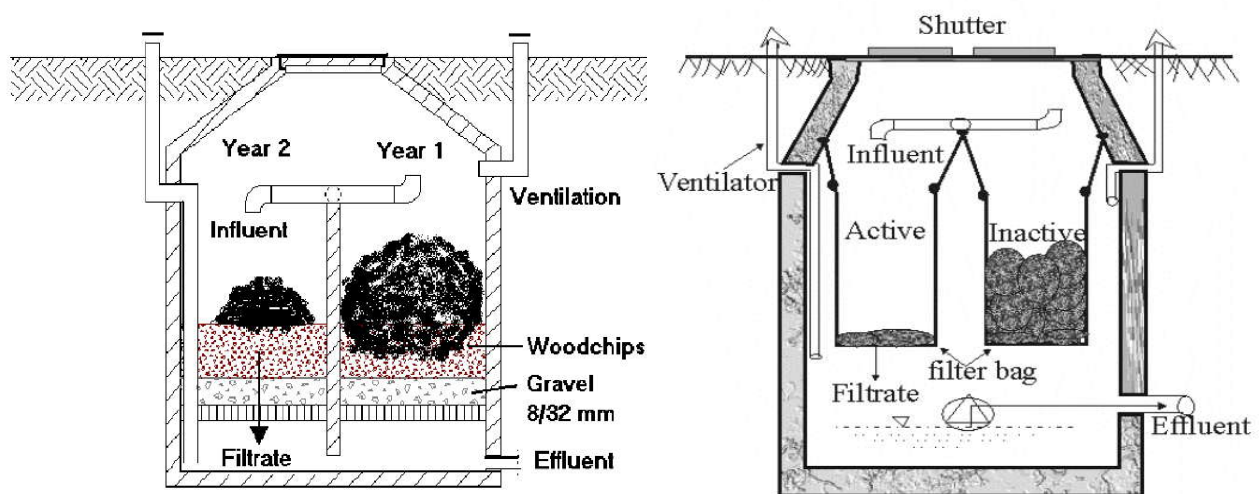
Faeces from composting toilets are removed as humus. If the partly decomposed faeces with soil and ash are moved from the toilet to be further processed to produce humus, soil enriched with humus holds water longer than soils not enriched with compost. Research has shown that plants grown in soils enriched with large amounts of humus require less watering and survive droughts better than plants grown in ordinary soils without this humus (Calvert, 2004).

### 5.1.2.2 Rottebehaelter system

Rottebehaelter as a component of decentralized system has been increasing used in Austria, Germany, and Switzerland for domestic wastewater pre-treatment (Gajurel, 2003).

Most of the Rottebehaelter systems are constructed near residential buildings. A Rottebehaelter (see Figure 5-2) consists usually of an underground concrete tank having two filter beds at its bottom or two filter bags that are hung side by side and used alternately in an interval of 6~12 months (Otterpohl, 2001; Lange and Otterpohl, 2000; Gajurel, 2003).

Those investigations in Germany have demonstrated to be beneficial and can be combined with concept of source separation (Gajurel, 2003). One important major advantages of this system is that it does not deprive agriculture of the valuable nutrients and soil conditioner from human excreta. And it also avoids expensive tanker-trucks that are extensively used in conventional system for transportation of sludge. Furthermore, compared to septic tanks, methane emission can be very low since outer parts of retained material maintain aerobic condition.



**Figure 5-2** Rottebehaelter system (left: filter bed system; right: filter bag system) (Gajurel, 2003)

It is watertight and structurally sound in order to avoid entering of extraneous groundwater in it and leakage of the filtrate into the groundwater, which could cause groundwater contamination. The top opening is covered by a concrete slab and provided with ventilation so that air can enter. A shutter is installed at the top for changing the filter bag or emptying treated material, adding straw etc. into retained material, inspection and so on.

The principal role of the filter bed (or filter bag) is to cause a clean separation of particulate solids of the influent with no additional energy consumption. The domestic wastewater is discharged into one or the two empty filter bags. The solid material is retained in the filter bag and when the filter bag is full, the flow is diverted manually to the next empty bag. The filled bag is left for further dewatering and degradation in order to get volume and pathogens reduction as well as a dry material. After 6~8 months, the bag with pre-treated materials is taken out and further composted with other household and garden organic waste in a local composter for a year prior to its use in the garden. The collected filtrate is pumped periodically to the constructed wetland and after treatment it is discharged into the watercourses nearby.

The amount of nutrient and carbon retained in the Rottebehaelter system at the end of the treatment has a significant meaning from ecological perspective. If the Rottebehaelter system cannot retain a high percentage of organic matters and nutrients present in wastewater, it will not be beneficial. According to the research results of Gajurel (2003), nitrogen retention in the existing Rottebehaelter system was approximately 30%~60% - averagely 76 mg/l (Schütze, 2005) of brownwater, phosphorus retention was above 30% - averagely 34 mg/l (Schütze, 2005), and Carbon retention was around 30%~50%.

It is also concluded by Gajurel (2003), soluble nutrients cannot be retained in Rottebehaelter. Therefore, from the aspect of ecological sanitation, Rottebehaelter system will be effective only if urine free household wastewater can be pre-treated. Hence, the volume of the wastewater discharged into Rottebehaelter has no influence on the decomposition process. Therefore, greywater and brown water can be treated together in Rottebehaelter, if greywater is not intended to be reuse as tap water.

The expecting amount of Rotte is relative smaller than the solid material originally from brownwater, which consists of faeces (approximately 50 kg/capital\*year) and toilet paper (6 kg/ capital\*year). Thus, there is approximately 5.6-ton solid material every year for 100 residents, which requires around 6-m<sup>3</sup> space due to water amount in faeces (Schütze, 2005).

### 5.1.3 The vacuum biogas system - high-tech for urban areas

#### 5.1.3.1 The process of anaerobic treatment

Anaerobic treatment can be traced from the beginning of wastewater treatment itself and have been used for the domestic and industrial wastewater over a century (Seghezzi, 2004). The simplest, oldest and most widely used process is septic tank. Concerns over the environment and rising costs for energy and for wastewater treatment have caused a renewed interest in anaerobic treatment and in using biogas produced during the treatment of organic wastes.

Anaerobic digestion is a complex microbial process involving many species of bacteria. Its primary objective is the stabilization of organic matter through its conversion to carbon dioxide (CO<sub>2</sub>) and methane (CH<sub>4</sub>) in an oxygen free environment. The overall process is often subdivided into four separate processes as follows (Cardew, 1998):

➤ *Hydrolyze phase*

In the hydrolyze phase, the organic molecular links have to be released through enzymes and be transformed into water-soluble elements. This process still happens in aerobic environment.

➤ *Acidification phase*

In the acidification phase, the bacteria (facultative and compulsory anaerobic) develop short chain organic acids, alcohols, H<sub>2</sub> and CO<sub>2</sub>. Also ammoniac and H<sub>2</sub>S are released.

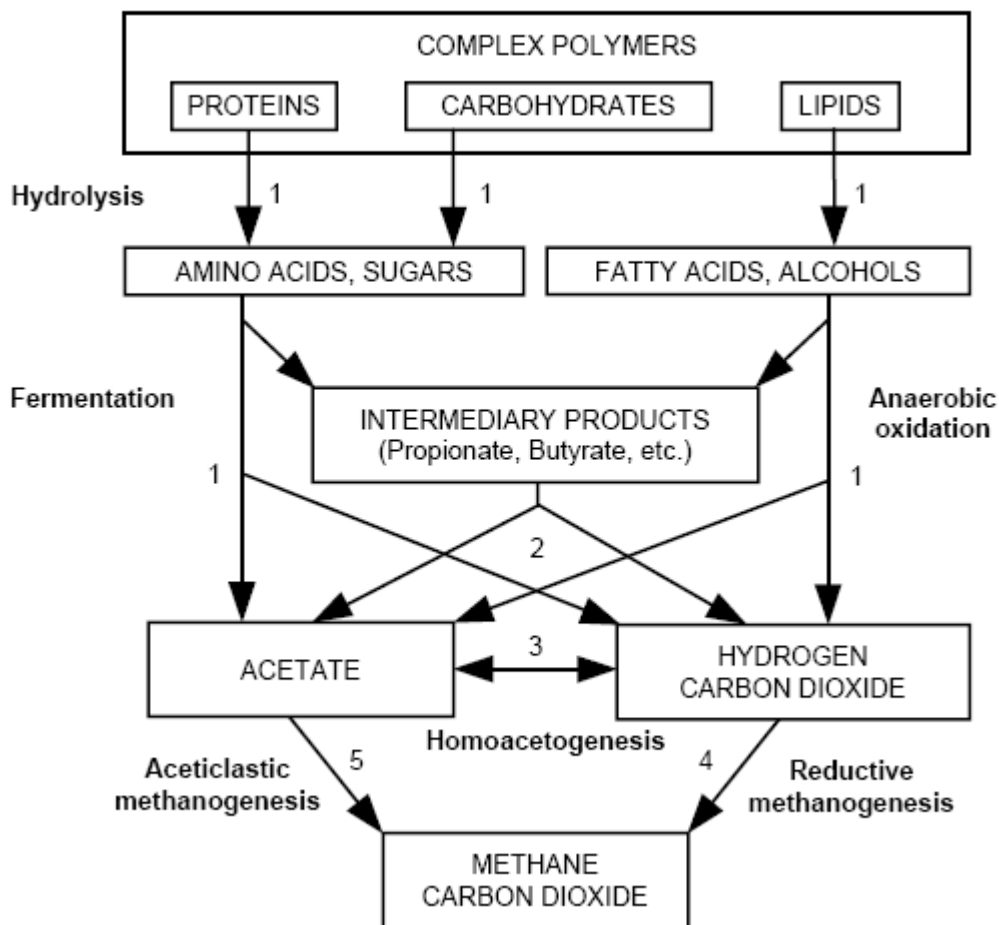
➤ *Acetogene phase*

In the acetogene phase, the short chain organic acids, alcohols are disintegrated into acetic acid.

➤ *Methanogene phase*

In the methanogene phase, methane will be finally formed out of mainly acetic acid and also out of H<sub>2</sub> and CO<sub>2</sub>.





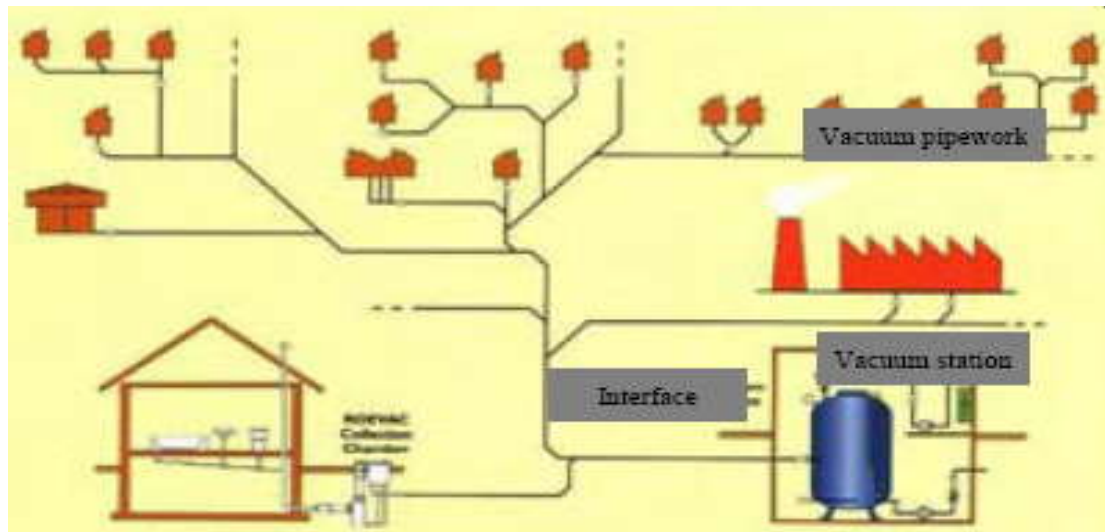
**Figure 5-3** Anaerobic digestion of organic matter (Seghezzeo, 2004)

### 5.1.3.2 Vacuum system (vacuum sewers and toilet)

While there are many viable options for Ecosan in rural and less densely populated peri-urban areas, there are still a fairly limited number of concepts available for urban areas (Otterpohl, 2003).

The vacuum technology is applied as a sewage collection tool in ships, trains and aircraft for many years. However, it can also be used in domestic technology for wastewater, especially with anaerobic digestion of the high-concentrated digestion (GTZ, 2005). Vacuum sewerage (pipeline) systems are particularly suited in sparsely populated and ribbon areas; hilly terrain, rocky soil, high ground water table and water scarce regions. Additionally, there are no slop requirements for these systems and only need shallow and narrow trenches, thus 20%~25% cheaper than conventional gravity sewerage (GTZ, 2005). Moreover, there are no leakage and odour problems, which usually occur in gravity sewage system.

Figure 5-4 presents the elements of a general vacuum sewerage system. The system components are a central vacuum station, generating the low pressure; the vacuum sewer lines, in which the wastewater and air mixture is transported; and vacuum sanitary installation (vacuum toilet for black water collection and piping). Blackwater is transported in a low-pressure system by using air instead of water as transport medium. A vacuum toilet needs only approximately 1l of water per flush, thus extreme water saving up to 80% can be reached (GTZ, 2005). The low dilution of the excreta allows a more concentrated collection than gravity system.



**Figure 5-4** Schematic overview of vacuum sewerage system (Mang, 2006)

### 5.1.3.3 Biogas utilization

In the processes of anaerobic digestion, anaerobic bacteria degrade organic materials in the absence of oxygen producing a gas principally composed of methane ( $\text{CH}_4$ ) and carbon dioxide ( $\text{CO}_2$ ) otherwise known as biogas that can be used as an energy source. With a history of over 30 years, biogas technology is an efficient, well demonstrated and provides a cost-effective method of disposing organic wastes and producing fuel and fertilizer without releasing greenhouse gas (Rose, 1999).

Figure 5-5 illustrates the major utilization of biogas. Biogas is an excellent source of energy and can be used to produce electricity as well as cooking and lighting gas. Additionally, biogas can be used to run water pump engines, electric generators, and agricultural machinery. An integrated system for the recovery of waste resources and improvements in sanitation should have a biogas reactor. The use of biomass as a substitute for fossil fuel presents a high potential for the avoidance of green house gas emissions. The benefits of biogas technology can be summarized as follows:

➤ *Environmental benefits*

The production of biogas can significantly reduce CO<sub>2</sub> and CH<sub>4</sub> emissions, which can cause greenhouse gas and global warming. This process is also a positive transformation of organic waste into high quality fertilizer for agriculture. Since all residues discharged from the plant are used, there is no request to satisfy the environmental standard for the wastewater discharging so as to achieve the protection of soil, water and air. Hence, in the rural areas the amount of firewood that is cut and burned for cooking can be largely decreased so as to protect vegetation and forest.

➤ *Energy benefits*

The predominant advantage for biogas production is the generation of high quality renewable fuel and deduction of dependence on fossil energy. Biogas has proven in numerous end-use applications: cooking, fuelling the boiler for steam generation, electricity and lighting.

➤ *Waste treatment benefits*

Anaerobic digestion usually requires less land than aerobic composting or landfill, and volume of sludge and slurry are relatively small, which can be used for fertilizing the rice land and vegetable growing.

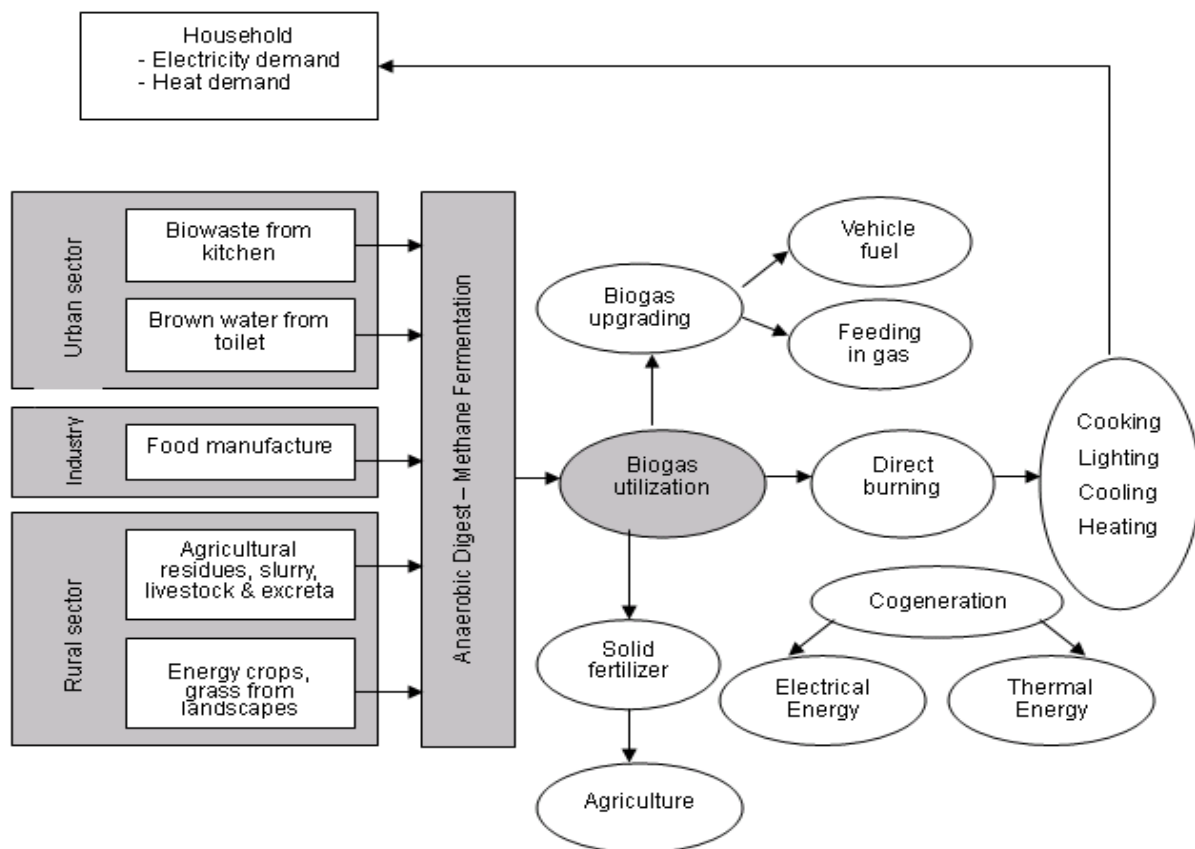
➤ *Economic benefits*

Promoting the biogas technology can enhance the economic growth, especially in developing countries, because of the reduction in the use of fossil fuel and saving the expenses on chemical fertilizer. Additionally it can also increase the agricultural yield and improve the quality of products. Reactor effluent is used to fertilise mushroom and fish production. Thus it is more cost-effective than other treatment options from a life-cycle perspective;

### **5.1.3.4 Pilot project in “Flingenbreite” (Lübeck, Germany)**

An integrated sanitation concept with vacuum toilets, vacuum sewers and a biogas plant for black water is implemented for the settlement “Flingenbreite” in Lübeck. It was built for a settlement of up to 400 inhabitants and the total area is 3.5 ha (Otterpohl, 2003). Such systems can be installed even in very densely populated areas in combination of MBR (Membrane-Bioreactor) for greywater treatment.

At the digester a vacuum pumping station was installed for both vacuum toilets and the vacuum pipes. Pipes are dimensioned 50 mm to allow good transportation by the air. The heat for the settlement is produced by a combined heat and power generation engine, which was supplied by biogas when the storage is filled. Heat is also used to heat the biogas plant.



**Figure 5-5** Biogas utilization

According to Otterpohl (2003), faeces mixed with the shredded bio-waste are hygienised by heating the feed to 55°C for 10 hours. The energy is further used by the digester that is operated mesophilic at around 37°C with a capacity of 50 m<sup>3</sup>. One important source for heavy metals is copper or zinc – plated pipes for drinking water. These materials will be avoided and polyethylene pipes are used.

In the “Flingenbreite” project, the sludge will not be de-watered for having a good composition of the fertiliser and for not having to treat the sludge-water. The relatively small amount of water added to the blackwater keeps the volumes small enough for transportation. There will be a 2 weeks storage tank for the collection of the digester effluent. Biogas will be stored in the same tank within a balloon that gives more flexibility in operation. The fertilizer will be pumped off by a truck and transported to a farm that has a seasonal storage tank for 8 months. These tanks are often available or can be built with little investment. Figure 5-6 shows the technical building where the vacuum-pumping station, digester, heat- and power generation and other devices are installed.



**Figure 5-6** Vacuum station, sanitization tank and biogas treatment plant for the collection and anaerobic treatment of black water and bio-waste (Otterpohl, 2001)

## 5.2 Yellow water management

### 5.2.1 Significance of urine separation

Source-separating of human urine could date back thousands of years with Chinese farmers using urine as liquid fertilizer (Winblad, 2000). Recycling of nutrients between urban areas and farmland is a crucial step towards ecologically sustainable development. Nutrient pollution of ground- and surface waters can be significantly reduced. Source-separated urine also greatly reduces the nutrient load of the wastewater stream improving treatment performance potential.

Urine is the most nutrient-abundant part among domestic waste components. With complete urine diversion, the majority of nutrients from the wastewater stream can be recovered: 80% of the Nitrogen (N), 55% of the Phosphorous (P), 60% of the Potassium (K), as well as a substantial fraction of Sulphur and Magnesium (Otterpohl, 2000). This equates to approximately 11g N, 1g P, and 2.5g K per person per day (Schütze, 2005).

Therefore, elimination of nutrients is no longer necessary and pharmaceuticals and hormones secreted by humans no longer reach the sewage treatment plant. Direct discharge of nitrogen, phosphorus and pharmaceuticals into surface waters during rainy periods is prevented. Moreover, nutrients can be recycled from concentrated urine much more efficiently than from a diluted waste stream, although application of these nutrients in agriculture requires treatment in order to reduce the levels of pharmaceuticals. Hence, utilization of the urine as an alternative fertilizer reduces the demand for chemical fertilizers, thus providing significant cost savings. In addition, according to Otterpohl (2000), significant water saving (up to 40 l/person/day or 50%) is possible with reduced flush demands compared to conventional flush toilet (WC).

Comparing energy demands for nutrient removal (conventional centralized approach) versus Ecological Sanitation system, according to GTZ (2005), a study of Swiss indicated that there should be considerable potential of energy-savings by urine diversion nutrient recovery. The energy demand of source separated nutrient recovery is reduced to half, comparing to the energy requirement for chemical fertilizer production coupled with conventional nutrients removal in conventional wastewater treatment system. In another word, energy demand for nutrient removal and production coupled with conventional nutrient removal in wastewater treatment requires more than doubled energy demands, comparing source separated system with nutrient recovery.

### 5.2.2 Facilities to achieve urine-separation

Urine diversion system is aimed at separating human urine at the source before it mixes with faeces. This can be achieved with specially designed toilets, piping systems and storage containers. The collected urine can then be further processed and used as a local fertilizer in agricultural production, thus closing the nutrient cycle. Several types of toilets and small-scale separation systems have been developed in the past few years.

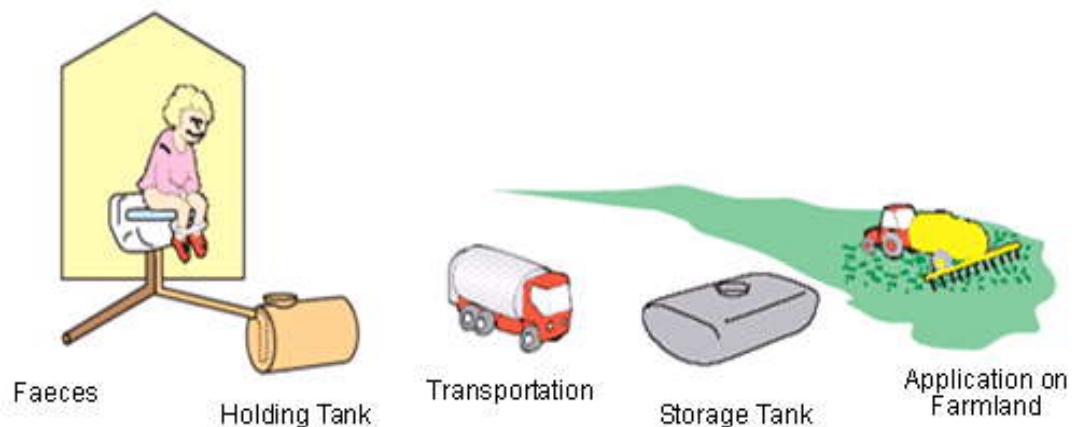
Urine-separating toilets differ from ordinary toilets – they have two bowls, a front bowl for urine and a rear one for faeces and toilet paper. The following figure 5-7 presents the typical urine-separating toilet used in Sweden. Toilet design is available as water flushing and waterless systems. Flush systems collect urine in diluted form, requiring larger piping and storage, and possibly treatment and transport, components. Waterless systems collect undiluted urine and require smaller piping and storage capacity. Vacuum toilet system with urine diversion is currently under development.



**Figure 5-7** Separating-toilet installed in Understenshjäden and Palsternackan of Sweden (Johansson, 2001)

### 5.2.3 Urine transportation and storage

Today urine transport and storage, as well as spreading techniques for nutrients reuse on arable land are key issues. The urine will be led to a separate pipe system to a holding tank, which is connected to households. Then the urine is collected and moved by a tank truck driven by farmer, who uses the urine as fertilizer.



**Figure 5-8** Schematic overview of urine separation systems, from toilet to field (Johansson, 2001)

Figure 5-8 presents an overview of urine separation system. This issue is quite big in countries in the region with cold climate or with poor economical resources like in the developing world. Lack of clear regulation regarding urine spreading for hygienic reasons makes the uncertainties even more problematic (Ganrot, 2005).

Basically, urine is relatively sterile and can be reused without treatment. However, due to faecal contamination, pathogens might be found in yellow water. In order to achieve adequate hygienic quality, the urine mixture should be stored for six months without the addition of any new urine. Thus it is sufficient for the urine to be used on any types of crop (Otterpohl, 2000; Johansson, 2001; Gajurel, 2003; Jösön et al, 1999). Recommended storage time at temperatures of 4~20°C varies between one and six months for large-scale systems depending on the type of crop to be fertilized (Stenström, 2004).

Based on the practice of separated collection of yellow water, farmers in Sweden have been collecting it in underground storage tanks for applying to their agricultural land (Jönsson et al, 1999). Figure 5-9 shows the holding tank for urine storage and Figure 5-10 shows tank trucks for urine transportation.





**Figure 5-9** Holding tank (left) (Johansson, 2001)



**Figure 5-10** Tank trucks for transporting (right) (GTZ, 2005)

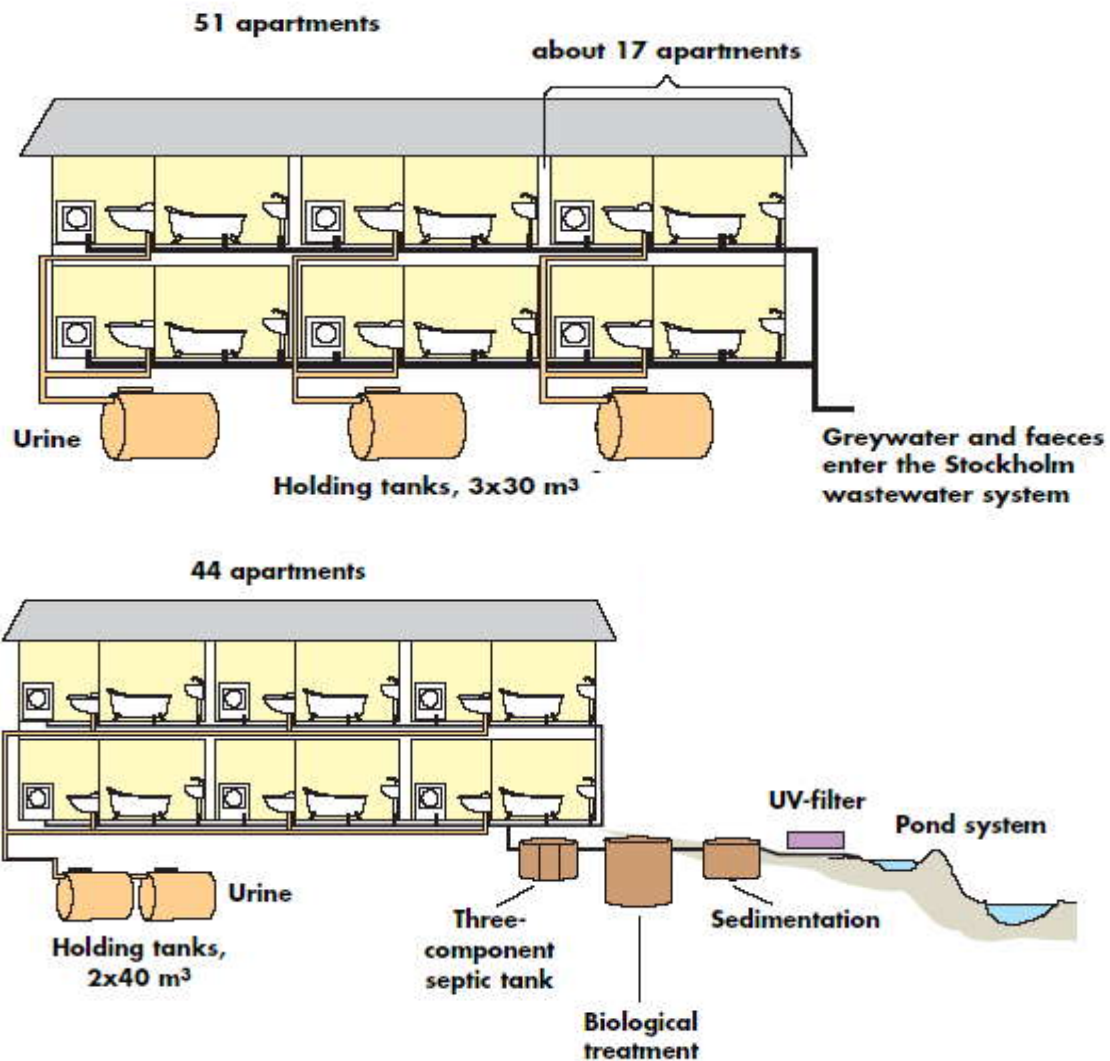
### 5.2.4 Measure for the reduction of nutrients' losses

It is important that the whole system of collection, storage and handling for human urine is constructed to minimize nutrient losses. In fresh urine, the greater part of the nitrogen appears as urea [ $\text{CO}(\text{NH}_2)_2$ ]. Urea hydrolyses rapidly into ammonia ( $\text{NH}_3$ ) during the storage and transportation of urine (Ganrot, 2005). In general, the decomposition of urea will lead to an increase in concentration of ammonia ( $\text{NH}_3$ ) and pH value. Thus, in this hydrolysis, pH is increased, which causes precipitation of calcium, phosphate, struvite and calcite resulting 90% of total nitrogen is present as ammonia (Gajurel, 2003; Ganrot, 2005). The ammonia can evaporate while transportation and application in agriculture as fertiliser (Gajurel, 2003; Ganrot, 2005; Johansson, 1999).

The high pH of the urine in the collection pipes, normally 9~9.3, coupled with its high ammonium concentration, means that there is a risk of losing N in the form of ammonia with the ventilation. However, according to Jönsson (2004) and Schütze (2005), these losses are easily eliminated by designing the system, such as the tank and pipes are not ventilated, but pressure equalized. Additionally, urine is very corrosive and therefore tanks and pipes should be made of resistant material, e.g., plastic or high quality concrete, while metals should be avoided.

Experiences from handling urine in Sweden has shown that the losses of nitrogen during storage could be minimized by having a low temperature, a low pH-value and avoiding aeration above the liquid surface in storage tank. Moreover, it can also be prevented by ammonia oxidation and with the biological nitrification, and then urine can be stabilised (Gajurel, 2003). However, a high temperature, low dilution, high pH and long storage periods are favourable for sanitation process of the urine mixture (Johansson, 2001; Gajurel, 2003; Ganrot, 2005).

The following Figure 5-11 shows an example of urine separation and wastewater systems in Sweden: Understenshjäden (upper) and Palsternackan (below).



**Figure 5-11** Scheme of urine separation and wastewater systems in Sweden: Understenshjäden (upper) and Palsternackan (below) (Johansson, M., 2001)

### 5.2.5 Nutrient recovery during urine processing

One important aspect for nutrient recovery is to increase the concentration of yellow water. On the one hand the decrease of volume is to save storage capacity in congested area; on the other hand a higher urea concentration is advantageous for definite utilization of yellow water such as using urea from yellow water as a replacement for industrial produced urea. Recently, many methods for treatment and volume reduction of collected yellow water have been studied. These methods could be beneficial, when a larger volume of urine solution has to be transported a long way to the agriculture farm. Generally, there are three major approaches:

### **Stabilization**

The aim of this technique is to reduce or stop urea hydrolysis and nitrogen losses as ammonia during storage and handling. Experiments were performed to decrease the pH value by nitrifying a part of the ammonia to nitrate, but complete nitrification was not achieved (Hellström, 1998). About 50% of total ammonia in urine could be stabilized by biological nitrification in biofilms. By nitrification in combination with drying, it is possible to concentrate over 70% of the nitrogen in 10% of the original volume (Johansson, 1999). By addition of acid to urine, the hydrolysis can also be prevented (Hellström, 1998; Ganrot, 2005).

### **Volume reduction**

The decrease of volume is to save storage capacity in congested area. Several methods have been studied, such as distillation, drying and partial freezing. By freezing, it is possible to concentrate 80% of nitrogen and phosphorus in 25% phosphorus in 25% of the original volume (Ganro, 2005).

### **Production of a solid fertilizer**

It is also possible to transform the nutrients in urine in solid fertilizers, and especially struvite formation, which is produced from wastewater and organic animal waste today in Japan and Europe, has been studied (Booker et al., 1999). More recently, struvite precipitation from urine-separating systems has also been investigated by scientists (Otterpohl, 2003). By crystallizing struvite from human urine, the volume is reduced, the handling is facilitated, hygienisation is improved, and the crystals obtained can also be stored for later use or directly used in agriculture (Ganrot, 2005).

Currently, storage and transportation of large amounts of urine and spreading, are main hinder in achieving system efficiency. According to the latest research by Ganrot (2005), three different urine processing techniques that can achieve efficient nutrient recovery are as followings:

- Volume reduction and nutrient concentration from urine can be achieved by partial freezing. By this method, more than 80% of both N and P can be concentrated in 25% of the original volume. Partial freezing can be realized by struvite precipitation and adsorption.
- By adding small amounts of MgO, with struvite precipitation, total amounts of P and half amounts of K could be recovered.
- Both natural zeolites and wollastonite adsorbed ammonium rapidly. Mineral adsorption could recover up to 80% of the N. Active carbon adsorbed N, reduced smell and color.

### 5.2.6 Direct use as liquid fertilizer

Human urine collected in separating systems can be directed as a liquid fertilizer (Jössson et al, 1999; Ganrot, 2005). The fertilizer value of pure urine similar to NPK 18:2:5 and for urine mixture (urine mixed with flush water) to NPKS 15:1:3:1 (Ganrot, 2005). For single households, urine could be applied to any crop without storage as long as one month passes between fertilization and harvest, and dilution of the urine should be avoided (Stenström, 2004).

However, Winblad (2002) claimed that nitrogen in stored urine is mainly found as ammonia, and ammonia is toxic to some plants if applied to the plants themselves. Therefore, the best and safe way to apply urine is to spray to the ground or inject it below the ground surface. The heavy metals content was extremely low, making urine a clean fertilizer. The emission of ammonia after spreading was slight. If the system was correctly designed, ammonia emissions in urine collection, transport and storage can be neglected.

Winblad (2002) also suggested that if people use urine to grow vegetables and fruits, the increased production results in greater food security at virtually no cost. When urine is applied to open soil before planting it can be undiluted. If used on growing plants it can be applied without or with dilution. Figure 5-12 present the urine fertilizer applied with mechanical injection.



**Figure 5-12** Urine fertilizer applied with mechanical injection (GTZ, 2005)

## 6. Rainwater management

### 6.1 Comparison of traditional solution and new management

The new challenge of rainwater management requires a fundamental change in the way we think about storm water. Instead of thinking of rainwater as something to be collected and treated, then disposed of outside the city, rainwater should be regarded as a resource, and the amount of rainwater introduced into combined system should be reduced. Therefore, decentralized rainwater management can be regarded as an alternative, the sustainable strategy and redevelopment of rural and urban human settlement, practically considering ecological, economical and social criteria.

The following Figure 6-1 gives a general comparison of the measures and results by using traditional rainwater drainage and decentralized rainwater management.

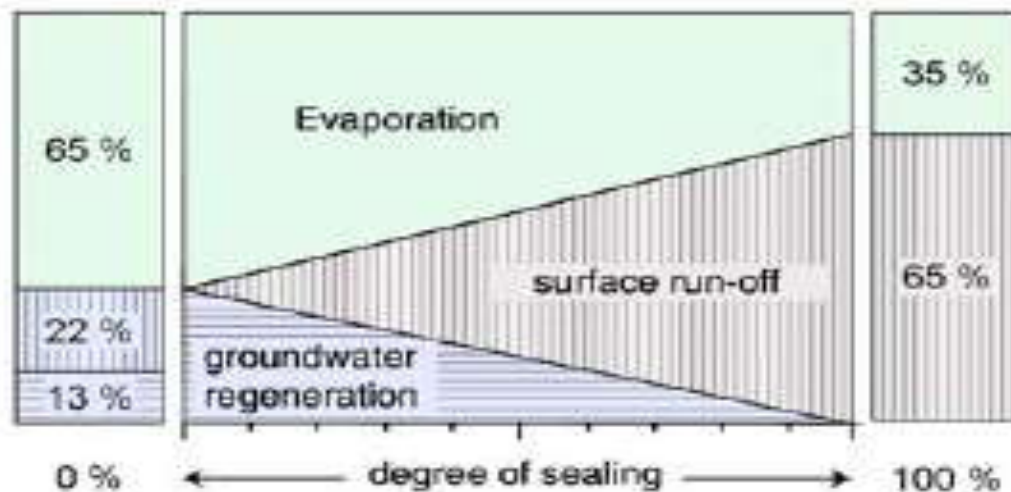
**Table 6-1** Comparison of traditional rainwater drainage and new management

<b>Traditional rainwater drainage</b>	<b>Rainwater new management</b>
Acceleration of surface flow (from settlement)	Slow down of surface flow (from settlement)
Centralized combination of surface water and other wastewater in sewage systems	Decentralized retention and storage, infiltration, and evaporation of surface water
Flow-peak always becomes larger	Flow-peak always becomes smaller
Shrinking of evaporation- and infiltration ratio	Stabilization and expansion of evaporation- and infiltration ratio
Maximal of surface flow	Minimum of surface flow

## 6.2 Overview of substructure

### 6.2.1 Runoff evaporation and infiltration

The natural proportion of evaporation, infiltration and runoff of a specific location is primarily depended on the factors of climate, duration and intensity of precipitation events (e.g., once 100 years), soil permeability, quantity and type of the vegetation (Schütze, 2005).



**Figure 6-1** Balance of surface runoff, evaporation and groundwater recharge for different degree of sealing (Meissner, 1997)

Based on the natural conditions in Germany, it is estimated that 50~60% of the rainfall evaporates, 22~35% infiltrates, and there is a 17% surface runoff. With a growing rate of sealed ground (e.g., establishment of buildings and roads), the proportion of the runoff rises up to 65% in average per year (on totally sealed surfaces). In that case, there is practically no more groundwater recharge and the remaining rainfall evaporation (Meissner, 1997).

In addition, on the one hand, the groundwater renewal rate varies considerably with evaporation. The planning of evaporation measure is significant for the improvement of urban climate and natural-closed water balance. On the other hand, through the measures of groundwater recharging and infiltration of relatively clean stormwater, the exploitation of drinking water from groundwater aquifer can be positively reduced. The adoption of decentralized stormwater infiltration can reduce both amounts of potable water extraction and wastewater production.



### 6.2.2 Site-survey

When consider a decentralized stormwater management, the prerequisites set by natural factors must be investigated. A decentralized stormwater management method is proposed in accordance with the particular geological, morphological, topographical, and soil-science foundation.

In order to evaluate the possibilities and feasibilities of rainwater infiltration implementation for artificial groundwater recharge in specific areas, it is very important to develop site-survey and obtain the detailed information that can be useful for the design of rainwater harvesting plans. In order to achieving data-collection, Geological Information Systems (GIS) and existing sewer system database might be helpful. Table 6-2 presents the necessary category groups of site-survey.

**Table 6-2** Category groups of site-survey and influence factors for decentralized rainwater management

<b>Built-up area structure factors</b>	<b>Geogenic factors</b>
<b>Site</b>	<b>Topography</b>
Nature of impervious area	Slope of area
Proportion of impervious area	<b>Soil</b>
Utilization of site	Thickness of layers
Distribution of impervious area	Type of soil
	Infiltration capacity
<b>Buildings</b>	Historical pollution
Size	<b>Geology</b>
Roof type	Type of rock
Drainage technique	<b>Ground water</b>
	Groundwater table
	Groundwater protection zones

Additionally, the population-density of specific area based on the site or land condition can be integrated into data collection, in order to make decentralized rainwater planning easier. If necessary, the information relating to the amount of household daily water consumption and needed rainwater, as well as expecting implementation methods, e.g., infiltration, retention and evaporation, should be also collected.

Disconnection potential, the potential for disconnecting stormwater from combined sewer system, is regarded as a function of the developed area. It is highly depended on structure factors including the availability of free areas. The disconnection potential varies and depends largely upon the area and the different

types of buildings and structures. To determine the disconnection potential, the different types of the developed area and building structures are needed to be analyzed and evaluated. Table 6-3 gives a general criterion of the evaluation of the disconnection potentials.

The inter-disciplinary and cooperate between architecture, urban-planning, landscapes maintenance and urban water management will reinforce the work of data collection. According to the site-survey that indicates characteristic of specific site, it becomes easy to determine which street or courtyard can be detached from sewer system in the future during rainfall, and whether certain rainwater management and implementation can be realized.

**Table 6-3** Criterion of the evaluation of the disconnection potentials (Becker, 2004)

<b>Building Types of structure</b>	<b>Old buildings, densely populated</b>	<b>Linear buildings</b>	<b>Rows of terrace house</b>
<b>Type</b>	Enclosed courtyard, courtyard, careful remediation	Linear building	Terrace house
<b>Structure of building</b>	Completely enclosed	Building blocks	Terrace house Semi-detached house
	With internal courtyard	Parallel to another	Close to another Center of village
<b>Structure of free area</b>	Rectangular	Large, long free areas	Often intersected with narrow ways
	Narrow internal courtyard	With parking spaces	
	Small, separate green area	With lawns With playground	Narrow gardens
<b>Opportunities for disposing other than in combined sewer systems (+ Favorable) (-Unfavorable)</b>	Closed form of building -	Open form of building +	Motivation with charges +
	No seepage area on side to road -	Seepage area on all sides +	Close form of buildings+
	Individual seepage areas in courtyard area -	Uniform ownership structure +	Property owned in small plots -
	Property owned in small plots -	Low utilization of free areas +	Intensive utilization of free areas -
<b>Estimation</b>	Suitable subject to certain conditions	Very suitable	Suitable
<b>Potential of disconnection</b>	10~15%	60~80%	30~50%



## 6.3 Strategies of decentralized rainwater management

Decentralized alternative approach seeks to redesign the urban landscapes, in order to minimize the volume of runoff that flows into the sewer system. Using storm water harvesting technologies and infiltration with modern implementation strategies, this approach shifts the focus from remediation to prevention by slowing, percolating, retaining and treating water where it falls, all before entering the piped wastewater system. However, there are neither universal formulae nor measures for the realization of decentralized rainwater management. The desired and attainable effects as well as the applicable technologies for decentralized rainwater management are dependent on the specific local basic conditions and sustainability criteria of each development area, e.g., infrastructure and natural basic conditions, culture and economy.

### 6.3.1 Planting vegetation of green roof

Recently, there is a tendency in some European countries to develop on-site stormwater retention system in the form of roofs covered by vegetation. A greened or vegetated roof can serve as a very effective stormwater management system. This practice is gaining wide attention for stormwater control and pollutant filtration systems. Germany is the leading country in terms of greened roof construction, also in Sweden there a number of such installations (Sieker, 2006).

The primary reasons why these systems are constructed is not only aesthetics and enhancement of amenity, but also the most important of all to reduce storm water runoff and contribute to insulation of buildings. Moreover, it can result in the reduction of heat island effect and the enhancement of biodiversity, and potentially also lead to improving water quality.

The precipitation that falls onto a greened roof either evaporated directly from the roof-surface (interception, then evaporation) or is transpired by the plants that compose the green roof (transpiration). In Germany, most of the precipitation in natural landscapes is evaporated. Approximately 80% of precipitation is evaporated or transpired by plants. Greened roofs can evaporate 60%~70% of annual precipitation. (Sibylle, Schmidt, 2005). The following Figure 6-2 and Figure 6-3 present two examples of greened roof in Germany.



**Figure 6-2** Intensive greened roof system established 1984 in Berlin (left) (Sibylle, 2005)

**Figure 6-3** Extensive green roof system (right) (Broschüre Landshut, 2006)

### 6.3.1.1 Types of green roof vegetation

Greened roofs can be designed as intensive (soil layers greater than 30cm, able to support larger plants) and extensive (soil cover can be down to a few cm, can only sustain low and durable plants) (Sebylle, 2005). Table 6-4 compared the characteristics of different greened roof.

**Table 6-4** Characteristics of different greened roofs (Schütze, 2005)

Types of greened roof	Water retention in average		Runoff coefficient	Height of roof structure	Material cost per m <sup>2</sup>
	Roof depth (cm)	in %			
Extensive	2~4	40	0.6	3~20 cm	25 €
	4~6	45	0.55		
	6~10	50	0.5		
	10~15	55	0.45		
	15~20	60	0.4		
Intensive	15~25	60	0.4	15~150 cm <sup>1</sup>	50 € <sup>1</sup>
	25~50	70	0.3	12~19 cm <sup>2</sup>	40 € <sup>2</sup>
	>50	90	0.1		

Explanation:

1 Intensive greened roof with garden

2 Intensive greened roofs without garden

### **6.3.1.2 Benefits of greened roof system**

#### **Reduction of stormwater runoff**

Measures for greening of roofs contribute substantially to the retention of rainwater. In the United States for instance, green roofs retain precipitation, which is well known for many years. The annual storage of rainwater varies between 50% and 80% of the annual rain (U.S. EPA, 2006). The following figure 6-4 compares the reduction of runoff between conventional impermeable roof and extensively greened roof.

#### **Reduction of temperature during summer time**

Another positive influence of greened roof is temperature reduction. And vegetation significantly contributes to an increase of the evaporation ratio and improving the air quality due to microclimate changes. The efficiency of a greened roof to reduce the inner city surface temperatures can be proved since 1970 in U.S.A. (U.S. EPA, 2006). Through isolation of heat in summer, the temperature of building can be much lower than bitumen roof.

#### **Energy balance**

Impermeable and sealing surface can create a different energy balance than is found in greened areas. The main cause of this changes are reduced evaporation and transpiration of the precipitation, as well as the ability of hard surface (e.g., concrete) to store heat. The amount of water will evaporate from the vegetation layer. The energy supply during the evaporation process works like an air conditioning system. According to Sibylle and Schmidt (2005), greened areas like meadows can consume 86% of all radiation balance as a yearly average. The experiment made at the UFA Fabric in Berlin, extensive green roofs transfer 58% of the radiation balance into transpiration via plants during summer time. The generated cooling-rates are on average 300 kWh/(m<sup>2</sup>\*a) in Germany. Hard material in urban areas like concrete and bitumen roofs usually transform up to 95% of radiation balance to latent heat. As a result, the temperatures inside building also rises and leads to increased energy consumption for cooling.

#### **Reduction of contaminant emission**

Although there is effective retention of rainwater and energy transformation in transpiration through extensive greened roof, on the other hand, there are considerable nutrient (e.g., phosphor) and contaminant (e.g., metal), which have converse effect to water protection. However, with the installation of greened roof and the gradual adsorption nutrients or metals by growing plants, the contaminant and nutrients can be reduced significantly.

## 6.3.2 Rainwater infiltration

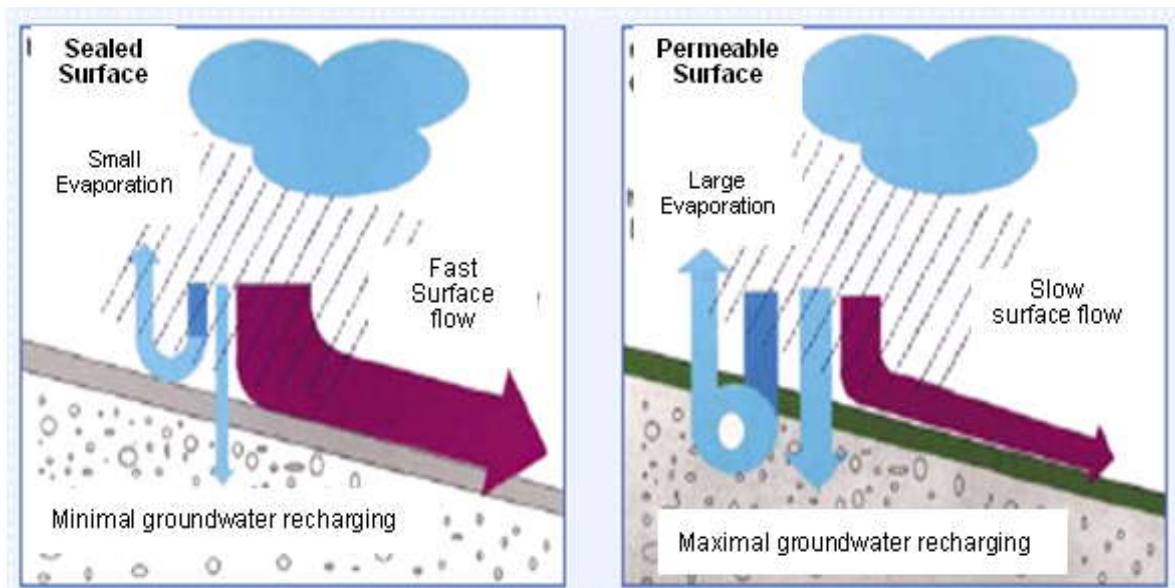
### 6.3.2.1 The necessity of rainwater infiltration

In many areas of the world, due to continuously and increasingly extraction of groundwater and construction of buildings, which directly increase the area of sealed ground, the ground water table is dramatically sunk. Therefore, one of the strategies for groundwater recharging is to increase artificial groundwater regeneration ratio. Otterpohl (1999) also suggested that relatively clean rainwater runoff should be disposed and reduced of by infiltration into ground if possible.

According to Schütze (2005), in the large city Hamburg, Germany, the groundwater regeneration ratio is less than 25 liters per m<sup>2</sup> per year. This very low regeneration ratio is caused by relative waterproof marsh soils as well as by a high proportion of sealed ground, which has resulted in the loss of rainfall infiltration for the groundwater regeneration.

“With measures for retention and infiltration rainwater, shallow pits and infiltration ditch systems allow the complete retention of extreme precipitation events in the investigated housing estates.....these measures do not limit the spatial use of the investigated area since the systems can be integrated in courtyards, gardens and can be installed underground, under traffic areas (Schütze, 2006).”

Concerning the proportion of evaporation, infiltration and runoff, rainwater infiltration can contribute essential benefits to the harmonization of natural water balance, and also positive influence for soil, weather, fauna and vegetation. Hence, they can not only significantly reduce the peak runoff in sewers, but also reduce the size of the sewage pipes required to handle the waste stream, which is important when aging systems have to be rebuilt. In addition, the construction of retention and infiltration systems is usually more economic than the construction of technical rainwater utilization system and the related construction work generally does not limit the use of space above ground, since the systems can be also installed underground. The following Figure 6-4 presents the drainage from sealing surface and from permeable surface.



**Figure 6-4** Comparison of drainage from sealed surface and permeable surface (Tietz, 2006; Geiger, 2004)

### 6.3.2.2 Types of infiltration

#### *Flächenversickerung*

The rainwater can be directed to infiltrate into the permeable surface or can be led to the permeable surface when it falls down on the surface with concrete layer. And green land with grass is quite suitable for infiltration, since the root penetration is similar with filter for continuous soil regeneration. Figure 6-5 presents the green land with grass for rainwater infiltration (left) and permeable surface for rainwater infiltration (right). The following Table 6-5 indicated the advantages and disadvantages of surface infiltration

**Table 6-5** Advantages and disadvantages of surface infiltration

Advantages	Disadvantages
Very good purify effect in green land	No space for rainwater retention
Easy for design and maintenance	Large space/surface-area requirement
Small cost for construction	Limited for application



**Figure 6-5** The green land with grass for rainwater infiltration (left) and permeable surface for rainwater infiltration (right) (Broschüre Stadt Landshut, 2006)

It is no doubt that permeable pavements facilitate direct infiltration of stormwater runoff and become the simplest solution to minimize the extension of hard surface in urban areas. Permeable pavements can be constructed on residential areas, e.g., pathways, driveways and parking lots. Runoff is stored in a layer of absorbent soil, sand or gravel, and on the ground surface in a pond area. Surface facilities can be aesthetically landscaped and integrated into the design of open space, they can also be applied at the neighbourhood scale.

By application of surface infiltration, the surface area must be large enough for heavy rainfall during summer, as there is no possibility for rainwater retaining. Hence, it usually demands high infiltration coefficient ( $K_f \geq 2 \cdot 10^{-5}$  m/s, namely 173 cm/day) (Kaiser, 2004), thus the soil layer underground should be fine sand or rough sand.

### ***Muldenversickerung***

In many cases in reality, the existing surface area for surface infiltration (*Flächenversickerung*) is usually not sufficient to provide the measures for handling with strong and acute heavy rain that often happens in very short time. It is also difficult to increase the surface saving-volume of rainwater through expanding infiltration space. Sub-surface facilities (*Muldenversickerung*) can provide an alternative for rainwater management. For sub-surface facilities, the infiltration coefficient should be reached  $K_f \geq 10^{-5}$  m/s (Sieker, 2006).

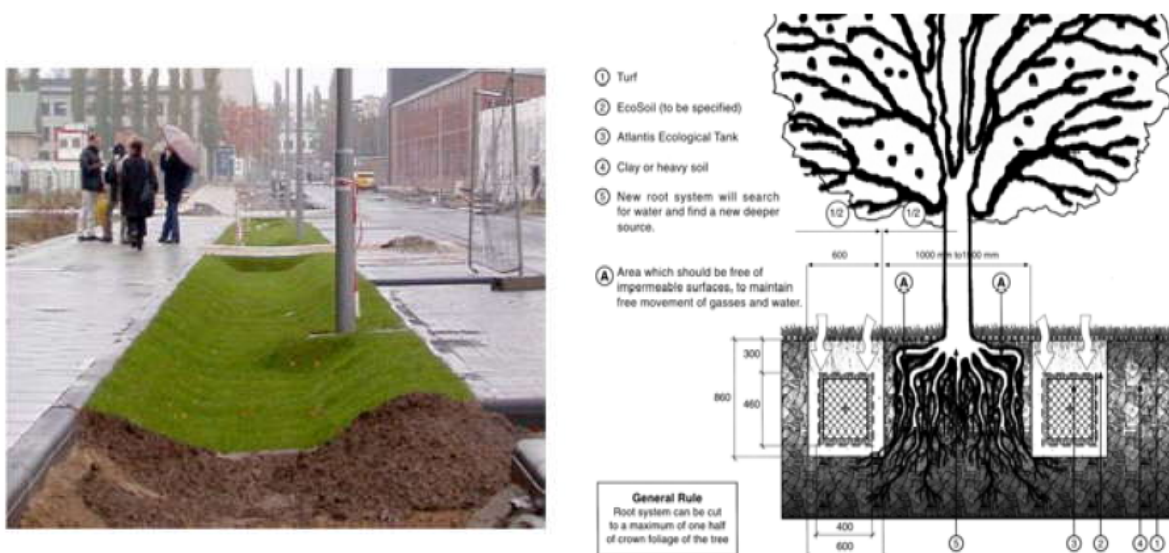
Sub-surface facilities include percolation basins, rock-filled trenches or pits – all terms refer to underground percolation structures, into which runoff is discharged and stored. They can be designed as a basin or a trench filled with gravel or crushed stone for temporary storage of water, which can later percolate into ground. The permeability is relatively small; rainwater can be temporarily stored underground and emptied in one day. It can also be integrated with pond facilities.



Figure 6-6 presents a Muldesystem for a decentralized infiltration of stormwater in Berlin Adlershof, where is directly led to linier road for traffic.

**Table 6-6** Advantages and disadvantages of *Muldenversickerung*

Advantages	Disadvantages
Possibility for rainwater retention	Medium to large space requirement
Good purify performance	
Easy to design	
Small construction cost	
High flexibility in spatial use	



**Figure 6-6** Shallow pit system in Berlin (left) (Schütze, 2005)

**Figure 6-7** Rigolensystem with artificial material around the tree (Schütze, 2005)

### ***Rigolenversickerung***

In order to enlarge the retention potential of stormwater, an additionally underground facility - *Rigolensystem* with exfiltration material is recommended (Sieker, 2006). In the trench-infiltration system (*Rigolenversickerung*), rainwater will be led to either the side of sealing space on the surface or the seepage pipe underground that is filled with gravels and crashed rocks. The pore-volume of filling material serves as retention space for rainwater and rainwater therefore can be retained and infiltrate afterwards. This system is strong recommended when the soil permeability is small or the space supply for surface- and sub-surface infiltration is limited.

The relationship between the size and retention-capacity of a retention system (e.g., pit, basin) depends largely on the vacant portion. Generally, in the retention system made of *Kiesschüttungen*, the pore-volume accounts for 35% of total system (Schütze, 2005) Figure 6-7 presents the construction of *Rigolensystem* with artificial material around the area of tree.

**Table 6-7** Advantages and disadvantages of *Rigolenversickerung*

Advantages	Disadvantages
Retention possibility via pore-volume of sand	Little purification performances for rainwater
Small surface requirement	No monitoring-possibility
No conflict of surface land use	High construction cost

***Mulden-Rigolenversickerung***

Very often, the most frequent adopted and implemented system is *Mulden-Rigolensystem*. Derived by its name, *Mulden-Rigolenversickerung* consists of *Mulden* and underground *Rigolen*. Rainwater will firstly retained in a basin or shallow pit (*Mulden*) and infiltrate through topsoil, then led to the seepage pipe underground (*Rigolen*). The exceeding rainwater from *Mulden* should not be larger than 0.3 meter (Schütze, 2005). Therefore *Mulden-Rigolensystem* has not only perfect purity performance from subsurface system (basin or shallow pit), but also good retention capacity from *Rigolensystem*.

For the effective and environmental-friendly application, the prerequisite of  $K_f$  (permeability of soil) is between  $10^{-5}$  and  $5 \cdot 10^{-6}$  m/s. The type of soil prefers fine sand. The distance between *Mulden-Rigolensystem* and surrounding buildings should be greater than 5 meters (Sieker, 2006).

**Schachtversickerung**

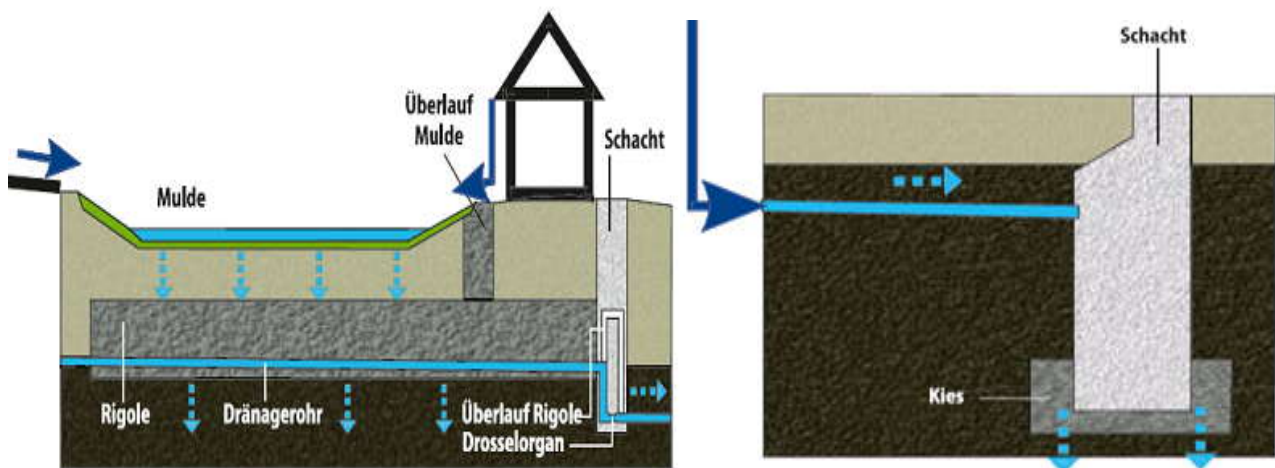
In *Schachtversickerungssystem*, rainwater flows through a permeable slot, in which rainwater will be temporally retained and then infiltrate into deeper layer of soil. This system requires small space and can be applied if the surface infiltration is not available. Hence, it is a suitable solution for single building.

*Schachtversickerungssystem* can only be applied to roof, which is not made of metal, in order to guarantee no pollutant in the infiltration process. In this type purity performance is poor since rainwater will directly infiltrated in to slot without any surface filter function. The distance between the bottom of slot and groundwater table should not be less one-meter (Sieker, 2006), and usually 3.5~5 meters (Kaiser, 2004).

**Table 6-8** Advantages and disadvantages of *Schachtversickerung*

Advantages	Disadvantages
Possibility for storing rainwater	Poor purity performance, GW pollution
Small requirement for surface space	High and intensive cost for construction
No limit for the use of surface area	Large Grundwasserflurabstand





**Figure 6-8** Scheme of *Mulden-Rigolensystem* (Geiger, 2004)

**Figure 6-9** Scheme of *Schachtversicherung* (Geiger, 2004)

### 6.3.2.3 Criteria for suitable option by application of infiltration

The nature-closed infiltration for decentralized rainwater management can be selected from following systems:

- *Flächenversickerung* (purification, infiltration)
- *Muldenversickerung* (purification, retention and infiltration)
- *Mulden-Rigolen-Versickerung* (purification, retention and infiltration)
- *Mulden-Rigolen-System* (purification, retention, infiltration & drainage)

Several significant criteria should be considered when choosing a suitable option by application of infiltration:

#### Requirement of soil permeability

A very important prerequisite for soil infiltration is sufficient permeability of different layers of underground. The clay soil has weak permeability. In contrast, the sandy soil has more than 100,000 times higher permeability than clay soil. Since rainwater usually direct infiltrate into groundwater, there is nearly no sufficient groundwater protection. The permeability of soil can be presented by  $K_f$ . The suitable soil permeability range from  $10^{-3}$  to  $10^{-6}$  meter/second (see Table 6-10 with black color). The smaller the soil permeability is, the larger spaces are required.

**Table 6-9** Permeability of different soil types (Tietz, 2006; Geiger, 2004)

Types of soil	Permeability	Coefficient of Permeability $K_f$ [m/s]
Rock debris	Very intensely permeable	$> 10^{-1}$
Rough gravel	Very intensely permeable	$10^{-2} \sim 1$
Fine/medium gravel	Intensely permeable	$10^{-3} \sim 10^{-2}$
Sandy gravel	Intensely permeable	$10^{-4} \sim 10^{-2}$
Coarse sand	Intensely permeable	$10^{-4} \sim 10^{-3}$
Medium sand	(Intensely) permeable	$10^{-4}$
Fine sand	Permeable	$10^{-5} \sim 10^{-4}$
Silty sand	(Weakly) permeable	$10^{-7} \sim 10^{-4}$
Coarse clay	Weakly permeable	$10^{-6} \sim 10^{-5}$

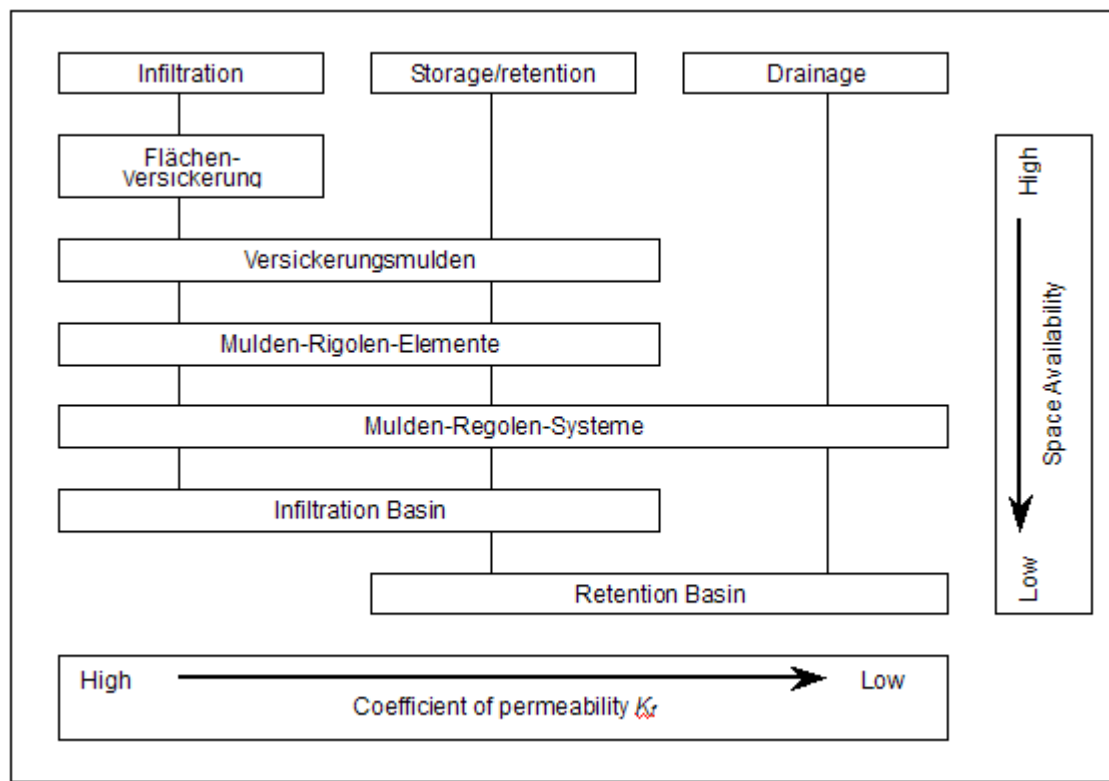
The permeability of investigated surface/sub-surface is of significance when planning infiltration. If the permeability  $K_f$  of soil is very high, *Flächenversickerung* system should be considered. If the permeability  $K_f$  of soil is moderate, *Mulden- or Mulden-Rigolen-Versickerung* is applicable. By small permeability  $K_f$  of soil, *Mulden-Rigolen-System* is necessary due to its drainage components. Table 6-10 presents the different coefficient of permeability for different infiltration system.

**Table 6-10** Coefficient of permeability for different infiltration system (Kaiser, 1995)

Coefficient of permeability $K_f$ -[m/s]	Variety for rainwater infiltration
$\geq 2 \cdot 10^{-5}$	<i>Flächenversickerung</i>
$\geq 5 \cdot 10^{-6}$	<i>Muldenversickerung</i>
$\geq 1 \cdot 10^{-6}$	<i>Mulden- und Mulden-Rigolen-Versickerung</i> without drainage
No constraints	<i>Mulden-Rigolen-System</i> with drainage

### Specific space requirement

The natural-closed infiltration system for decentralized rainwater management differ largely from traditional underground sewer system, since it requires suitable space in settlement area and often has conflict with spatial use and planning. In practice, the space available for designing infiltration system is very limited. The space requirements for the described infiltration system are different. By *Flächen* infiltration, the space requirement is large; by *Muldenversickerung*, the space requirement is reduced; *Mulden-Rigolen-System* demands smallest space. Figure 6-10 investigates the criteria including soil permeability and space requirement for selecting an infiltration system.



**Figure 6-10** Criteria for choosing an infiltration system (Kaiser, 1995)

### Groundwater protection

In order to realize sustainable regeneration of groundwater, it is crucial that the groundwater should be protected from rainwater contamination. Basically, the rainwater quality is substantially influenced by the qualities of the rainwater collection areas. The influence factors include the geological structure, the filtration performance and the filter distance. Polluted areas (e.g., industrial area, heavy transportation road) should be abandoned, since groundwater quality can be deteriorated by tricking of contaminated precipitation. On the contrary, lightly polluted rainwater from roofs and terraces can be usually led to infiltration without pre-treatment.

Additionally, the quantity and quality of groundwater renewal is dependent largely on the quantity and quality of infiltrated rainwater, the characteristics of soil and the runoff surface, as well as the air pollution. Especially in some urban area groundwater is extracted near the surface of ground water aquifer. In order to protect groundwater from contamination, the infiltrated rainwater must be guaranteed with relative good purified quality, e.g., basin with grassed surface serves similar like filter system. Thus facilities like *Rigole* or *Sickerschacht* are not suitable systems.

### **Construction cost**

The cost for constructing an infiltration systems should be cost-effective and at the same time resource-consumption should be minimized. From these points of view, *Flächen- und Muldenversickerung* could be the best options.

In the contrast, *Mulden-Rigolen-Versickerung und –System* has potentials to cost more due to the construction of *Rigole* underground. And also they might result in more resource-consumption.

When choosing a suitable infiltration option, both economical and ecological aspects should be taken into an overall consideration. In general, the easy-designed surface facilities (*Flächen- und Muldenversickerung*) are favorable options. If necessary, the combination with under-ground system, *Mulden-Rigolen-Versickerung System* is also applicable.

### **Public involvement**

The reaction of public is very important for the transformation and implementation of decentralized rainwater management. According to a confrontation and survey of residents who were living in the area with conventional rainwater solution, the attitude to the decentralized rainwater retention and infiltration showed different preference: one third of residents could accept the newly alternative method, 10% rejected, and 50% of inhabitants were open-minded. The positive response indicated that through decentralized rainwater management, more green spaces and free spaces can be re-built and re-arranged, in order to reduce high-grade building construction (Schütze, 2005).

## **6.3.3 Rainwater catchment and utilization**

### **6.3.3.1 Experience of worldwide application**

Rainwater catchment systems have a long history. However, during the twentieth century the use of rainwater collection systems has declined in many parts of the world due to the development of more advanced technologies. Recently, the concept is receiving increased recognition as source of water supply in many parts of the world. The renewed interest and increase use of rainwater during last decade is related to a number of factors. These include (Gould, 1999):

- The failure of centralized piped systems due to operational and maintenance problems;
- Problems with the contamination of groundwater and surface water supplies;
- Increased demand on water supplies due to population growth.

The concept of rainwater catchment system is simple, consisting of process of collecting, storing and using rainwater as a supplementary water source. Generally, this system is easily constructed and maintained with independence of central water supply system. This review concentrates on small-scale, collecting rainwater from roofs for use. Rainwater catchment systems can be used to provide:

- The main source of potable water;
- A supplementary source of potable water;
- A supplementary source of non-potable water, e.g., toilet flushing, garden watering and vehicle washing.

### **Potable water systems**

The use of rainwater catchment system for potable water supplies in developed countries occurs mainly in rural locations (Fewkes, 2006). In rural areas centralized sewer system are usually uneconomical due to low population densities. Similarly, the use of groundwater supplies is often not feasible due to economics or reliability of supply. Therefore, the role of rainwater catchment systems can be regarded as supplementing water supply from centralized water supply facilities and also demonstrated the principles of ecologically sustainable development. Fewkes (2006) also indicated that nowadays the use of rainwater system is widespread in many rural areas of the United States, Australia, and Canada and provides the domestic water requirements of small communities and individual households.

The predominate argument and discouragement of the use of rainwater are public health concern. As a matter of fact, over 3 million Australians currently use rainwater from tanks for drinking in urban and rural regions with no reported widespread adverse health effects (Fewkes, 2006). The rainwater collected from roofs in an inner city in industrial area and stored in tanks was of acceptable quality for hot water, toilet and outdoor uses, although roof runoff was sometimes found to be contaminated.

### **Non-potable water systems**

The utilization of rainwater catchment systems to supply non-potable water to buildings during the last 15~20 years has become popular in urban areas in many developed countries (Leggett, et al 2001). This increased awareness and application has arisen because a number of problems linked to centralized systems of water supply and disposal have been identified.

In Europe, Germany is the country leading the way with the installation of rainwater collection systems. The potential of rainwater system became apparent in Germany since 1970's (Leggett, et al 2001). In the last decade, there were more than hundred thousands of installations for rainwater reuse in Germany (Schütze, 2005). Two main problems were experienced. In Germany, a high proportion of water for

potable use is abstracted from ground water sources and resulted in lowering the water table with adverse environment effects. The ground sources were also becoming polluted representing a potential health risk. Secondly, heavy rainfall in wet weather frequently reached the maximum capacity of predominant combined sewerage system.

In addition, Fewkes (2006) also estimated that in Germany during the last ten years, 100,000 systems have been installed in low and high-rise housing and commercial buildings. To satisfy the non-potable demand in the dwellings, additional rainwater is collected from parking spaces, paths and surrounding streets to supplement the roof water. It is first collected in a cistern and then treated in several simple stages before being used for toilet flushing and garden watering. Moreover, the number of rainwater catchment system in the UK and Japan is also increasing.

### 6.3.3.2 System categories

Two basic types of system are identified by Leggett, et al (2001), and concentrates upon the systems used for supplying non-potable water in developed countries:

➤ *Directly pumped system*

Rainwater is pumped directly from the storage tank to appliances within the building. Mains top-up water is supplied to the storage tank.

➤ *Indirectly pumped system*

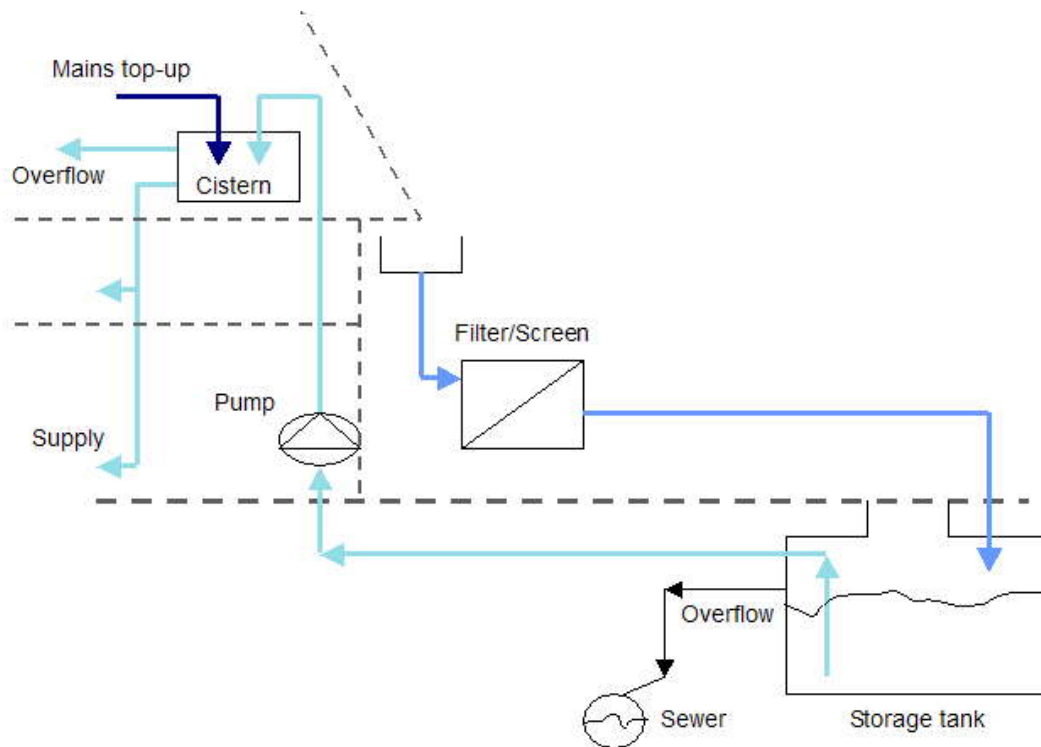
Rainwater is pumped from the rainwater storage tank into a feed cistern located in the building, which supplies water to appliances by gravity (see Figure 6-11). Mains top-up water is supplied to the feed cistern.

### 6.3.3.3 System components

Potentially stormwater can be the water supply for all or some uses at households. It can be divided into potable uses and non-potable uses (toilet flushing, cleaning, car-washing, lawn-watering). Stormwater can be potentially harvested from all available impermeable surfaces including roofs, yards, pavements, residential parking lots and streets. Several system components are described as below.

#### **Catchment Area**

The most common catchment area for rainwater system is the roof. The preferred surfaces are those, which are chemically inert, e.g., slates. Metal roof coverings are acceptable, but the slightly acidic nature of rainwater can produce some dissolution of metal ions from the surface (Leggett, et al, 2001).



**Figure 6-11** Schematic of indirectly pumped rainwater catchment system (Leggett, et al., 2001)

Rainwater collected from paved areas surrounding the building can be used, but is likely to be more heavily polluted and require extra treatment. Permeable paving systems are an exemption because they provide some filtration in their sub-base and allow bio-degradation of soils. The quality of rainwater collected via permeable paving is particularly suited to irrigation.

### Collection system

Stormwater collection system can be designed in a number of ways including:

- A bucket under a rain-pipe collecting roof runoff;
- Storage roofs constructed to collect and store runoff;
- Permeable pavements with water storage possibility;
- Storage tanks in cellars including supply and distribution hardware.

The simplest rainwater collection system consists of a water bucket placed under or connected to the rain-pipe evacuating rainwater from roofs. Water collected in such system is usually reused for garden irrigation. It can be manually piled out with the bucket, or through a tap at the base for a watering can. Larger tanks, equipped with pumps, are used in commercial buildings collecting water from roofs, and providing it later for landscape irrigation, car washing.

The most typical rainwater collection system, however, consists of a tank in the ground or in the cellar storing rainwater harvested from the roof. Water from rainwater storage tank is pumped to supply toilet flush system and washing machines. Due to limited size of the tank, a possibility of filling it with drinking water from the municipal supply system during dryer periods needs to be considered. Common rainwater can be reused for non-potable purposes without treatment. However, filters are usually installed to prevent debris and other coarse material from entering the tank.

### **Treatment**

For non-portable applications, filtration is usually the only needed process prior entry into the storage tank (Leggett et al, 2001). A range of different filter types including screen, slow sand, rapid sand, membrane, and active carbon filters can be used as filters. Experiences showed that fine filters are not recommended, due to blockage and frequent maintenance.

### **Storage**

A storage tank or cistern is required to collect rainwater runoff, because rainfall events occur more randomly than system demand. The capacity of the rainwater storage is important from economical and operational point of view. For instance, the size of the storage will influence:

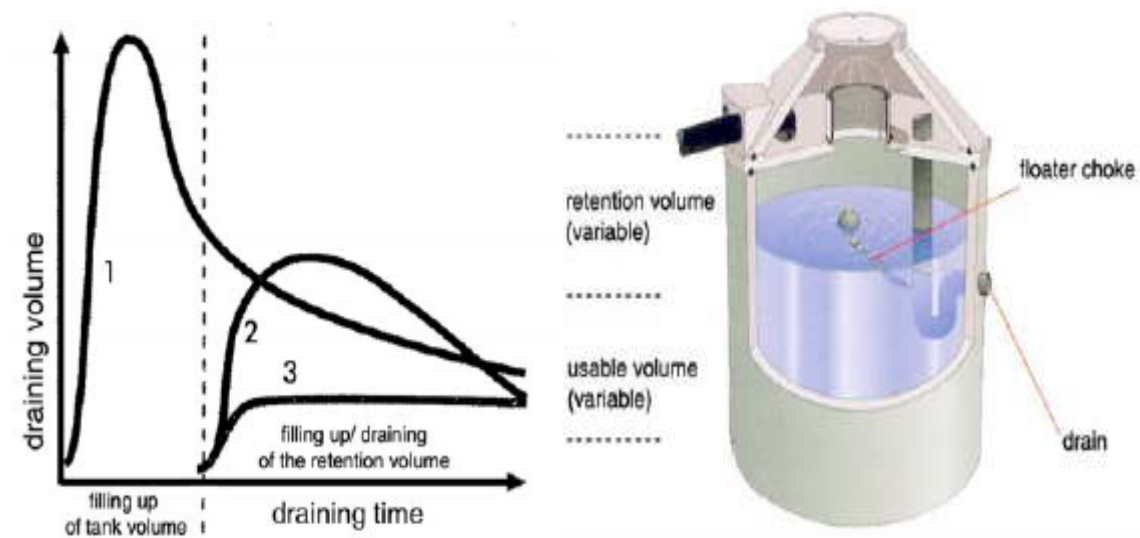
- the volume of water conserved;
- the installation cost of the system;
- the length of time rainwater is retained, which can directly affect the final quality of water supply;
- the frequency of system overflow, which affects the rate of removal of surface pollutants;
- the volume of water overflowing into the surface drain.

A storage tank can be constructed from a variety of materials, e.g., plastic, concrete or steel. The preferred location is below ground sheltered from daylight, which minimizes algal growth in the collected water. For instance, a small storage tank can usually be 1~2 m<sup>3</sup>, and medium- or large tank can be 75 m<sup>3</sup> for household utilization (Schütze, 2005).



In addition to the initial filtration, further treatment occurs within the storage tank via floatation and settlement. Flotation occurs in the tank when particles are less dense than water and float to the surface. Similar particles more dense than water settle to the bottom of the tank. Within this settled layer, an aerated biofilm can be developed for biological treatment. As a consequence, the rainwater just below the surface layer is the cleanest. Floating suction facilities are often used to extract rainwater from just below the surface.

For the retention of rainwater, special designed retention cisterns have to be utilized. They consist of a primary volume for the utilization of rainwater, and secondary volume for retention of rainwater. In Figure 6-12 (left), the characteristic curves (1) for the draining volume of rainwater tanks without retention and draining, and for retention cisterns without curbed draining (2), as well as with curbed draining (3) are presented. In Figure 6-12 (right), the cistern for secondary volume is equipped with a curbed drain for the retention of rainwater, which exceeds the primary volume. Due to the temporary retention of the secondary volume and its automatic draining, it is suitable for the case of successive rainfall.



**Figure 6-12** Characteristic curves for the draining volume of rainwater (left); Sketch of a rainwater cistern with primary usable and secondary retention volume with curbed drain (right) (Schütze, 2005)

## **7. Implementation of decentralized wastewater management in a semi-urban area of Beijing**

### **7.1 Introduction**

With fourteen million people, the agglomeration of Beijing belongs to one of the mega-cities in the world and is the second largest city after Shanghai in China. Beijing is in a semi-arid region, and has a seasonal temperate continental monsoon climate. In winter, the weather is dry and cold, governed by Mongolian high-pressure systems. In summer, it is warm and humid, as controlled by Pacific low-pressure systems (Wei, 2005). Storms reach the city frequently during summer time with an average precipitation is 640 mm per year. Approximately 85 percent of this precipitation concentrated in June to September (Wei, 2005; Hou & Hunter, 1998).

Beijing is located in the centre of a region of water shortage. Compared to 9,000 m<sup>3</sup> per capita - the worldwide average level, annual per capita water use in Beijing is less than 300 m<sup>3</sup>, which is only one eighth of the average of China and one thirtieth of the world average (Wei, 2005; Hou & Hunter, 1998). According to Hou and Hunter (1998), since the early 1960s Beijing has experiences several crisis of water shortage, each time the central and municipal governments implemented a series of measures like increasing groundwater exploitation and local water diversion projects, all of which helped the city to overcome these difficulties. However, in the past 20 years, drastic economic development and population growth have resulted in dramatic increases in water demand. Today, Beijing is being listed among the world top ten cities suffering from lack of adequate water resources, and water shortage is now a limiting factor that affects the sustainable development of the city.

Although the water resources in Beijing have guaranteed the economic development by the government, the ecological environment has been significantly degraded. Groundwater has been over-exploited, causing a rapid drop in the level of the groundwater table. Wei (2005) reported the groundwater has been over-extracted by up to 6 billion cubic meters since 1960s, which has resulted in the drying up of fountains and land surface subsidence. By the 1980s, gross over-pumping of groundwater led to rapid subsidence at a rate of about half a meter per year, and today water table levels have dropped by more than 40 meters below the surface with a total of about 4 billion m<sup>3</sup> of groundwater overdraft (Hou & Hunter, 1998).

The city's water resource now presents a great challenge. Another negative impact on the ecosystem is that most of the rivers in Beijing are dry for a large part of the year. Between 30-50% of Beijing's water supply comes from river, streams and reservoirs, and the Beijing area contains more than 100 rivers and is crossed by five river systems: Yongding, Chaobai, the North Grand Canal, Daqing and Jiyun Canal (Hou & Hunter, 1998). Today, these rivers are highly threatened and the dominant river of Beijing – Yongding River, has had no flow for decades. Hou & Hunter (1998)

## 7. Implementation of decentralized wastewater management in a semi-urban area of Beijing

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also reported Miyun Reservoir now acts as the primary source of urban drinking water from surface water. However, it too has experienced decreasing water levels with a total drop of 67 meters since the 1950s.

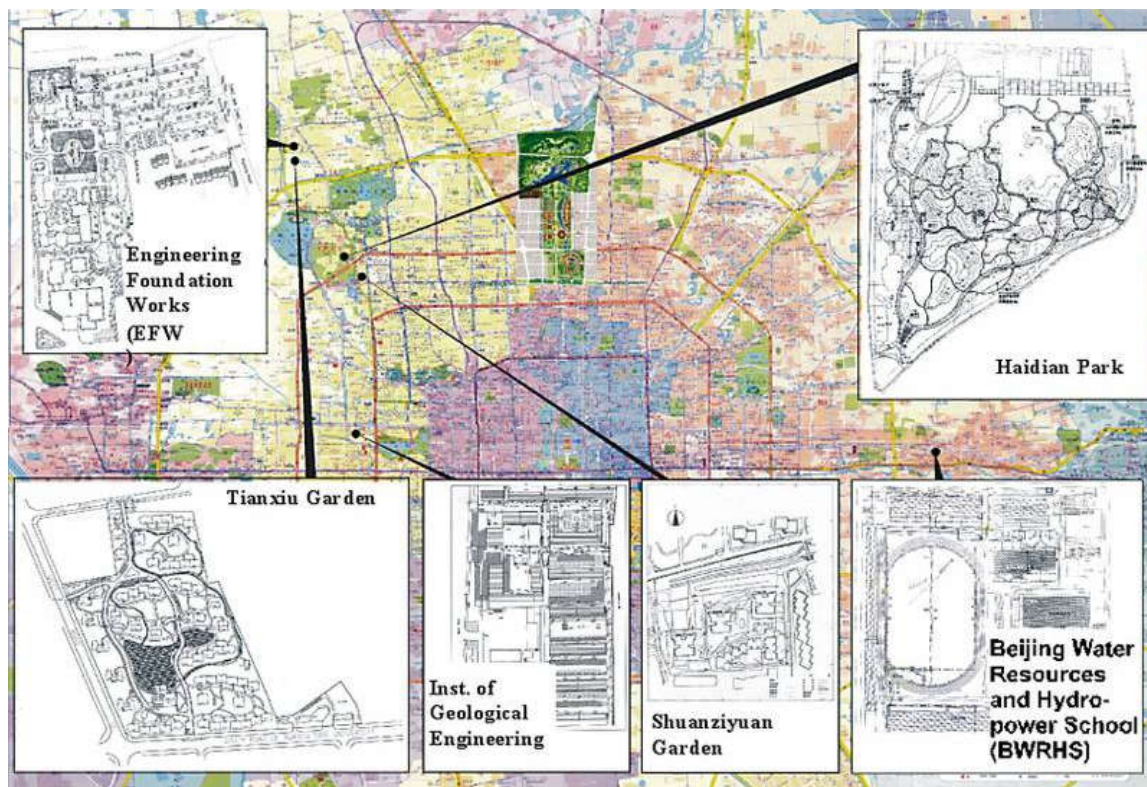
The Beijing municipal government has recognized that the only way to alleviate water-related problem is to insist on sustainable water resources exploitation and utilization. Therefore, the Olympics 2008 in Beijing will run under the motto “Green Games – Sustainable Development”. In a four-year joint Chinese-German pilot project, a new concept for rainwater management and greywater recycling in urban area has been demonstrated. One of these projects is the Tianxiu Garden located in semi-urban area – Balizhuang (Haidian district of Beijing), which consists of various residential complexes and the residential complex of the Beijing Institute of Geological Engineering (see Figure 7-1 & Figure 7-2). These two new buildings are six-story constructions with 10 residential units per floor. The specific objectives of the project are:

- To decrease drinking water consumption by installation of water-saving facilities;
- To demonstrate rainwater harvesting can result in optimal saving of drinking water and without any loss of quality or compromise in human health;
- To quantitate the actual potential savings of drinking water in households by a decentralized greywater recycling technology;
- To evaluate the water quality improvements, and quantitative water saving by both rainwater and greywater recycling systems in this project;
- Evaluate the cost and savings by such technology as evidenced in this demonstration project.



**Figure 7-1** Appearance of Tianxiu Garden

7. Implementation of decentralized wastewater management in a semi-urban area of Beijing



**Figure 7-2** Location of Tianxiu Garden in Beijing (Wilhelm, 2003)

Table 7-1 indicates the number of inhabitants in Tianxiu Garden. There are 82 families and 218 inhabitants in Tianxiu Garden. Table 7-2 presents the water consumption of greywater (kitchen, bath and laundry) and requirement amount for toilet flushing.

**Table 7-1** Numbers of inhabitants (Geo Terra GmbH, 2003)

	Building No. 6	Building No. 7	Total
Apartments	51	31	82
Inhabitants	134	84	218

**Table 7-2** Water consumption (Geo Terra GmbH, 2003)

	Building No.6		Building No. 7		Total (liter/day)
	(liter/capita*day)	(liter/day)	(liter/capita*day)	(liter/day)	
kitchen, bath/shower, laundry	90	12,060	86	7,224	19,402
Toilet flushing	34	4,556	33	2,772	7,328

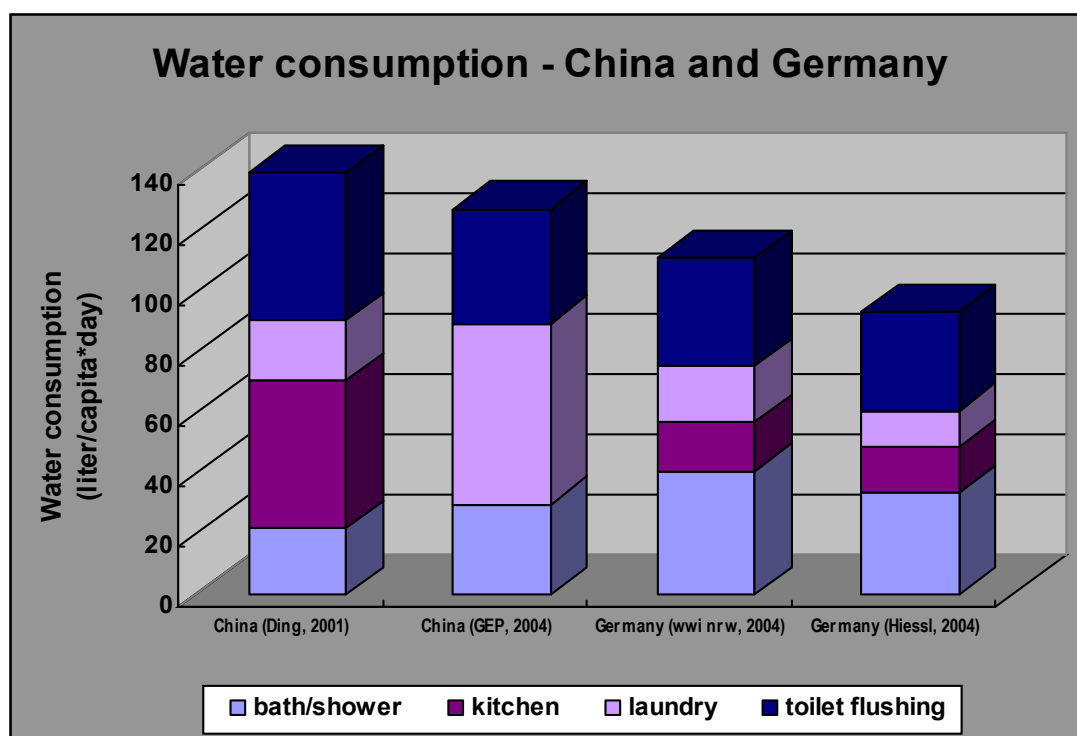


## 7.2 Methodology and processes

### 7.2.1 Water-saving measures

When planning for urban water management, it is essential to control water consumption. People should be provided with fresh water for basic needs while unnecessary consumption should be prevented. Figure 7-3 compares water consumption between China and Germany, and the daily water consumption in China is generally higher than that in Germany. An efficient use of water is especially crucial wherever the water resource is scarce. Efficient use of water also gives more options for cost-efficient and volume- and space-saving solutions for wastewater treatment.

Water saving potentials can be found in the area of sanitary devices and water-saving technology. Since 40 percent of water used in Beijing goes to the personal needs, Beijing authorities also plan to encourage the use of water-saving technology. It is reported by Wei (2005) the amount of water wasted by leakage every year almost equals to the annual output of a waterworks. Therefore, introduction of water-saving technique is no doubt one of the ways of controlling water use in households. The development in the industrialized countries in Europe shows that this is possible without satisfying the supply or comfort for the residents. By using water saving equipment such as water-saving shower nozzles, water consumption as well as energy for producing hot water can be reduced.



**Figure 7-3** Comparison of water consumption between China and Germany  
(Adapted from Geo Terra GmbH, 2003)

Table 7-3 presents that the important steps and measures for water consumption decreasing is installation water-saving appliance in Tianxiu Garden:

- Reduce tap flow from 15 l/min to 6 l/min by maintenance of dripping taps and flow regulation both in bath and toilet;
- Reduce the bath flow from 20 l/min to 9 l/min by using flow regulation and stopping automatic showers;
- Reduce flushing-flow in toilet from 6-9 l/flush to 3-5 l/flush by using toilet stop bottom and toilet with minimum box volume.

**Table 7-3** Water-saving measures

	Water saving measures	Standard tap flow	Reduced tap flow
Kitchen	Maintenance of dripping taps	15 l/min	6-10 l/min
	Flow regulation for taps		
Bath	Use of flow regulation	20 l/min	9 l/min
	Stop automatic showers		
Toilet	Toilet with stop bottom	6-9 l/flush	3-5 l/flush
	Toilet with minimum box volume		

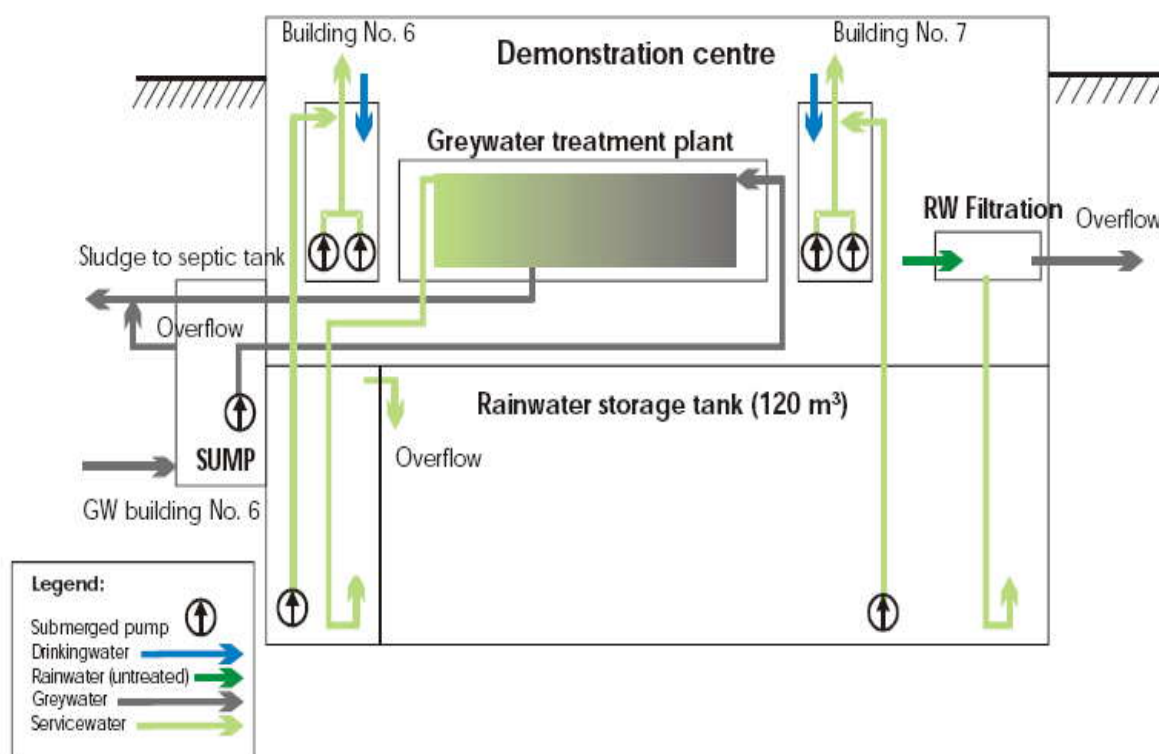
Table 7-4 estimate the potential of fresh water consumption decreasing by adopting water-saving measures. Due to installation of water-saving appliance, 79.5 liter/(capita\*day) potable water can be saved.

**Table 7-4** Potential of consumption decreasing by saving-measure (per capita)

	Standard flow (l/min)	Reduced flow (l/min)	Saving flow (l/min)	Demand per day (min)	Saving water (l/day)	Saving water (l/year)
Kitchen	15	8	7	2.5	17.5	6,387
Bath	15	9	6	3	18	6,570
Toilet	8	4	4	4	16	5,840
Toilet	8	1	7	4	28	10,220
Total	46	22	24	13.5	<b>79.5</b>	29,017

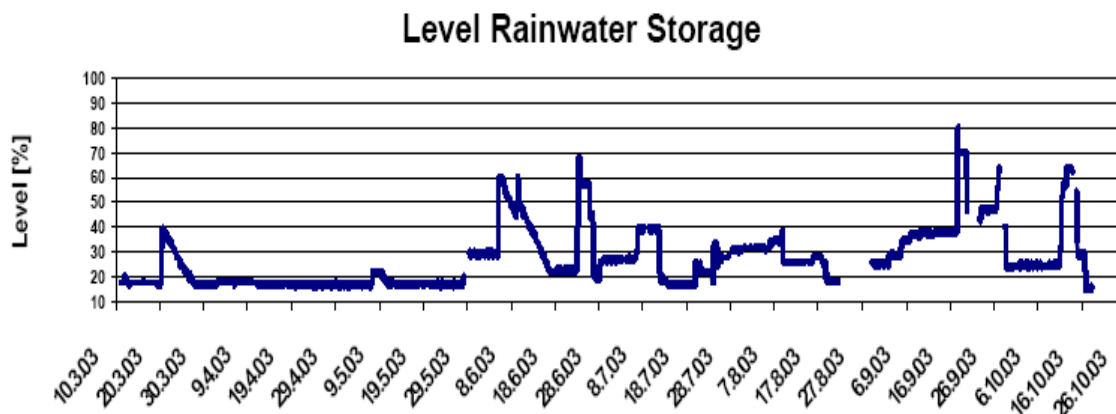
### 7.2.2 Rainwater recycling

Figure 7-4 illustrates the demonstration centre in Tianxiu Garden. The demonstration centre, consisting of a rainwater usage installation for supplying non-portable water to building No.7, and a greywater processing plant for supplying water to building No. 6, is located beneath the cycle park area between two buildings.



**Figure 7-4** Overview of demonstration centre (Geo Terra GmbH, 2003)

This typical rainfall feature can be reflected in the monitoring chart of level rainwater storage in 2003 in Tianxiu Garden Project (see Figure 7-5). This annual chart is typical for northeastern China. It is characterized by a long dry period in winter and heavy rainfall in summer.



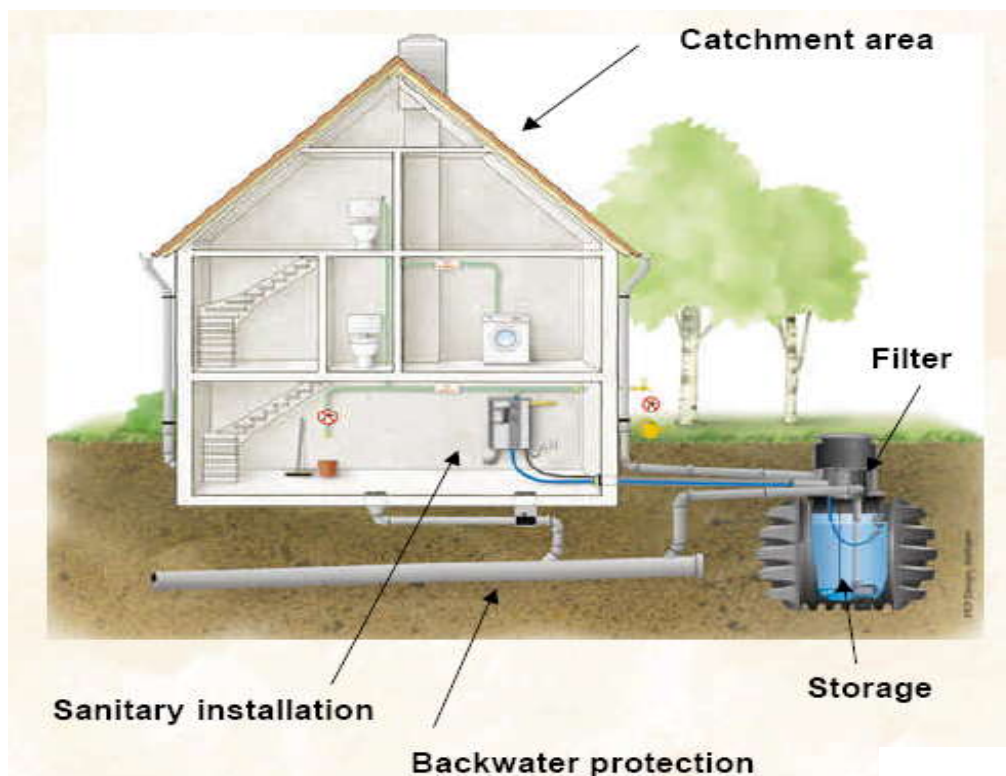
**Figure 7-5** Monitoring of rainwater storage in 2003

The utilization of a rainwater catchment system to supply non-potable water to buildings during the last 15-20 years has become popular in urban areas worldwide (Leggett, et al 2001). The increased awareness and application has risen because a number of problems linked to centralized systems of water supply and disposal have been identified. Since rainwater is regarded as relatively unpolluted water, for non-potable application, filtration is usually the only needed process prior entry the storage tank.

The concept of rainwater management in Tianxiu Garden is to reuse rainwater runoff from the roofs of both buildings for toilet flushing. First, the roof drainage water of both buildings are collected and directed through a filter system into the water-tank under the demonstration centre. Next, the rainwater is filtered by a GEP filter (developed by Geo Terra GmbH), using the principle of the slotted strainer. When adequate rainwater is at hand, the rainwater unit is supplied with water from the tank, using a submersible pump. Figure 7-6 presents the schematic of rainwater catchment area and facilities for storage.

The sludge arising during the biological processing was directed to a small sewage treatment installation. The overflow from the rainwater tank was directed into the wastewater drains, together with the drainage from the small sewage treatment plant.





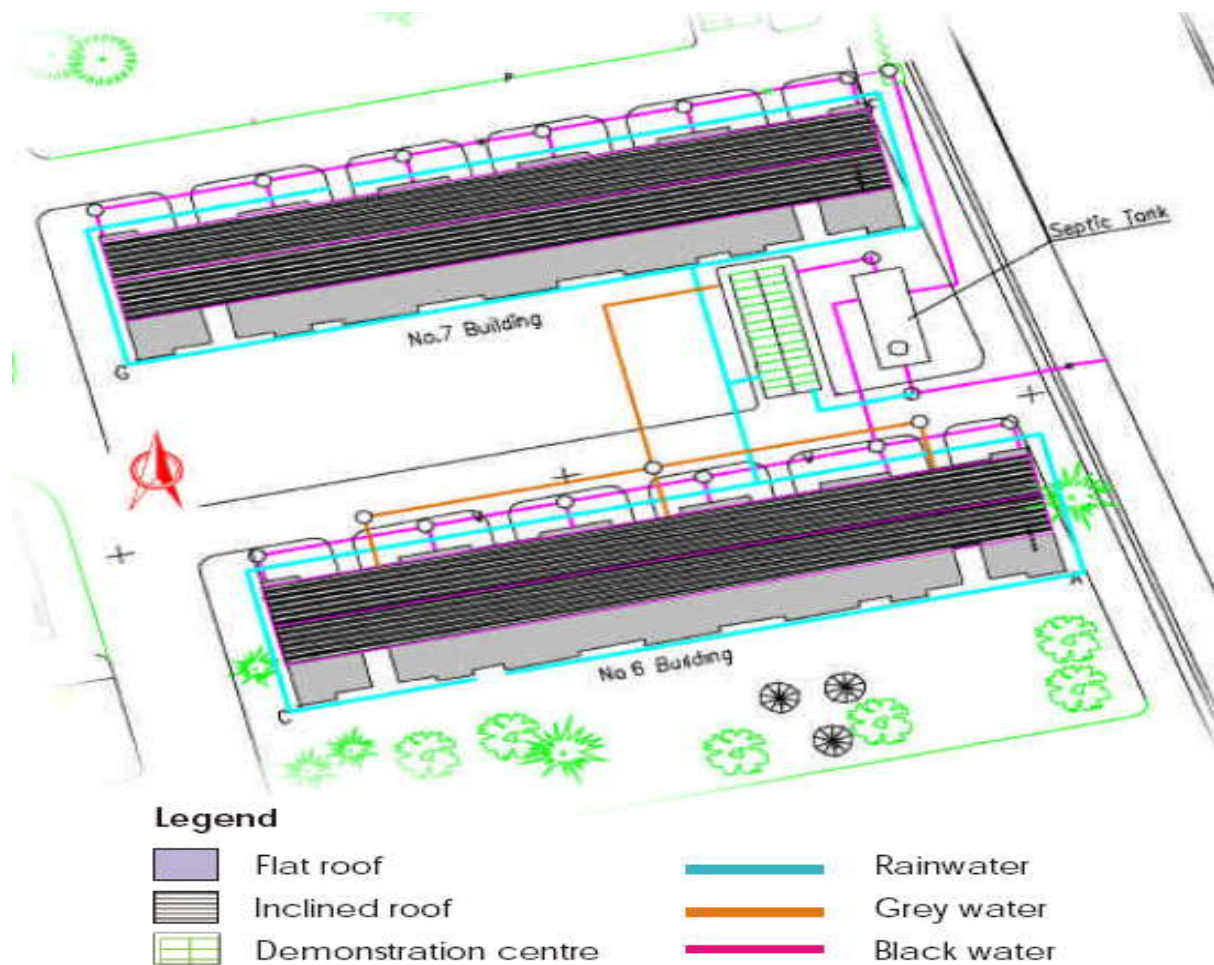
**Figure 7-6** Schematic of rainwater catchment area and facilities for storage  
(Geo Terra GmbH, 2003)

### 7.2.3 Greywater treatment and recycling

Greywater contains relatively few nutrients and can be easily treated to a reusable quality. Decentralized treatment of greywater should be done by biofilm process (Otterpohl, 2000). Appropriate technologies range from natural processes (e.g., constructed wetlands and lagoon system), and infiltration system (e.g., slow and fast sand filter), to high-tech biological process (e.g., Membrane Bioreactor (MBR), Sequencing Batch reactor (SBR), and Rotating Biological Contact (RBC)). Mechanical pre-treatment is necessary for most biological treatment technologies.

In urban areas of mega-cities in developing countries, drinking water used for flushing toilet accounts for 20%-40% of the total water daily consumption in a household (Otterpohl, 2000). The concept of greywater management is to recycle the greywater from showers and basins of building No.6 and reuse for toilet flushing after appropriate treatment in building No.6.

The following figure 7-7 illustrates the schematic of ground plan for greywater- and rainwater treatment and recycling.



**Figure 7-7** Schematic of ground plan (Geo Terra GmbH, 2003)

Additionally, four steps of treatment procedures can be described as follows (see Figure 7-8):

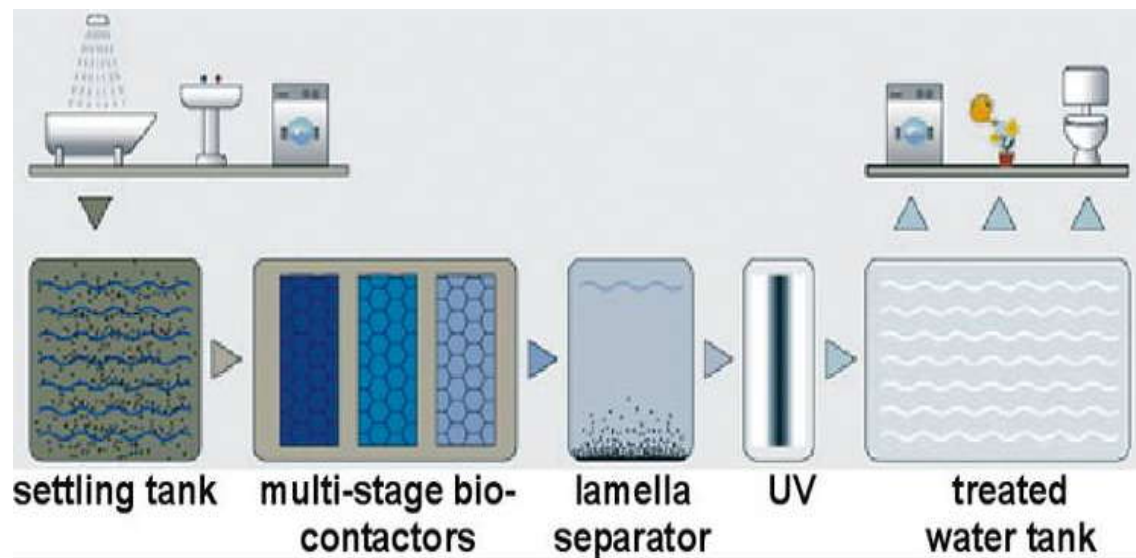
- The raw water firstly enters the **primary settling tank**, in which settleable solids can be settled to the bottom while floatable oil and greases rise to the top. It serves as the primary treatment and holding device.
- Next, the processed water enters the **Rotating Biological contact (RBC)**, This process is simpler to operate than activated sludge since recycling of effluent or sludge is not required.
- **Lamella Separator** serves as a secondary settling tank, in which treated water are separated from biological sludge.

## 7. Implementation of decentralized wastewater management in a semi-urban area of Beijing

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- In order to attain high quality standards, the processed greywater is disinfected with **UV-disinfection**, which is considered to be the primary mechanism for the destruction of pathogenic organisms.

After treatment, the grey water will be stored in a service water tank beneath the building.



**Figure 7-8** Processes of greywater treatment (Geo Terra GmbH, 2003)

## 7.3 Results

### 7.3.1 Rainwater recycling

A simulation based on these measurements, and consideration of the planning data (see Table 7-5), results in the storage curve illustrated in illustration (see Figure 7-9).

**Table 7-5** Planning data of rainwater harvesting

Category	Data
Roof surface (flat roof)	1176 m <sup>2</sup>
Runoff coefficient (flat roof)	0.5
Roof surface (inclined roof)	735 m <sup>2</sup>
Runoff coefficient (inclined roof)	0.8
Resultant runoff coefficient	0.62
Annual rainfall	564 mm
Roof drainage/inflow volume	1078 m <sup>2</sup>
Roof drainage under consideration of runoff efficient	668 m <sup>3</sup>
Inhabitants of buildings	218
Service water requirements for toilet flushing	33 l/(capital*day)
Service water requirements for toilet flushing	2625 m <sup>3</sup> per year

#### Explanation

- $Q_c = A * r * p$   
 $Q_c$ : Catchment's storm water amount or roof drainage  
 $A$ : Catchment's area  
 $r$ : Run off coefficient  
 $p$ : Annual precipitation
- Roof drainage  $Q_c = 564 \text{ mm} * 0.62 * (1176 \text{ m}^2 + 735 \text{ m}^2) = 668 \text{ m}^3$
- Daily service water requirements per capita = 33 liter/(capita\*day)
- Yearly service water requirements for two buildings = 30 liter/(capita\*day) \* 365 \* 210 = 2300 m<sup>3</sup>.

Taking into account the proportions of flat and pitched roofs, then a medium drainage factor of 0.62 is reached. This results in a usable volume of 668 m<sup>3</sup> roof drainage water and service requirements per year is 2,625 m<sup>3</sup>. Accordingly, only 25.4% of the required amount for toilet flushing water can be fulfilled with rainwater runoff recycling (668 m<sup>3</sup> is divided 2,625 m<sup>3</sup>). A higher degree of drinking water substitution cannot be achieved by using rainwater.

Figure 7-9 outlines the storage efficiency of rainwater in Tianxiu Garden Project. At a storage-volume of 115 m<sup>3</sup> (18% of the annual roof drainage 668 m<sup>3</sup>), 90% of the roof drainage water was used for flushing toilets. Using this calculation, the storage would have overflowed 30 times in 14 years, whereby the peak value was 129 m<sup>3</sup> overflow one day. As a rule, the rainwater storage tank is empty from mid-October to mid-April.

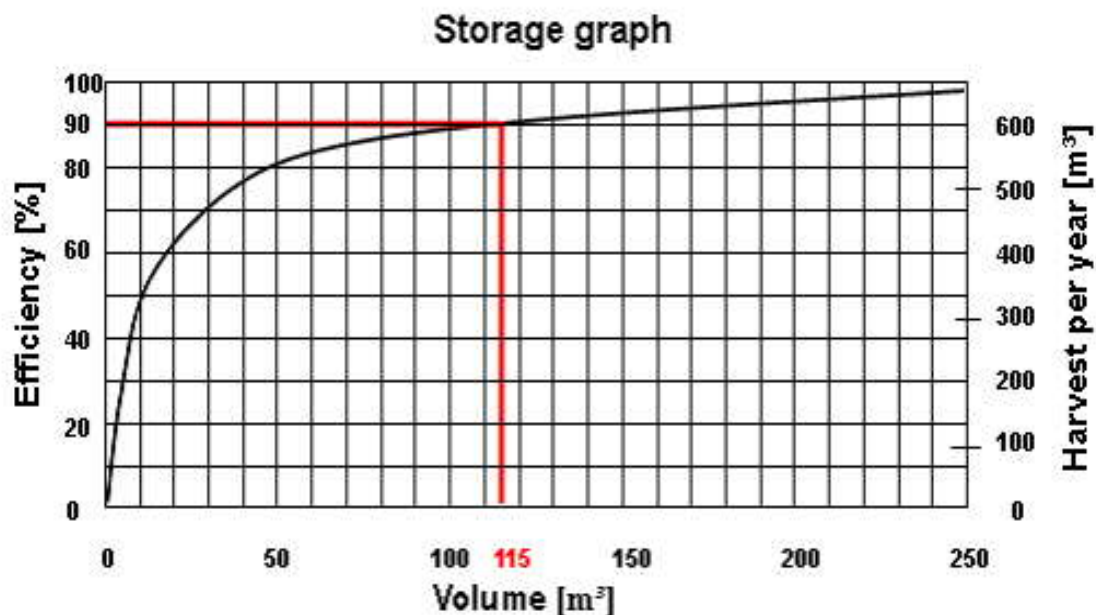


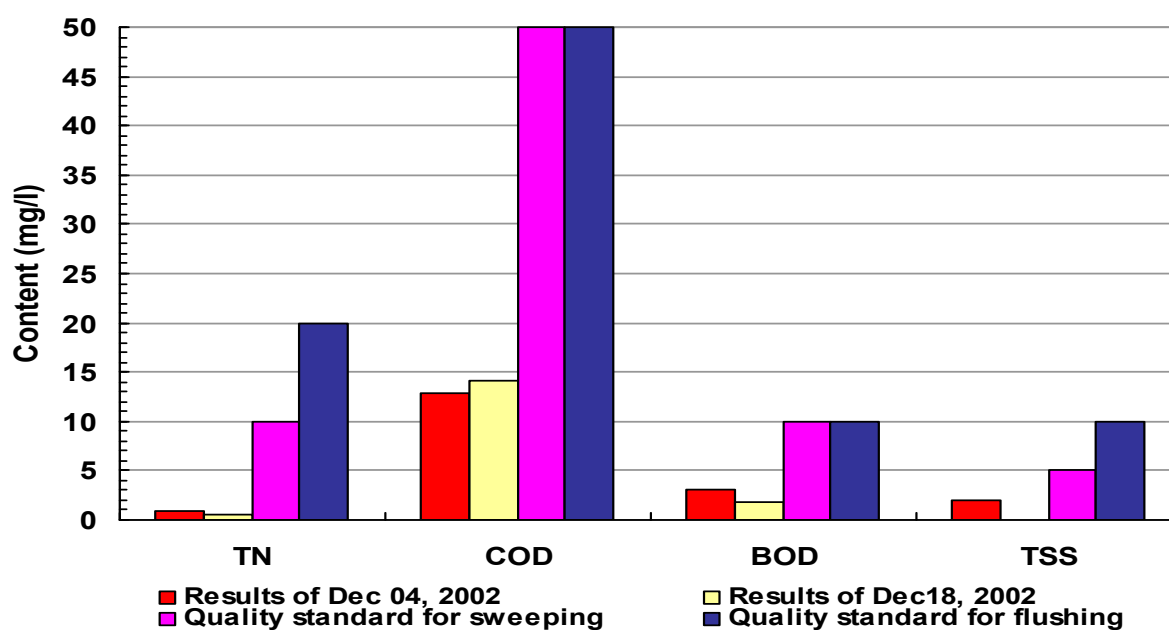
Figure 7-9 The graph of rainwater storage efficiency

### 7.3.2 Greywater treatment and reuse

Two experiments of the determination on greywater treatment performance were made respectively. Table 7-6 shows the performance of both experiments by operating with Rotating Biological Contactor (RBC), in which the removal rate of TSS, BOD<sub>5</sub>, COD and ammonia achieved high levels and attained significantly lower than standards. However, for some uncertain reasons, phosphorus removal rate was rather low, with an actual increase observed in experiment 2. Additionally, Figure 7-10 illustrate a comparison of performance in two experiments with quality standard in Germany.

**Table 7-6** Performance of greywater treatment by operating with RBC  
(Geo Terra GmbH, 2003)

Parameter (mg/l)	Experiment 1			Experiment 2			Quality standard for sweeping	Quality standard for flushing
	Inlet	Outlet	Removal rate	Inlet	Outlet	Removal rate		
TSS	65	2	97%	22	0	100%	5	10
BOD	86.2	3	97%	123	1.8	99%	10	10
COD	132	12.9	90%	200	14.1	93%	50	50
Total Bacterial	4,70E+03	320	90%	3,60E+03	2	100%	—	—
Coliform	2,83E+05	92	93%	2,38E+05	4	100%	3	3
Turbidity	48	2	96%	74	1	99%	5	10
Ammonia	7,72	0,86	89%	6,41	0,52	92%	10	20
TP	5,42	2,81	48%	4,02	5,24	-30%	—	—



**Figure 7-10** Comparison of performance in two experiments with quality standard

## 7.4 Discussion

### 7.4.1 Rainwater harvesting

A rainwater harvesting system may consist of only two components: a cistern with integrated filter and a compact control unit inclusive of pump. To achieve the standard and requirements of recycling for toilet flushing and laundry, the quality of treated rainwater from cistern should be high.

The water savings potential by using rainwater to flush toilets in the demonstration area is not great enough. Exclusive connection of the roof surface of two residential buildings can result in substitution of only 25.4% of toilet flushing water in a building. The high water demand of the dense population leads to a rapid depletion of the volume of tank and thus a further availability of retention volume. However, to relieve pressure on the drainage system and to avoid flooding in summer time, rainwater-harvesting technology can well be implemented.

Obviously, there are some problems associated with implementing such a system in Beijing. First, it has been already noted that majority of Beijing's rainfall occurs during the summer months. This means that storage tanks need to be sufficiently large (and possibly communal facilities) to ensure rainwater availability during dry periods. Otherwise, during the dry winter months, this system is virtually useless. Also, in order to provide an incentive for citizens to install such a system, technology must be combined with policy measures.

An additional problem is the high pollution load from the air. The city has been experiencing explosive urban growth over the past decades with substantial increases in transportation/related air pollution.  $\text{NO}_x$  emissions increase exposure to  $\text{NO}_2$ , which also contribute to two major pollutants of concern: Ozone ( $\text{O}_3$ ) and particulate Matter (PM). This urban aerosol pollution resulted in extremely high scattering and absorption coefficient, as well as extremely low visibility. Severe air pollution decreases the rainwater quality in the urban part of Beijing and imposes restrictions on its usage. Without proper pretreatment, pollution of the upper groundwater layers may occur. Therefore, rainwater reclamation only does make sense if measures against air pollution are undertaken. For sustainable reuse of rainwater in urban areas, runoff from highly contaminated areas other than roofs must be collected and treated.

Additionally, German techniques using a cistern with integrated filter and a compact control unit for rainwater harvesting, drainage and treatment have to be adapted to Chinese conditions, because differences in these two countries exist both in rainfall intensity, annual rainfall distribution and the quantity of urban runoff pollution. Therefore, it is very important to investigate and support these suggested drainage concepts scientifically.



### 7.4.2 Greywater recycling

In Tianxiu Garden Project, recycling of light-polluted greywater from showers and basins of the two buildings was only re-used for toilet flushing. The greywater recycling installation was designed for a daily purification volume of 10,000 litres. The calculated requirement for flushing toilets consists of 7,412 litres per day (218 inhabitants \* 34 liter/(capita\*day)). As a consequence, an overproduction of greywater is possible.

Greywater recycling is independent of seasonal variations in water volume, and is therefore a more suitable technique than rainwater harvesting for saving water in China. In addition, the wastewater volume is reduced. Compared to rainwater utilization, the technology is much more complex and therefore incurs higher investment costs. Moreover, there is a real economic incentive for Beijing to implement effective water management, especially greywater treatment and recycling, which will bring benefits for irrigation in agriculture and groundwater recharge.

### 7.4.3 Water- and cost saving analysis

The following Table 7-7 present the potential of water- and cost savings. And the calculation is based on German investment and water price.

**Table 7-7** Water- and cost saving analysis (Geo Terra GmbH, 2003)

Number of stages	2x 1/2	2	3	4	5	6
Capability in m <sup>3</sup> /d	1	3	6	10	15	25
Investment incl. Installation	36.000 €	45.000 €	57.000 €	62.000 €	69.000 €	77.000 €
Investment per m <sup>3</sup> capability	36.000 €	15.000 €	9.500 €	6.200 €	4.600 €	3.080 €
Water saving per year	365	1095	2190	3650	5475	9125
Money saving per Year	1.460 €	4.380 €	8.760 €	14.600 €	21.900 €	36.500 €
ROI in Years	24,7	10,3	6,5	4,2	3,2	2,1

Explanation

- Water price is based on 4 Euro/m<sup>3</sup>
- ROI – Return of Investment

As mentioned above, the greywater recycling installation was designed for a daily purification volume of 10,000 litres (10 m<sup>3</sup>). Table 7-7 present the water- and cost saving analysis. In the stage 4, in the circumstance of capacity 10 m<sup>3</sup>/day, the total amount of water and financial savings per year by greywater recycling that can be achieved amounts to 3650 m<sup>3</sup> and 14,600 Euro (=3650 m<sup>3</sup> \* 4 Euro/m<sup>3</sup>).



Moreover, decreasing the investment by mass production is expected. The more volume of greywater is treated, the less investment is required. Since this calculation is based on German water price, there are significant economic benefits that could be achieved by recycling greywater. However, the true value of water is not fully realized by most users worldwide. In China, the cost of water is much lower than that in Germany (less 1 Euro/m<sup>3</sup>). Thus the economic benefits are not as high as expected in Europe.

#### 7.4.4 Energy Efficiency analysis

**Table 7-8** Energy efficiency analysis (Gratziou, et al., 2006)

Process	flow rate (m <sup>3</sup> d <sup>-1</sup> )	Energy consumption (KWh)				
		15	150	750	1500	3000
Oxidation Ditch		1291	1527	2508	3709	6061
Trickling Filter		1269	1309	1420	1537	1754
Rotating Biological Contactor		1442	1466	1506	2060	2275
Compact Sequential Batch Reactor		1250	1863	4265	7288	13325
Waste Stabilization Ponds		12	36	76	104	144
Constructed Wetlands-Lagoon		12	36	76	104	144
Constructed Wetlands-Chlorination		1193	1216	1256	1284	1324

In general, there are quite a few technological options, which range from natural treatment systems (e.g., constructed wetlands) to chemical-biological treatment systems (e.g., Trickling Filter, Sequencing Batch Reactor, Membrane Bioreactor), suitable for greywater treatment in small-scaled decentralized WWTP. According to the investigation of Gratziou, et al., (2006), Table 7-8 presents different energy consumption based on various equipments and daily hydraulic loading. Since the total greywater consumption is approximately 19.4 m<sup>3</sup>/day (see Table 2), there are no much differences of the energy consumption between RBC and other mechanical-biological options. However, the larger the flow rate, the more attractive is the energy efficiency of RBC.

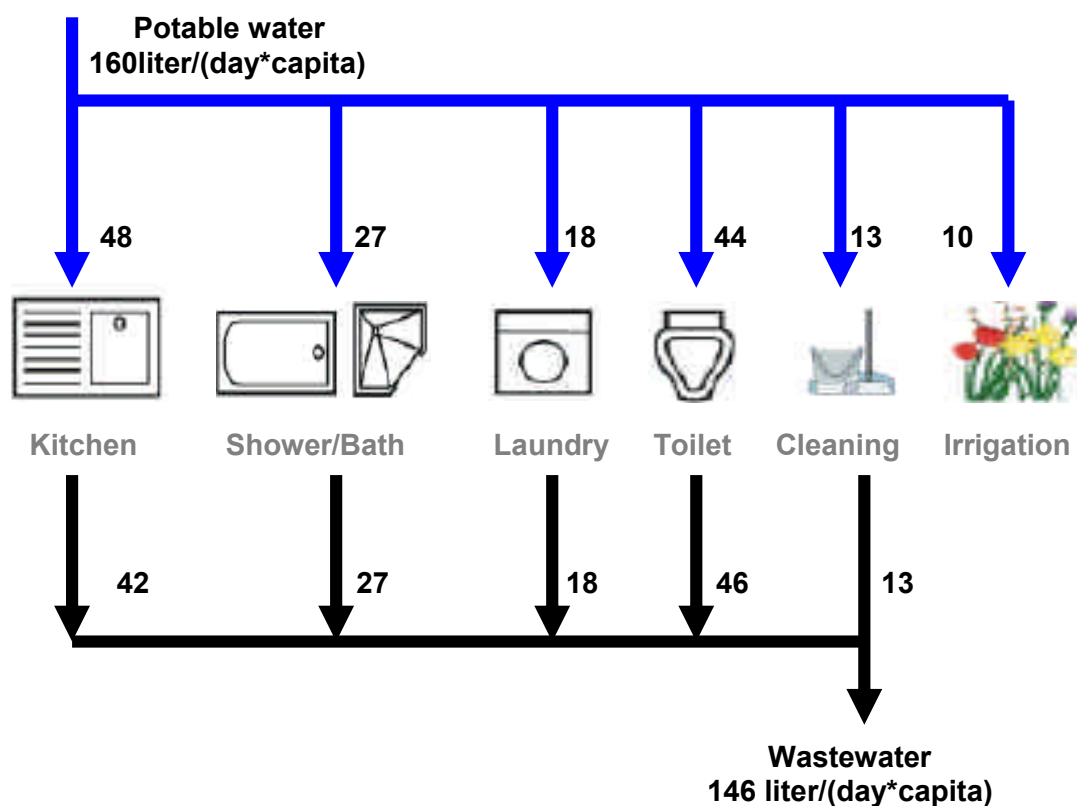
## 7.5 Scenarios of decentralized management in Tianxiu Garden

Beijing is a metropolitan area in water scarce region. The ideal blueprint is that it should be supplied with local tap water and will not have to completely depend on water intensive centralised infrastructure in future. The fundamental idea of innovative and integrated water concepts are based on the principle of separating different flows of domestic wastewater according to their characteristics. The prevention of wastewater should first priority. And then the re-use of water can contribute to large savings of water and thus to a prevention of wastewater. Several scenarios are discussed bellows.

**Table 7-9** Daily water consumption of Tianxiu Garden (Geo Terra GmbH)

	<b>Total (l/capita*d)</b>	<b>BuildingNo.6 (l/capita*d)</b>	<b>Building No.7 (l/capita*d)</b>	<b>Total (l/d)</b>
Apartments	<b>82</b>	51	31	-
Inhabitants	<b>218</b>	134	84	-
Kitchen sink Bath/shower Laundry/cleaning	<b>89</b>	90	86	<b>19,402</b>
Toilet flushing	<b>34</b>	34	33	<b>7,412</b>
Irrigation	<b>30</b>	30	30	<b>6,540</b>
<b>Total supply</b>	<b>153</b>	154	149	<b>19,584</b>

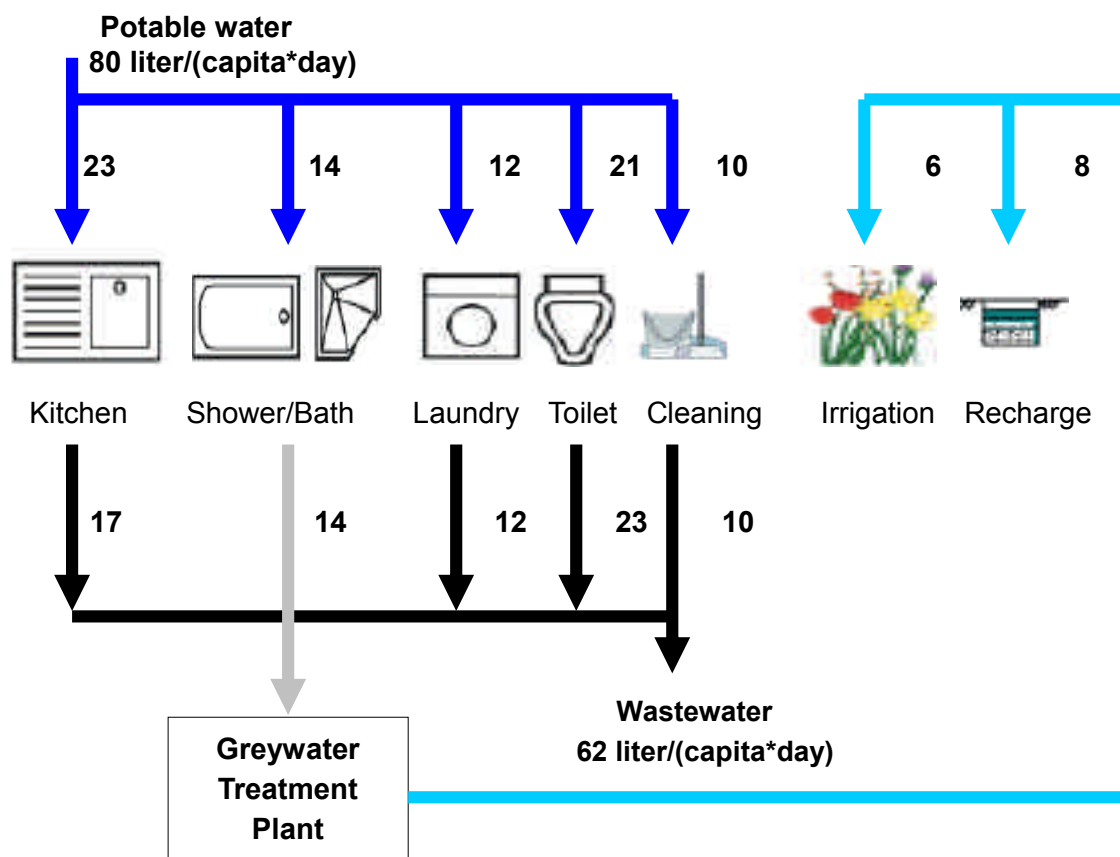
**Water consumption pattern in Tianxiu Garden (centralized system)**



**Figure 7-11** Water consumption in Tianxiu Garden

Figure 7-11 presents pattern of water consumption in Tianxiu garden. Generally 160 liter potable water is needed for each person per day (see Table 7-9). Approximately 48 liter/(capita\*day) are consumed for kitchen, 27 liter/(capita\*day) for shower/bath, 18 liter/(capita\*day) for washing machine, 44 liter/(capita\*day) for toilet, 13 liter liter/(capita\*day) for cleaning and 10 liter/(capita\*day) for garden irrigation individually. In conventional wastewater management, the wastewater would normally be combined and conveyed to centralized treatment plant. After treatment they would be disposed into surface water.

**Scenario 1: Water saving and recycling of low polluted greywater**

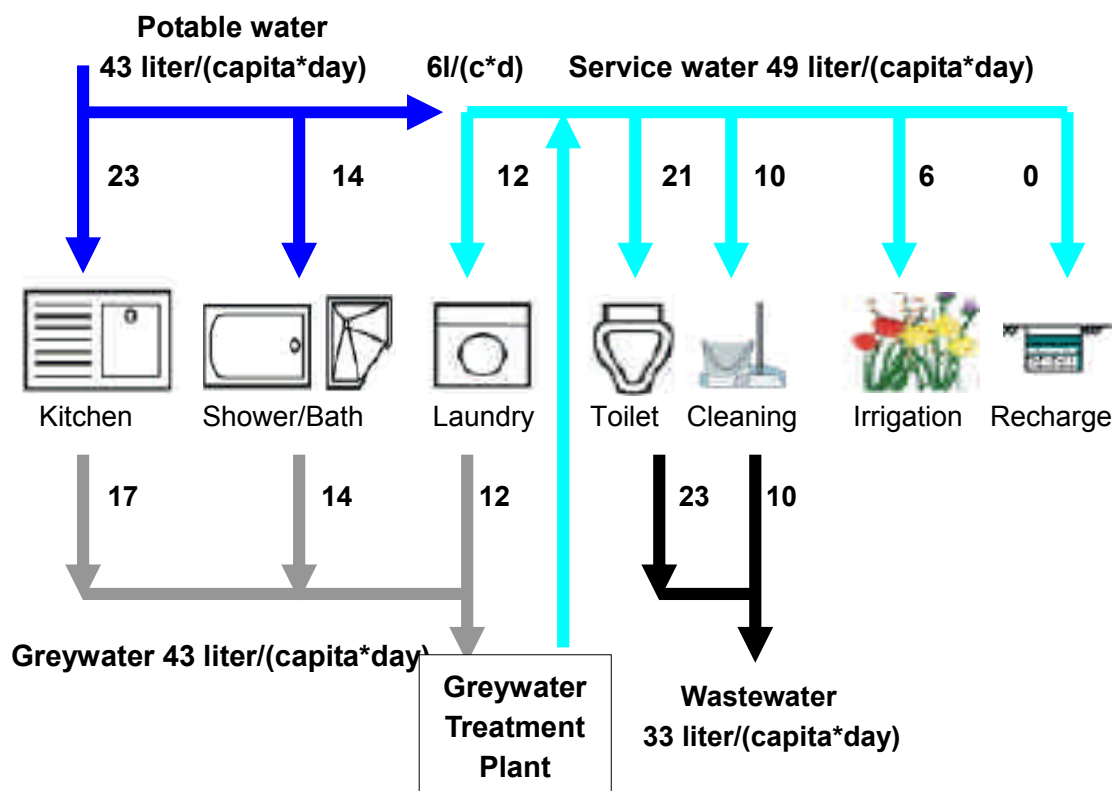


**Figure 7-12** Water saving and recycling of low polluted greywater

In scenario 1, under the concept of decentralized wastewater management, Figure 7-12 indicates the potential of water saving and recycling of low polluted greater. With the installation of water-saving equipment in Tianxiu Garden, approximately 79.5 liter potable water could be saved for each person per day (see Table 7-4). Therefore only around 80 liter/(capita\*day) are needed from municipal water supply.

As low polluted greywater, 14 liter/(capita\*day) greywater from shower/bath are recycled: 6 liter/(capita\*day) for irrigation and 8 liter/(capita\*day) for ground water recharging. If greywater are not recycled, approximately 94 liter/(capita\*day) potable water are normally needed from municipal water supply (80+14=94 liter/(capita\*day)).

**Scenario 2: Water saving and recycling of high-polluted greywater**



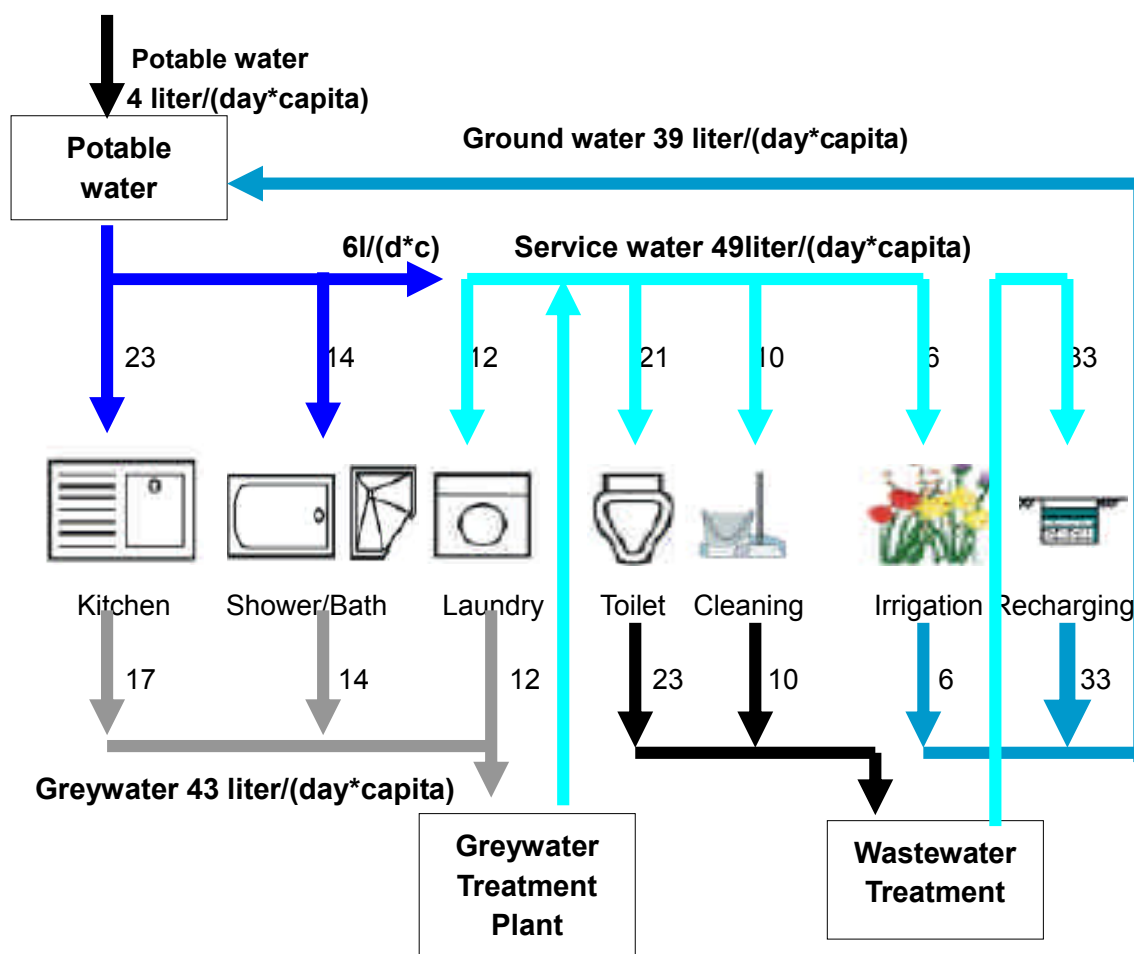
**Figure 7-13** Water saving and recycling of high-polluted greywater

Scenario 2 presents the potential of water saving and recycling of high-polluted greywater (see Figure 7-13). Under this concept only 43 liter/(capita\*day) potable are needed.

In scenario 2, approximate 43 liter/(capita\*day) greywater from kitchen, shower/bath and laundry are recycled (17+14+12 = 43 liter/(capita\*day)). 49 liter/(capita\*day) service water including the recycled greywater 43 liter and potable water 6 liter are generated. And these service water will be distributed to laundry (12 liter/(capita\*day)), toilet (21 liter/(capita\*day)), cleaning (10 liter/(capita\*day)) and irrigation (6 liter/(capita\*day)) respectively. Additionally, approximate 33 liter wastewater is produced.

Due to 51 liter/(capita\*day) water are saved (43 liter from recycled greywater and 8 liter from groundwater recharging), only 43 liter/(capita\*day) potable water are needed (94-51=43 liter/(capita\*day)) from municipal water supply.

**Scenario 3 Water saving, water reuse and closing the loop**



**Figure 7-14** Water saving, water reuse and closing the loop

In Scenario 3, Figure 7-14 presents the potential of realizing the ecological principle – closing the loop. In another words, there should be no input of potable water and no output of wastewater.

Similar with scenario 2, 43 liter/(capita\*day) of greywater are treated and recycled. Once again 49 liter/(capita\*day) of service water including recycled greywater 43 liter/(capita\*day) and potable water 6 liter/(capita\*day), will be distributed to toilet, laundry, cleaning and irrigation.

The difference between scenario 2 and scenario 3 is that 33 liter/(capita\*day) of wastewater, which comes from toilet (23 liter) and cleaning (10 liter), will be treated, and then recharged into groundwater so as to be reclaimed again (together with another 4 liter from water resource) as potable water (after being treated in potable water treatment plant).

## **8. Implementation of decentralized wastewater management in an industrial park of Tianjin**

In earlier days, the focus of industries was aimed to continuously achieve opportunities for higher production yields. On the other hand, the by-products generated from the manufacturing processes were generally considered as “waste” and disposed of, if no apparent uses could be found for these materials. As a consequence, heavy and unnecessary burdens were imposed on the environment. This situation has changed greatly in recent years. And waste/wastewater minimization, reuse, recycling and recovery are quite obviously emphasized from both environmental protection and industrial economic point of view.

### **8.1 Eco-industrial parks (EIPs)**

#### **8.1.1 Characteristics of eco-industrial parks (EIP)**

Generally, the goal of an eco-industrial park (EIP) is to improve the economic performance of the participating companies, while minimizing their environmental impacts. Despite the number of terms, they all relate to the clustering of businesses to achieve primarily environmental, but also social and economic benefits. The study of eco-industrial parks has assumed great deal of importance within the past ten to fifteen years. In 1995, Côté & Hall proposed this definition of Eco-industrial Park:

*“..... is an industrial system which conserves natural and economic resources; reduces the costs and liabilities of production, material, energy, insurance and treatments; improve operating efficiency, quality, worker health and public image; and provides opportunities for income generation from use the wasted material.”*

Indeed, there is a growing body of literature on the subject and one of the best definitions of an EIP has been provided by the USEPA (United States Environmental Protection Agency). It states that an EIP is (Lowe et al., 1995):

*“..... a community of manufacturing and service businesses located together on a common property. Member businesses seek enhanced environmental, economic, and social performance through collaboration in managing environmental and resource issues. By working together, the community of businesses seeks a collective benefit that is greater than the sum of individual benefits each company would realize if it optimized its individual performance only.”*

Also, Zhu and Côté (2004) implied that eco-industrial parks can be best regarded as a community in cooperation and interaction, efficiency in the use of natural resources, and through its system the community aims to close material cycles in the chain and takes account of the entire life cycle from extraction of raw materials to product consumption and waste.

Likewise, Côté & Cohen-Rosenthal (1998) concluded that to be a real eco-industrial park a development must be more than:

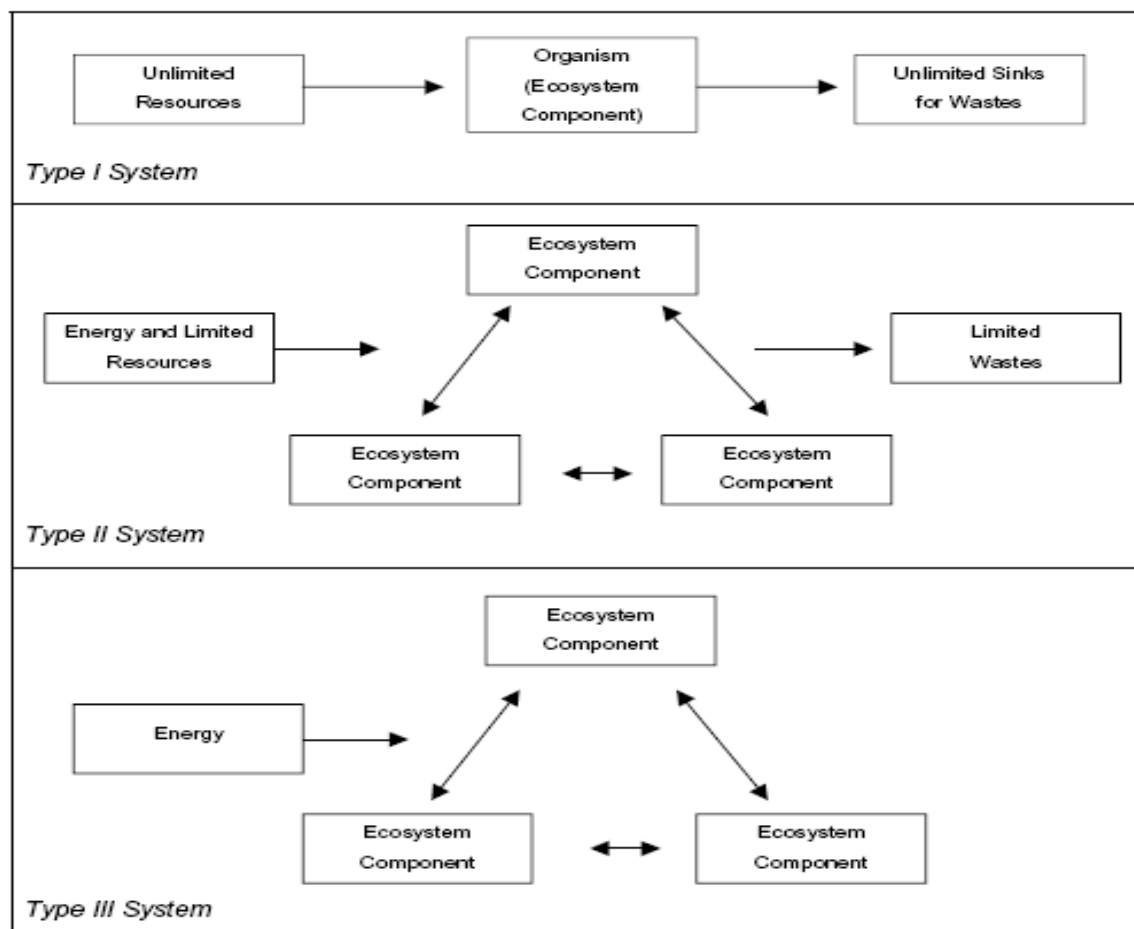
- a single by-product exchange or network of exchanges;
- a recycling business cluster;
- a collection of environmental technology companies;
- a collection of companies making “green” products;
- an industrial park designed around a single environmental theme (i.e., a solar energy driven park);
- a park with environmentally friendly infrastructure or construction or
- a mixed-use development (industrial, commercial and residential)

As a matter of fact, EIPs seek to mimic the efficiencies of living processes to promote more sustainable production and consumption systems, as a result they reduce the production of waste (materials and emissions) and convert by-products into reusable products and resources (Roberts, 2004; Korhonen and Sankin, 2005). Industries symbiosis engages traditionally separate industrials in a collective approach involving an exchange of materials, energy, water and by-products. That means in an EIP, there are some factories and plants that are connected with each other like food chain, thus the waste and wastewater from one factory is the raw material for another factory. Therefore these factories form a close ecosphere. As a result, the EIP not only can efficiently reduce the pollution, but also can maximize the material utilization.

Admittedly, EIP pay much attention to material and energy exchanges between companies in local and regional economies. The basic philosophy is to change linear production processes (raw materials are converted into products, by-products and wastes) into loops (used products, by-products and wastes of one process are used as resources for another) by imitating the cyclical use of resources in natural eco-systems. It concentrates on closing the loop of materials and enhancing energy cascading in industrial areas, in order to achieve low energy consumption and raw material consumption as well as friendly environment.

Moving from linear production to closed-loop material and energy use is key theme in industrial ecology, and it is also one of the characteristics of a mature eco-industrial park. Lowe (1993) implied that the goal is that bringing the industrial systems as close as possible to being a closed-loop system with near complete recycling of all materials. This process, described as a change from Type I to Type III system (Allenby, 1992) is regarded as the evolution towards industrial ecosystem. Figure 8-1 presents the scheme of moving from linear- to closed-loop material and energy use.





**Figure 8-1** Scheme of moving from linear- to closed-loop material and energy use (Allenby & Braden, 1992)

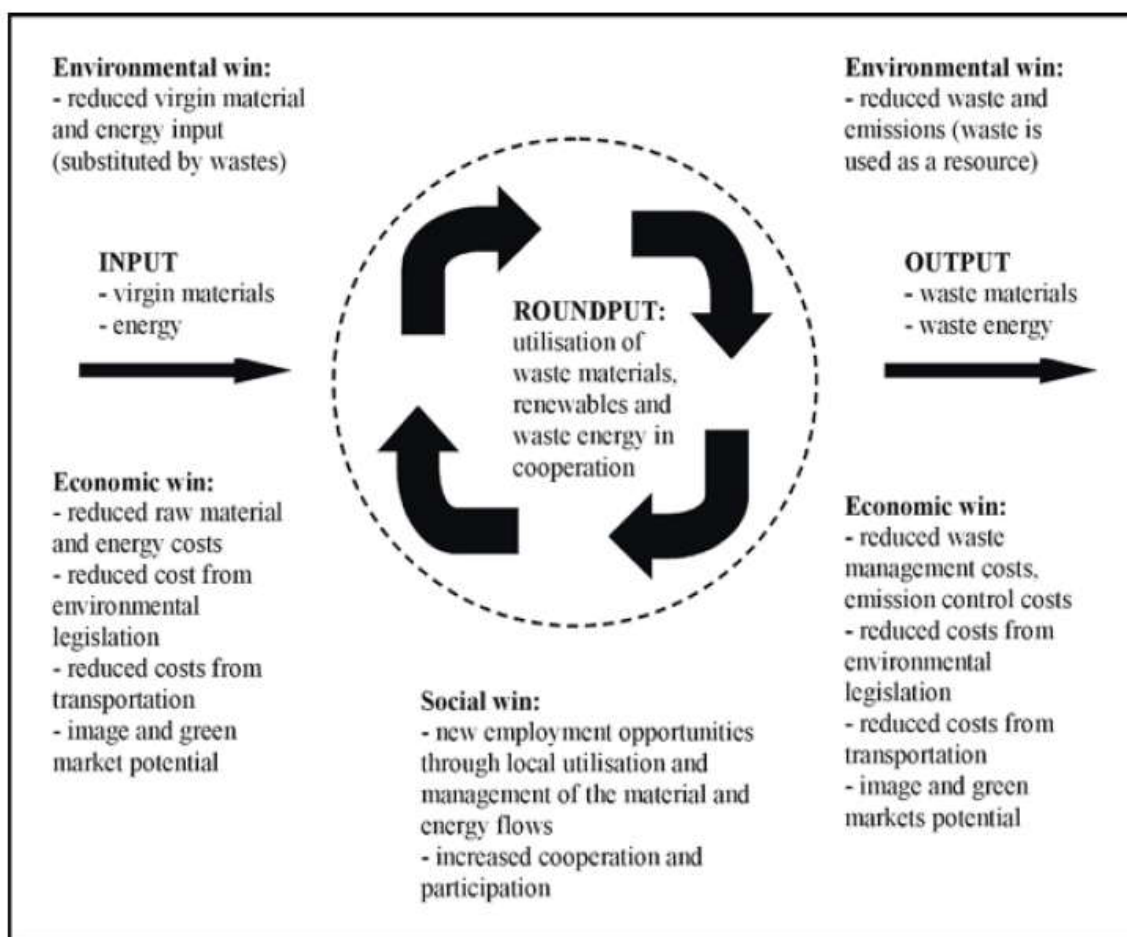
Allenby & Braden (1992) described Type I as a linear assemblage, where energy and resources enter the system and products and wastes leave it. They also implied that many early stages of industrial development show characteristics of a Type I system. However, this concept could only work in a situation with unlimited resources to feed the system and unlimited space to deposit wastes and used products.

The characteristics of Type II are: reduced input of resources, limited amount of waste leaving the system, and collaboration of ecosystem components exchanging energy and material. This type represents high-technology industrial systems with a certain degree of pollution prevention and waste recycling.

A Type III represents the dynamic balance of ecological systems, where energy and wastes are constantly recycled and reused by other organisms and processes within the system. This is a highly integrated and closed system. Garner & Keoleian (1995) also indicated that this system represents a sustainable state and is an ideal goal of industrial ecology. In a totally closed industrial system, only solar energy would come from outside, while all by-productions would be constantly reused and recycled within this system.

### 8.1.2 Benefits and strengths of the eco-industrial park

Studies have shown that a number of benefits can arise at different levels when enterprises work together. Basically, eco-industrial parks aim at achieving economic, environmental and social benefits, which could be concluded as followings (see Figure 8-2): (i) from the environmental point of view, virgin raw materials and energy use are reduced and replaced by wastes and by-products produced in the area; emissions are also reduced and the biodiversity of the area is cherished; (ii) from the economic point of view, reduced raw material, waste, energy, and emission could directly contribute to the reduction of the costs of companies. Meanwhile, co-location contributes to the cost-reduction of transportation for enterprises; (iii) the social benefits in the area create more jobs and improve working conditions. Attention is paid to the total well-being of the communities.



**Figure 8-2** Environmental, economic and social benefits related to material and energy flows in the vision of a successful eco-industrial park (Saikku, 2006)

### 8.1.3 Strategies for designing an eco-industrial park

The understanding of how companies in eco-industrial parks interact could result strategies cover a wide range of features. While some people merely refer to connecting material and energy flows, others go far beyond that, addressing e.g., integration into the surroundings, construction technologies and the management, as well as social factor (Lowe et al., 1998). Components of eco-industrial parks include new or retrofitted design of infrastructure and plants, pollution prevention, and energy efficiency. Côté (2003) concluded the strategies for designing successful industrial parks (see Figure 8-3).

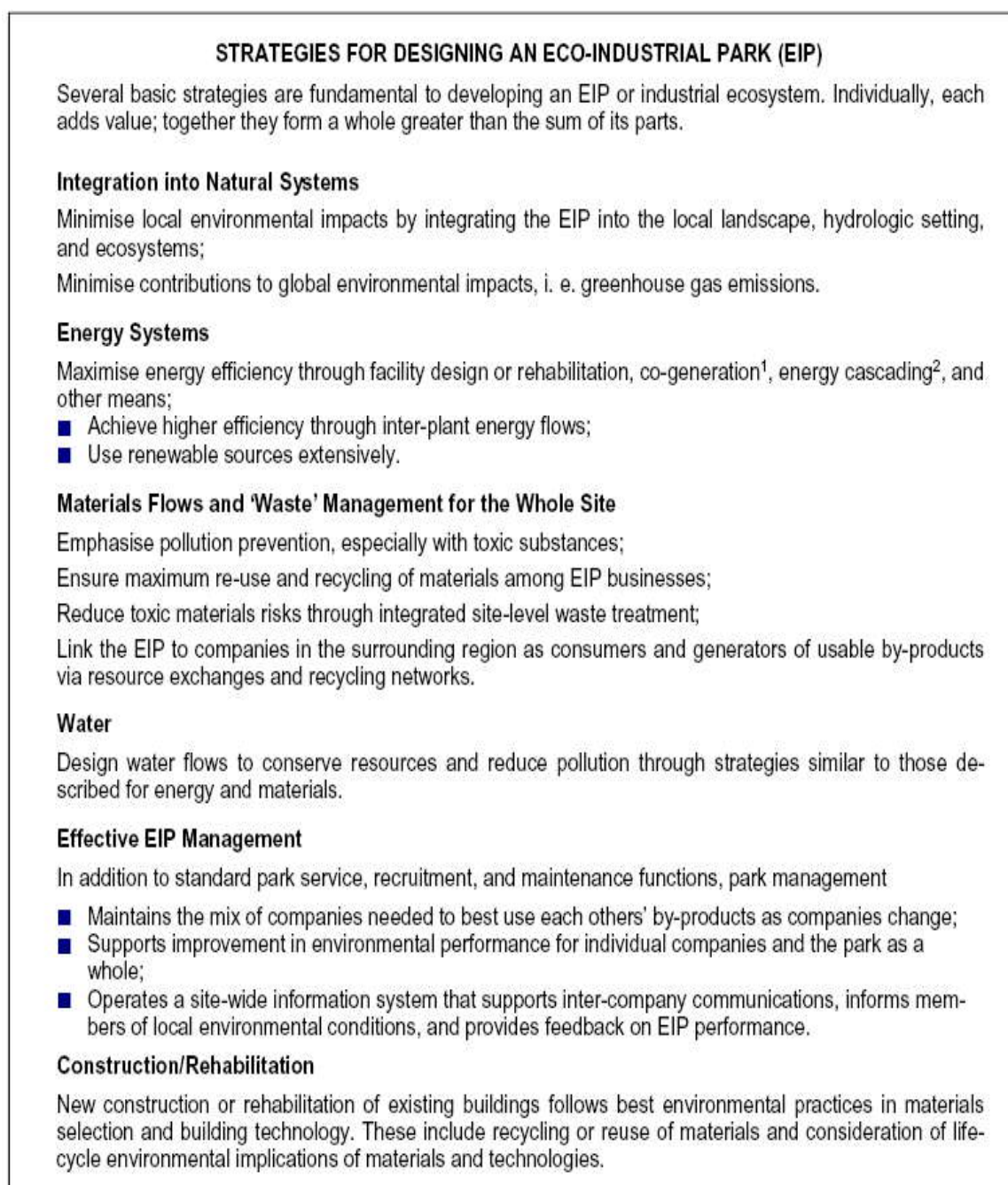


Figure 8-3 Strategies for designing eco-industrial park (Côté, 2003)

## **8.2 Application of industrial parks in China - TEDA**

China is experiencing exponential change in the world. However, the availability of resources for development, destruction of natural capital, and release of an increasing variety of toxic materials made China facing the greatest challenges to develop its industry and economy without demolishing the natural environment and with low natural resources consumptions at the same time.

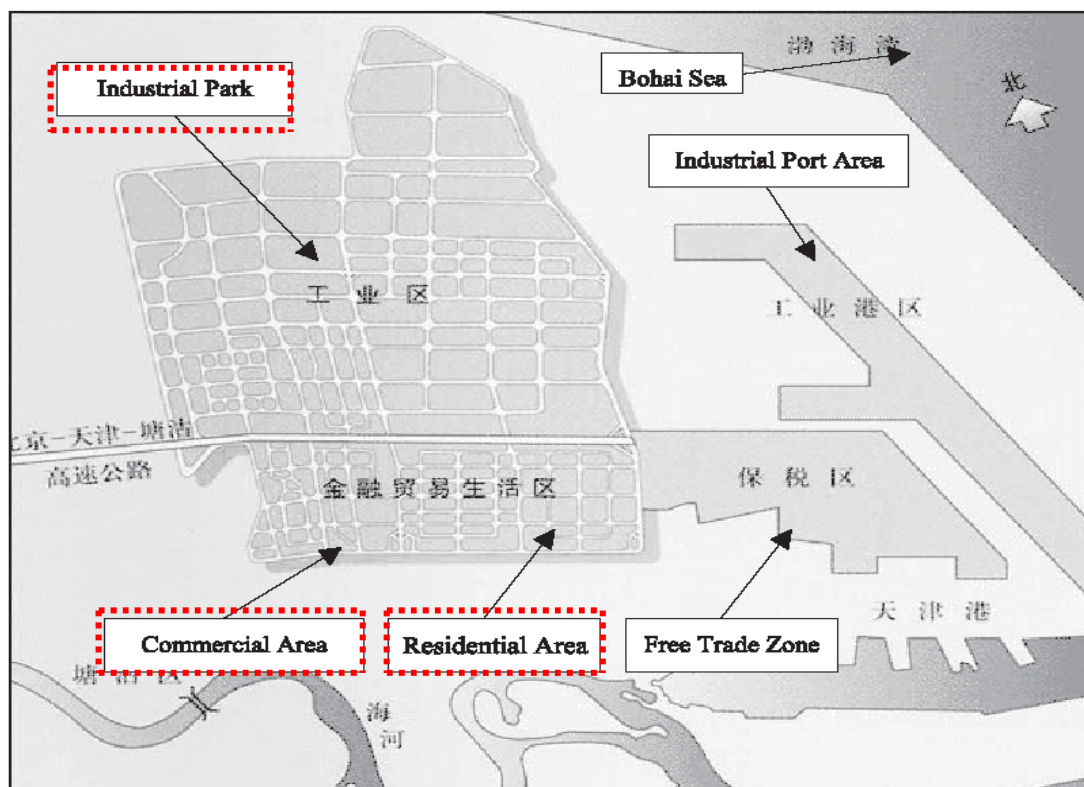
Salonen (2004) indicated that in most of Asian countries such as China, industrial parks are frequently designed as a basis for national economic development plants, whereas in Europe the driving force for the formation of industrial parks is the structural change of the industry. To use the concept of eco-industrial parks to help generating much higher productivity and increasing efficiency of natural resource utilization is one of the key strategies in China's circular economy initiative (Bi, 2004). The circular economy approach involving resource-use efficiency integrates cleaner production and industrial ecology in a broader industrial firms, networks or chains of firms, and regional infrastructure to support resource optimization.

The Chinese government started to set up eco-industrial park projects in 1999, and in the last two decades, over 100 industrial parks supported by the Chinese central government were built in over 20 provinces (Yang, 2006). Currently there are two kinds of solution that are suitable for China to build an eco-industrial park. One is to redesign the existent industrial parks and build the network of by-product exchange to connect the enterprises with each other so that the park can achieve the low energy and material consumption. Another is to build a new eco-industrial park with one or several anchor companies.

### **8.2.1 Establishment background and the location of TEDA**

Established in 1984, TEDA (Tianjin Technological and Economic Development Area) is one of the economic - technological development areas that first approved by the State Council of China.

TEDA is the centre of Circum-Bohai Economic Circle, and also the key and symbol Area of Tianjin Binhai New District. Relying on Beijing and Tianjin, radiating in three directions of north China, Northeast China and Northwest China, the area is a golden zone with dense population, assembled cities, good transport facilities and high purchasing power. It has a planned area of nearly 36 km<sup>2</sup> including separate sections for industrial development and mixed residential, financial and commercial uses (see Figure 8-4). Consequently, TEDA functions in a similar manner to a small municipality. The Jing-Jin-Tang Super Highway which runs through TDEA divides the area into three functional areas of the south – industrial, commercial and residential – with some limited agricultural activities within its boundaries.

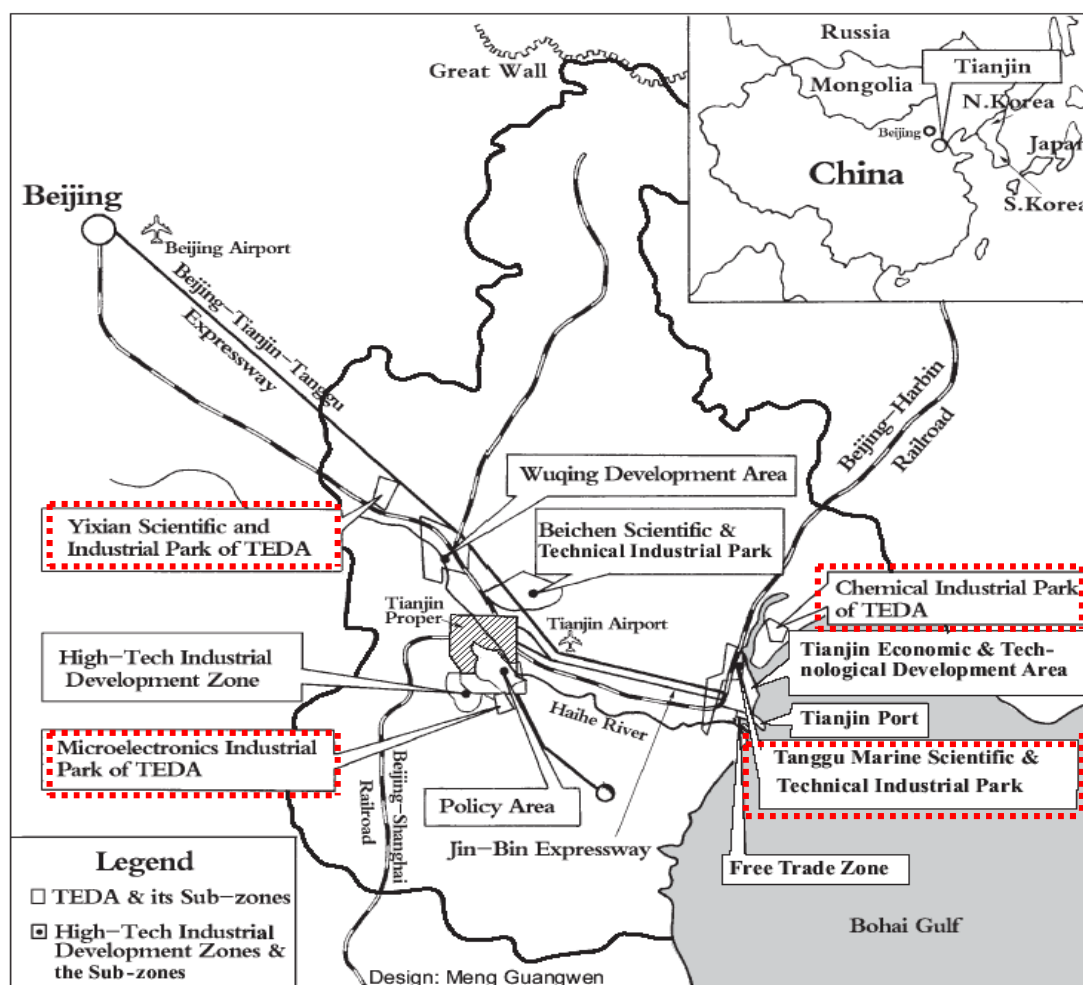


**Figure 8-4** Functional Planning Map of TEDA (Ge & Yi, 2006)

According to Tan and Bao (2006), the main Area is located in the east of Tianjin, with a planned area of 33 square kilometres. In addition, there are also four satellite development areas in the neighbourhood (see Figure 8-5): the TEDA West Area of Tanggu District, Yixian Scientific and Industrial Park of Wuqing District, Microelectronics Industrial Area of Xiqing District and Chemical Industry Area of Hangu District.

It was also reported by Tan and Bao (2006) that in 1997 Ministry of Commerce has conducted a comprehensive assessment for the state economic - technological areas. TEDA has kept the topmost position since then, and becomes a successfully developed state economic - technological area with the best investment environment in China. In 2000, TEDA was recognized by Fortune as “China’s Most Admired Industrial Park”. In 2000, TEDA became state demonstration area of the ISO14000 Regional Environmental Management System. It was designated “Environmental Management Experimental Park of Chinese Industrial Parks” in 2001 by State Environmental Protection Administration and United Nations Environment Program and meanwhile an objective of developing into an Eco-industrial Park were set up. In 2002, six cities, including Tianjin, were elected by United Nations Industrial Development Organization (UNIDO) as “China’s Most Dynamic Areas.”





**Figure 8-5** Geographic location of TEDA and its satellite development areas (Meng, 2003)

The reason why TEDA was selected as a case study is based on a number of criteria: i) this industrial zone is one of the largest in China, therefore its demonstration effect on other Chinese industrial parks is great; ii) TEDA is currently eager to adapt innovation to its resource and environmental management processes. That is why in 2000, TEDA was recognized by Fortune as “China’s Most Admired Industrial Park”; iii) also because most of the tenants in TEDA are completely foreign-owned enterprises and joint ventures, they are interested to have a higher level of environmental awareness and would like to collaborate with other enterprises in terms of resources and environmental management; iv) TEDA was suitable for the research study given their environmental challenges, especially their increasingly severe water crisis. In particular, TEDA is facing not only a freshwater resources challenge, but also is experiencing a deteriorating aquatic environment due to excessive water discharge.

## **8.2.2 The formation of eco-industrial chain**

Basically, an eco-industrial park is a community of companies located in a single region and exchange by-products and energy. In an eco-industrial system, downstream enterprises could use the byproducts or waste of upstream enterprises as resources for the production of new products. This process of forming a products chain is an Eco-industrial Chain. In this process, primary products increase in value along with the extension of industrial chain, so that materials and energies can reach maximal utilization. The industrial chain enables products recycling and wastewater reclamation, which are important characteristics of eco-industry.

Since all the key factories are located in TEDA and Tianjin city, the short transport distance and quick information communication can lower the cost, and cut down energy consumption, waste/emission discharge. Focusing on modern Industry, TEDA takes industrial development as its economic mainstay, and formed an eco-industrial structure with different industrial features, including four key Industries: electronic information, biological pharmacy, automobile and food & beverage.

### **8.2.2.1 The eco-industrial chain of electronics and information industry**

Centering on Motorola (China) Co., Ltd., the eco-industrial chain of electronics industry in TEDA is structured with upstream enterprises (e.g. Green Point Co., Ltd.), middle-stream enterprises (e.g., Battery factories), and terminal enterprise – Motorola (China) Co., Ltd. (see Figure 8-6). Meanwhile, Rising Co., Ltd. and Tianjin Dangerous Solid Waste Treatment Centre together form a waste treatment chain (see Figure 8-7). The products chain ensures material recycling through step-by-step products circulation within the industrial community leading by Motorola.

Within the material chain, Motorola is heading for zero-discharge of waste in the process of mobile phone production. The production waste includes tin soldering paste, packing paper, industrial powder of welding operation and substandard products. After the formation of the material chain, the tin soldering paste discarded from Motorola becomes the resource for Rising Co., Ltd., and the soldering paste waste with high quality are processed into end products – paste with lower quality, which will re-enter the market. The cooperation with Tangshan No.1 Packing Factory forms a closed recycle from purchasing to reclamation of packing paper. Tangshan No.1 Packing Factory does not only supply but also reclaim the packing paper from Motorola, and the reclaimed packing paper is re-pulped by Lingxian Environmental Protection Company and processed into mobile phones packing molds for Motorola again.

The following Figure 8-6 and Figure 8-7 are based on the information provided by Tan & Bao (2006).

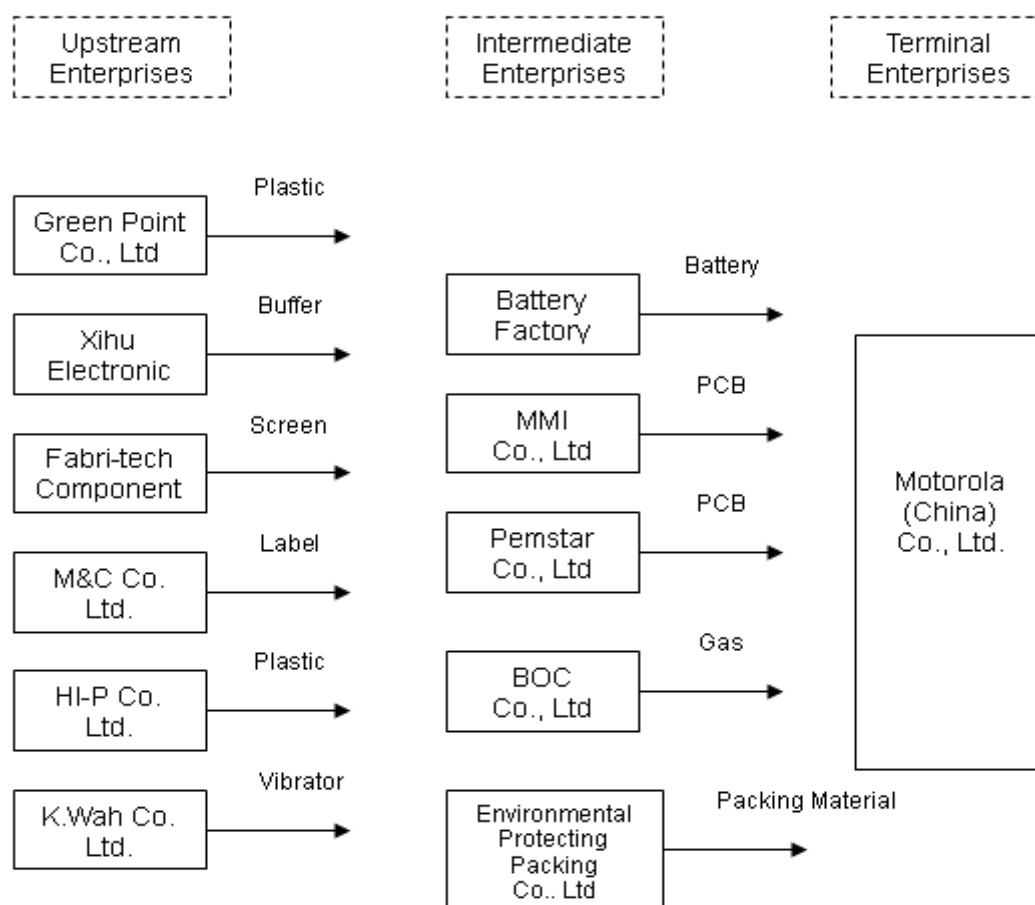


Figure 8-6 The eco-industrial material chain centering on Motorola Co., Ltd.

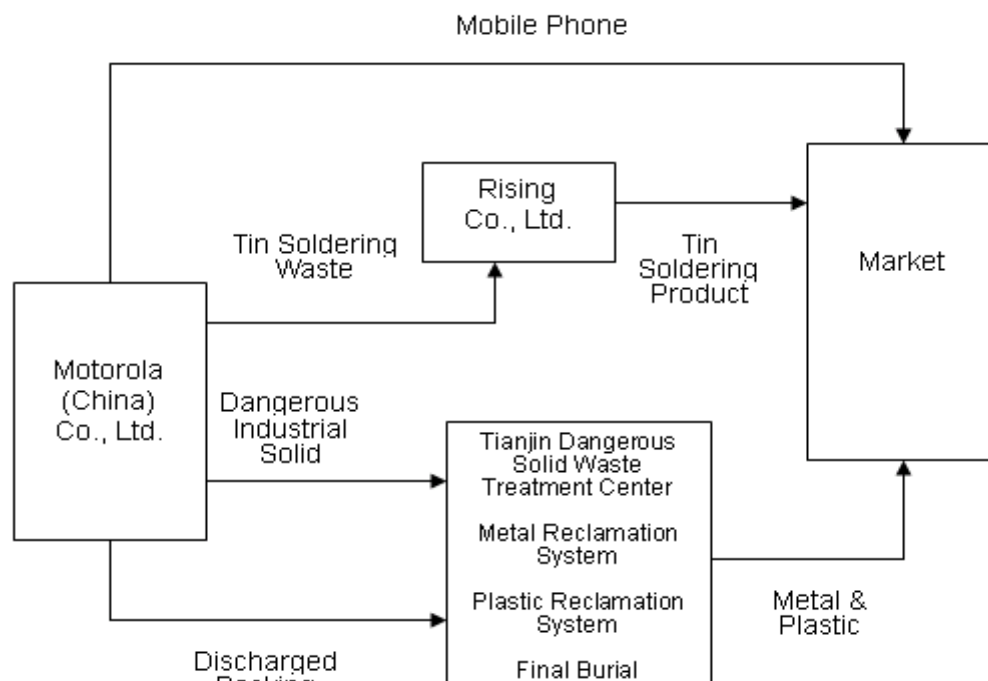


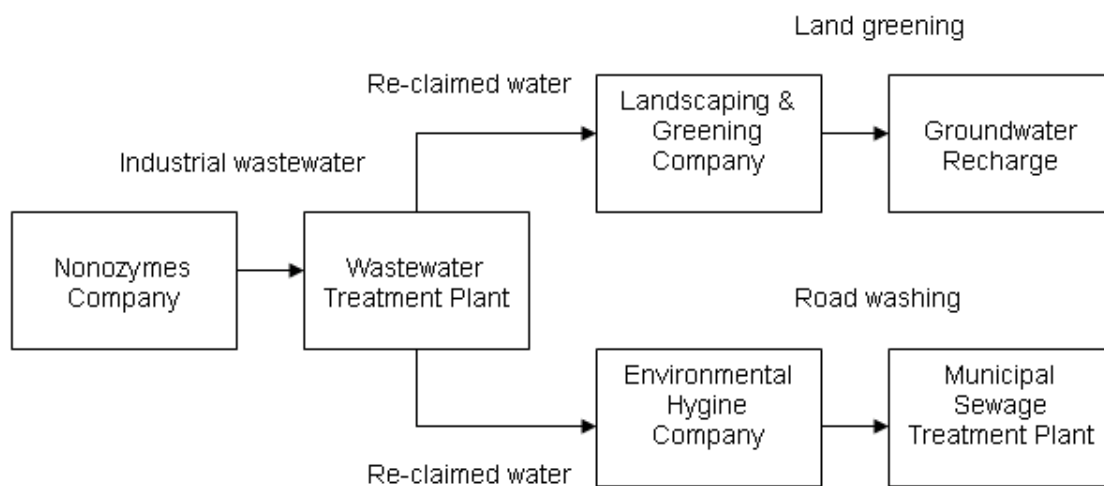
Figure 8-7 Waste chain and recycling process in mobile phone production



### 8.2.2.2 The eco-industrial chain of biopharmaceutical industry

Surrounding with Nonozymes Company, the eco-industrial chain of Biopharmaceutical industry in TEDA is characterized as a chain of industrial wastewater (see Figure 8-8) and solid waste recycling. Based on the report of Tan & Bao (2006), Nonozymes is a bioengineering company with a large amount volume of wastewater discharge, therefore it has established a wastewater treatment factory with a designed capacity of 2000 tons per day, and the quality of the treated water meets the state criterion for landscape irrigation.

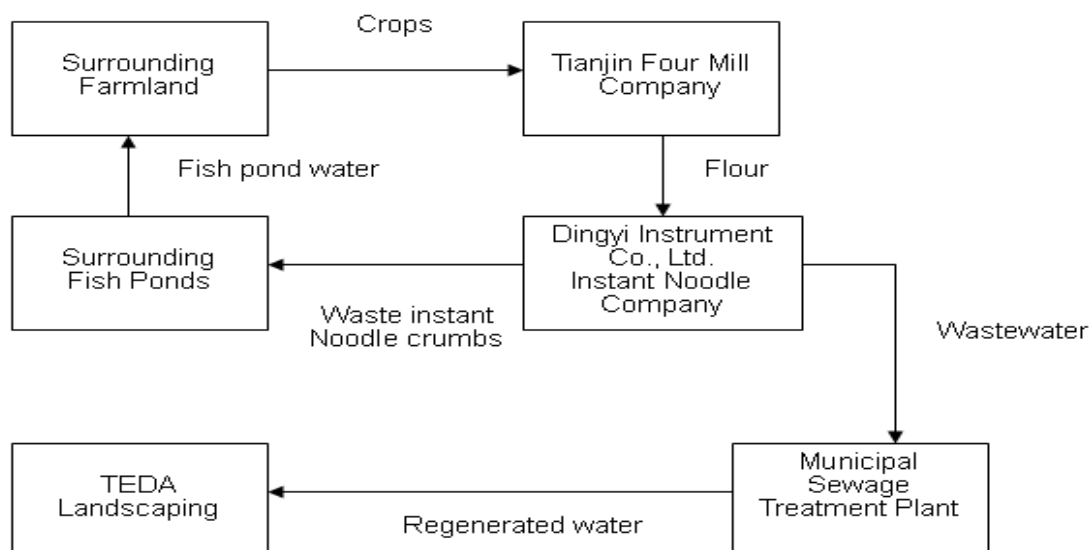
Apart from irrigating for the landscape in its own factory-area, Nonozymes, through cooperating with TEDA Landscape Greening Company and Environmental Hygiene Company, provides free reclaimed water for public green lands irrigation and roads washing in the Industrial Area. The volume of utilized reclaimed water has risen gradually from none in 1999 to 11,000 tons in 2000, 11,600 tons in 2001, and 16,400 tons in 2002 (Tan & Bao, 2006). Solid waste recycle has also made a great achievement. High-grade fertilizer made from the solid waste is suitable for farmlands and green lands.



**Figure 8-8** The eco-industrial chain of industrial sewage treatment centering on Nonozymes Company

### 8.2.2.3 The eco-industrial chain of food and beverage industry

The eco-industrial chain of food and beverage industry in TEDA is centering on Tianjin Dingyi Company's instant noodles production. The significant characteristic of this chain is the recycle of waste flour crumbs and wastewater (see Figure 8-9).

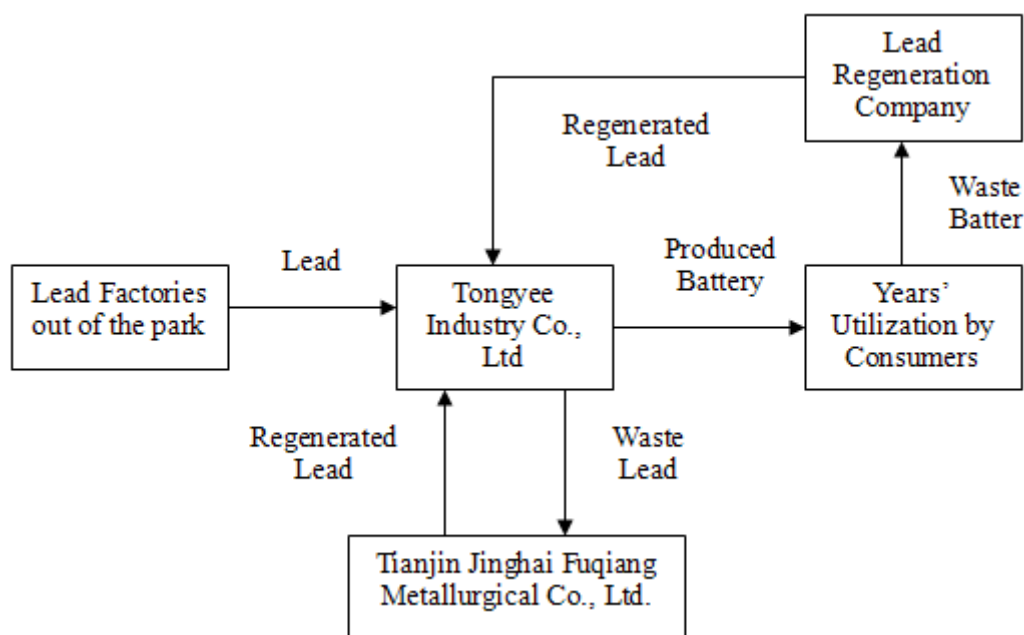


**Figure 8-9** The eco-industrial chain of Master Kong Instant Noodles

Every year Tianjin Dingyi Company produces about 4,000 tons of waste instant noodle crumbs, which can be used as feeds for the fish pond in the surrounding area. The fish-cultivating water is nutritious and can be used for irrigation of the neighbouring farmlands. Meanwhile, Tianjin Flour Mill Company can obtain crops from farmland and generate flour for the Dingyi Instant Noodle Company. Additionally, according to Tan & Bao (2006), every year approximately 550,000 tons of the wastewater out of the production process can be transported to TEDA New Water Resource Factory for treatment, and the regenerated water can be used for green lands irrigation in the industrial park. In this way, a trans-industrial ecological chain is formed, consisting of wheat growing that is the first industry, instant noodles production that is the second industry and wastewater regeneration that is the third industry.

#### 8.2.2.4 The eco-industrial chain of automobile industry

Another typical eco-industrial chain is in automobile industry and closed recycle of battery products recycle and waste reclamation of Tongyee Industry Co., Ltd. (see Figure 8-10). According to TEDA (2003), on the one hand, the discarded battery products are reclaimed and resolved by Regeneration Company, and the regenerated lead from this company is used again as resources for battery production. On the other hand, around 3,000 tons/year of the lead-containing waste out of the production process are treated by Tianjin Jinghai Fuqiang Metallurgical Co., Ltd., and transformed into regenerated lead with production of 1,800 tons/year, which will be put into the production again as resources for Tongyee Industry Co., Ltd. Thus a benign circle is formed within the industry.



**Figure 8-10** The eco-industrial chain of lead recycling centering on Tongyee Industry Co., Ltd.

## 8.2.3 The regeneration and utilization of water resources

### 8.2.3.1 Water scarcity and water supply

Located in the east of northeast China and without any natural river or lake, TEDA is an area lack of natural water resources seriously. The lack of water sources will be the biggest obstacle for the future development. For almost two decades, TEDA and the Tianjin region have suffered from a water deficit problem due to scarcity of resources and resource depletion. In particular, it was reported in 2000, 2001 and 2002, since Tianjin faced severe drought and as early as the mid 1990s, the area's main reservoir for freshwater was utilized to capacity (TEDA, 2003). Early efforts to tap other reservoir sources did little to alleviate the pressure for fresh water needs, because currently the whole North China region is suffering from water shortage and surrounding areas are not willing to provide a portion of their decreasing water supply to TEDA.

Several sources can be used for water supply in TEDA, including surface water, groundwater and seawater. Surface water and groundwater are the most highly used sources, providing 26.82 million m<sup>3</sup> of water in 2001 for the zone's consumption needs. Of this, 25.33 million<sup>3</sup> (94.4%) was surface water, and 1.49 million m<sup>3</sup> (5.6%) was groundwater (TEDA, 2002). And the Erwangzhuang reservoir is regarded as the main source of surface water (16.37 million m<sup>3</sup>), which receives water from the Luan River, a branch of Haihe River. Generally, Water from Erwangzhuang Reservoir is further treated in the TEDA Water Treatment Plant and the generated potable water is

classified as Class I under the national standards for drinking water.

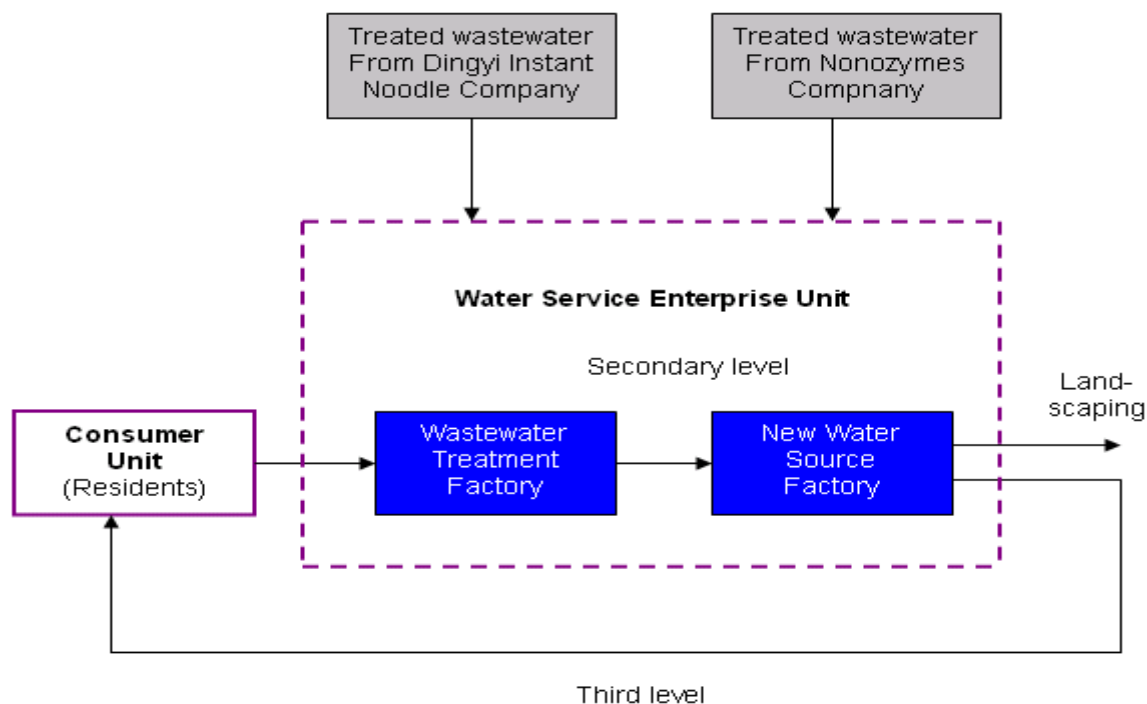
TEDA also has access to a large supply of sea-water, given its location, but this source of water has not been highly exploited (TEDA, 2002), since desalination options are still considered too expensive, and the use of seawater in manufacturing options has been limited to a few companies in the estate that are co-located next to the shoreline. Examples of businesses in TEDA using seawater daily in their operations included a heating plant and some recreation sites, such as saunas and swimming pools.

### **8.2.3.2 Wastewater treatment and recycling**

Water is a key driving-force of economic and social development and it has a basic function if maintaining the integrity of the natural environment. Addressing the ever increasing demands from demographic and economic pressures, wastewater treatment and water recycling as well as demand management measures are being introduced to counter the challenges of insufficient supply. Due to the above severe scarcity of water resource, TEDA has to made it clear to develop water regeneration industry, and preliminarily formed “a regional water recycle mode with a fairly large scale” (TEDA, 2001).

According to Geng and Yi (2006), within TEDA there is a dual pipe system for storm water runoff and for industrial and residential effluent. Storm water pipes, some of which are open gutters, release water directly into the sea without treatment. Industrial, commercial and residential wastewater is processed through the plants, receiving secondary treatment before release into the ocean. All companies are required to comply with national water discharge regulations before releasing their wastewater into the general sewage systems. Several tenant companies have their own wastewater treatment equipment at their manufacturing sites to reduce costs, including Novozymes Company and Dingyi Instant Noodle Production. The administrative cost of treating wastewater is covered by the TEDA administration and subsidized in part by freshwater fees.

In general, the regenerated water recycle system in TEDA consists of two units, namely the consumer unit (residential buildings) and water service enterprise unit (Wastewater Treatment Plant) (see Figure 8-11). The consumer unit is both the producer and the consumer of regenerated water; water service enterprise unit is in charge of transforming the wastewater into standard regenerated water for consumers through the overall treatment of different enterprises. At present, TEDA Water Service Enterprise Unit includes TEDA Waste Water Treatment Factory and New Water Source Factory. Wastewater is generated from residential buildings, Ding Yi Instant Noodles Production, and Novozyme Company is further treated in this unit. The quality of treated wastewater could reach third level and be reused in residential buildings after treatment by the water service enterprise unit.



**Figure 8-11** Schematic of water regeneration and reutilization in TEDA

### 8.2.3.3 Administration for water management

According to Geng and Yi (2006), there are several departments related to water management in TEDA (see Figure 8-12). These include the Water Planning and Saving Office (WPSO) at the Construction Bureau (for water planning and conservation) and the Environmental Protection Bureau (for water quality monitoring and wastewater emission). Other departments related to water management include the social development bureau (for water-related health issues), the policy research office (for water policies), the revenue bureau (for water tax), and the finance bureau (for water infrastructure budget and water-related subsidies).

Among these branches, the most active department for water resource management in TEDA is the Water Planning and Saving Office (WPSO) at the Construction Bureau, which focus on reducing freshwater consumption among all types of users. Their responsibility is to plan and manage water issues in the zone and to develop and implement conservation strategies. The office's daily activities involved training tenant companies on the management of water-saving and monitoring water consumption through a computer system. However, their system does not have enough data on water quality and quantity, only basic information (e.g., annual water use quantity of all the companies in TEDA). Hence, WPSO is also in charge of managing the Water Treatment Plant (WTP) and Wastewater Treatment Plant (WWTP).

Given increasing concern over the scarcity of water resources in TEDA, there has been some coordination among the various departments related to water issues. Up to date, there have been regularly two strategy meetings between the head of the WPSO, TEDA Administrative Commission, Finance Bureau, Water and Wastewater Treatment Plants and the Environmental Protection Bureau (TEDA, 2003). According to Geng and Yi (2006), however, this type of inter-departmental cooperation is not the norm, but the volunteer. None of these agencies are subordinate to one another, nor can any of them play a leading role on water conservation and wastewater reuse.

In many cases, the water-related jurisdiction of these agencies is not clear. In addition, the wastewater treatment plant (WWTP) is authorized by WPSO to take the lead responsibility on guiding water conservation and stipulating relevant policies (Geng and Yi, 2006). However, the water treatment plant income depends on selling more water. Thus, there is some concern about the effective and efficient planning and management of water resources in TEDA. As a result, the possibility of setting up a new administrative institution that has integrated supervision authority over water-related issues at the zone level might be taken into account.

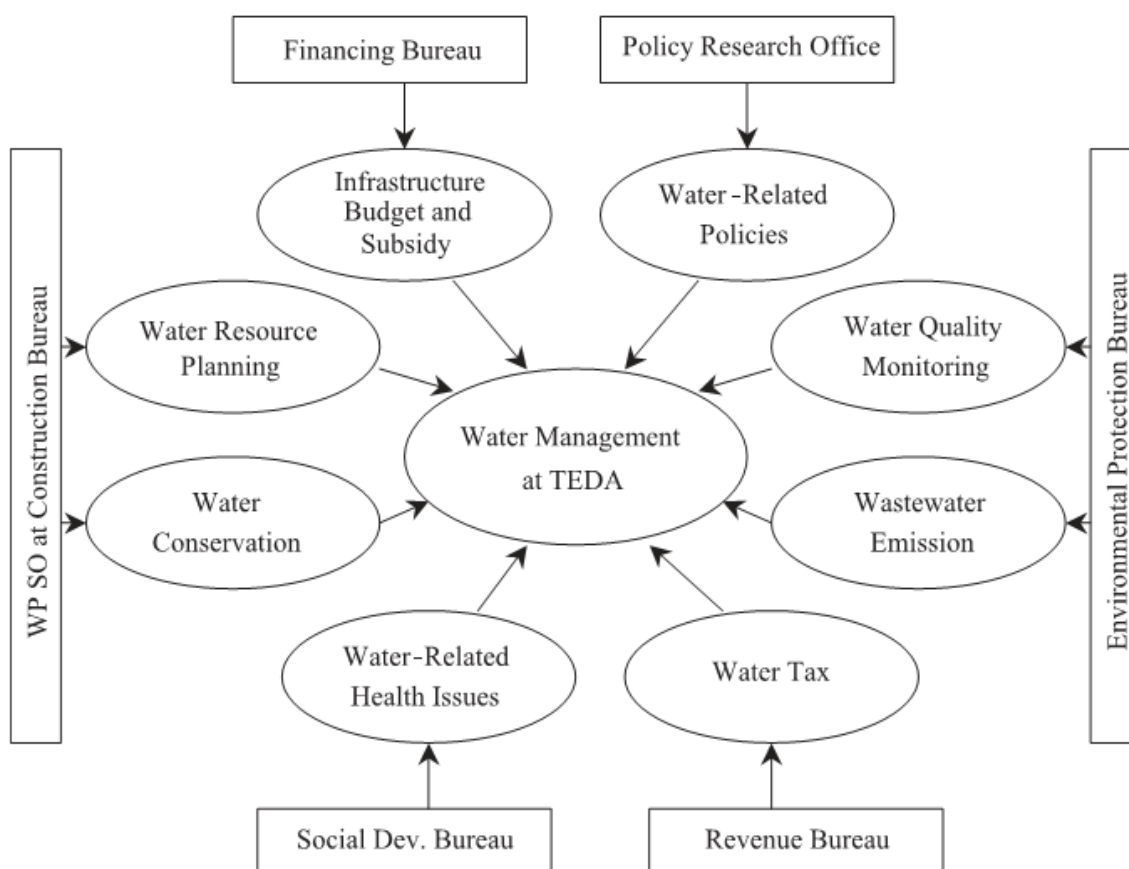


Figure 8-12 Administrative Structure for water management at TEDA (Geng and Yi, 2006)

## **8.2.4 Integrated water management framework within an industrial park**

As a general rule, in the past with smaller population, less intense economic activity and with less affluent settlements and the people and producing companies within them demanding much less water than today, supply potential of the resources was usually greater than the demand for it. As populations have grown, the economic activity has developed and as societies have become more affluent, thus the demand for water has increased. From environmental standpoint it is not generally necessary to supply each expressed demand, but from social standpoint there is a need for planners for approaches to be tailored to the individual circumstance of country and local region. Decision-makers and government have to find ways to diminish supplies between ever-increasing demands. The traditional fragmented approach is no longer viable and a more holistic approach is essential.

Similar to TEDA, many industrial parks in various countries and regions are facing significant water management issues due to limited supply, rising demand in all sectors and a lack of integrated planning. The development and implementation of a comprehensive, integrated water management strategy with water reuse as a major component is one way to mitigate the impact of the increasing imbalance between limited supplies and rapidly growing demand, as well as addressing such issues as the significant deterioration of the environment, extensive exploitation of groundwater and increased pollution.

### **8.2.4.1 Integrated water management at the industrial park level**

In the past, water resources were often developed on a single purpose basis, focusing mainly on activities such as irrigation. Large-scaled projects that were based on single purpose were characteristic of water management, leading to the almost complete usage of the available site for dams and other related civil works. However the current and the foreseeable trend indicate that water problems of the future will continue to become increasingly more and more complex, and interacted with other development sectors like agriculture, energy, industry, transportation, and communication, and with social sectors like education, urban planning, and regional development.

Therefore water can no longer be viewed in isolation by one institution or any one group of professionals without explicit consideration of other related sectors and issues. New approach requires new decision-making mechanisms in order to select alternatives for managing water resources. The old top-down approaches are being replaced by models involved multiple objectives and decision makers, in which stakeholder, NGOs and government agencies all participate in the decision-making process. This new paradigm requires a restructuring of existing institutions and the collaboration of professions from different backgrounds to handle the difficult task of conducting planning and management initiative in an integrated way.

Faced with such unexpected complexities, many in the profession started to look for a new paradigm for management, which will hopefully solve the existing and the foreseeable water problems. This concept is not new and was the re-discovery of a basically more than 60-year old concept: Integrated Water Resource Management. The most widely accepted definition of Integrated Water Resource Management (IWRM) is that given by the Global Water Partnership: "IWRM is defined as a process that promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems".

Integrated water management should be an approach that considers the goals of all relevant stakeholders. This approach also requires that all relevant factors related to water issues should be considered in the decision-making process. Such a holistic approach requires not only supply management, but also demand management, water conservation, cost-analysis, water quality control, recycling and reuse of water. Integrated water management also addresses issues related to public involvement, environmental and ecological aspect, socio-cultural aspects, efficient use of surface water and groundwater as well as water pollution control. Therefore, the integrated water management at the industrial park level requires planners and management to consider the broader environmental and social implications of their decisions.

### **Policies and regulations**

Policies are required to address institutional barriers to implementation of the integrated water management. There are often complicated administrative arrangements for water planning and management, especially for industrial parks in developing countries (Bouwer, 1997). The case of TEDA indicated that the artificial segmentation of water-related agencies makes an integrated water planning and management system difficult to achieve. One possible solution would be the establishment of a new administrative institution that can integrate the supervising authority over water-related issues at the industrial park level. Another option would be to create an inter-agency to develop a more integrative policy frame work and coordinating day-to-day management of water resources.

The more scarce water or capital is, and the more conflicts arise over water, the more important it is to have in placed a coherent and comprehensive water regulations and policies. Thus, policies should help adjust the industrial structure of an industrial park, for example, by limiting the development of large water-using industries, and relocating large water users to a water abundant park and balancing water demands by assessing water-use efficiency. Regulations that can help solve potential conflicts among tenants and industrial parks as well as between tenants. Other policies, such as those that can encourage cleaner production and water cascading among tenants and can facilitate the coordination of the relationship between industrial parks and local communities, should also be adopted according to local realities.



Such integration requires that industrial park managers should integrate all the relevant policies in a broader complex system including natural, social and economic contexts at an early stage in order to avoid potential water resources problems. In order to do so, industrial park management can help establish a committee for dealing with these issues. The committee members should include park managers, tenant representatives, government agents and other stakeholders so that everyone's wishes and benefits can be fairly considered. These members should work together to prepare appropriate regulations and enforce the implementation of relevant policies.

A critically important element of integrated water management is the integration of various sectoral views and interest in the decision-making process, with due attention given to upstream-downstream relationships. Moreover, the successful implementation of this integrated policy framework requires the management to establish effective monitoring and evaluation mechanisms, to consider appropriate economic incentives as well as penalties, and to ensure increased community involvement in water management. Therefore, decision-makers should consider the concerns of all relevant stakeholders. Partnership between tenants, industrial park managers and public authorities brings added value to both the communities and to all parties.

### **Economic instruments**

It has become increasingly evident that water problems can no longer be resolved by the water professionals or the water ministries alone. The water problems are becoming increasingly more and more interconnected with other development-related issues. The growing scarcity and rising cost of water has led to an increased awareness that water must be allocated and used more efficiently. Economists conclude that this is best done by treating water as an economic resource. Economic instruments, such as prices, quotas, and effluent charges, can play a key role in water conservation at the industrial park level, helping ensure sustainable usage through such activities. It can also be used to provide incentives for the development of water efficient and reuse technologies.

#### ➤ Prices

In principle, charging the full cost for water assures the long-term viability of water supply service and effectively constrains water demand. A basic principle of current natural resource management is that consumers should pay prices for water services in accordance with the principles of economic efficiency. Such a pricing system will equate demand and supply for water services at the economically appropriate level and in an environmentally acceptable way (Asano and Mills, 1990). In order to achieve more efficient water demand management, the consumer and the polluter should be required to pay the full social cost (including capital, operation, maintenance and external costs associated with its use) of providing water and related services, including treatment and damage costs.

The adoption of this principle will create more efficient administrative arrangements for the integrated management of water and other natural resources. If the price of water is below that which reflects water resource availability, supply and treatment, then the tenants are inclined to waste water (e.g., by not identifying and repairing leakages) or use it inefficiently (e.g., by overuse or inappropriate use). On the contrary, when the price of water reflects water resource availability, supply and treatment, there will be an economic incentive for water to be allocated rationally and for the development and use of water-efficient technologies involving the substitution of capital for water (e.g., the application of cleaner production).

### ➤ Quotas

Quotas for water use have proved to be a powerful tool to control water use at a regional level. The application of a quota system can also be useful at the industrial park level. The successful implementation of a quota system is dependent on “a planned water use system” operated by industrial park managers. Such a system sets up penalty mechanisms for water use that exceeds the given quota. Tenants would be required to pay several times of the normal rate for water when they exceed the given quota. This measure can encourage tenants to apply state-of-the-art water conservation technologies and seek potential collaboration opportunities with their neighbours in the industrial park. By doing so, both internal water recycling ratios and systematic water efficiency could be greatly increased. The case of TEDA has partly tested its feasibility.

### ➤ Effluent charges

The main objectives of effluent charges are to recover the costs by the regulatory authority for its pollution control function, to change the behaviours of the discharger, and to raise funds for cleaner production. Raised fund could be utilized in support of research and development related to water reuse and recycling. Such charges should be stipulated by industrial park managers and local regulatory authorities together by considering local situations. Charges should first cover the administration cost, usually maintenance, and the monitoring costs for compliance sampling. Charges should also cover the cost related to wastewater treatment, cleaner production and relevant research activities. In addition, the charges can be used for subsidizing water conservation equipment for some large water users.

By doing so, effluent charges may serve as a significant incentive to reduce total water consumption and wastewater discharge in an industrial park, and improve economic and financial effectiveness and efficiency. The above-mentioned argument demonstrates that economic instruments should be regarded as an important element of integrated water resource management within an industrial park. However, economic instruments should be used in conjunction with other measures (e.g., a top-down approach, capacity building) in order to achieve the intended results.

### **Capacity building**

As an essential requirement for the efficient management and planning of water resources, capacity building includes the strengthening of institution, managerial systems and human resources, developing effective means to facilitate community participation and communication, and promoting the creation of policy environments. Institutional capacity building is a means of enhancing performance. In the context of integrate water management, capacity building is the sum of efforts to nurture, enhance and utilize the skills and capabilities of people and institutions at all levels so that they can make better progress towards a broader goal. At a basic conceptual level, building capacity involves empowering and equipping people and organizations with appropriate tools to solve their problems.

Generally, capacity building should directly reflect the needs of the industrial park concerned. Good communication and extensive interactions between different stakeholders and levels are essential requirements for successful capacity building process. Awareness-raising activities, including TV promotions, newsletters and workshops, should be carried out periodically in order to build understanding. These actives can also create opportunities for stakeholders to strengthen their mutual understandings, which will be the solid foundation for further collaboration. On the basis of such initiatives, a local network on water issues could be established for exchanging experiences, transferring technology and enhancing cooperation across disciplines. Such a network can take advantages of modern information technologies so that the various water resource stakeholders participate fully in its management.

#### **8.2.4.2 Implementation of an integrated framework**

The successful implementation of integrated water and wastewater management is engineering process and needs the involvement of different parties. If not well organized, it will result in negative impacts. The implementation of integrated water and wastewater management within an industrial park consists of six stages:

##### **Organization establishment**

The first step is to establish a new specific organization. Members are from industrial park management, tenants, local government officials, community representatives, water and wastewater engineers and consultants, economists and other stakeholders. Such team should have multi-disciplinary expertise and benefit all the stakeholders. The next step is to establish the boundary limits for the study. This means that all potential water reuse and wastewater minimization opportunities should be considered when settling limits. If the boundary limits are too narrow, then many wastewater reduction and reuse opportunities may be lost. Many successful integrated water and wastewater management projects have proved that reasonable establishment of a boundary can help balance regulatory compliance, economic investment, internal resource limits and technology availability.

### **Data collection and analysis**

At this stage, management of industrial parks should carry out a water investigation within the boundaries in order to understand the current status of their water and wastewater problems. Basically, a preliminary assessment should be done in order to identify the potential constraints and objectives. During this process, the tenants of the industrial park should be convinced and ensured the significance and benefits of integrated water and wastewater management, and the potential barriers should be eliminated. Management also has to collect broader information on local community demands, groundwater recharge, and topological, geological and geographic data in order to encourage more water reuse. This needs the involvement of experts from hydrological engineering, civil engineering, urban planning and other fields. Therefore, integrated management can create enormous data demands and it will never be possible to collect all the relevant information, if decisions are to be taken within reasonable time periods. Often, decisions have to be made without complete information and with a degree of uncertainty. Managers must therefore set up priority for their information needs, discuss with related agencies and compatibility of the database, and ensure that the data coming from those agencies are adequate and are understood.

### **Quantitative modelling**

After acquiring the necessary data, managers need to find appropriate optimization software or computation tools to work out the quantitative model. And they can choose a model to meet their needs by considering their own conditions and too often the availability and complexity should be considered in making that choice. After setting up the model, managers need to calculate the potential savings and cost on freshwater and wastewater discharge, in order to help decision-makers to make smart decisions on water resource allocation. Team members may find different scenarios when they use different objective functions, variables, parameters and constraints. Thus they need to carry out a comparison study in order to identify the advantages and disadvantages of the various options and alternatives before a final selection can be made.

### **Decision-making and implementation**

It should be noticed that there is no single one-for-all technological solution, economic tool, or institutional structure can be applied to all situations. Decision-making support tool might combine information on a user's given situation with information on available technologies and approaches, and then helps a practitioner select the best approach. A decision-making support tool should compare and contrast different water and sanitation technologies and approaches, including their construction, operation and maintenance, cost, financing, and institutional requirement. It should also incorporate the special needs of different geographic locations and the need for community's involvement.

Based on modelling, the team can prepare a detailed analysis of the most suitable alternatives in terms of local reality and then submit them for the decision-makers to make the final decision. Meanwhile they need to clarify and

evaluate a sizable list of problems or issues. Another task at this stage is to prepare detailed guidelines for implementation once the final option is determined. These guidelines should involve training and education module, financial support module and conflict solution module. These guidelines should consider the tradeoffs between water reuse goals, available budgets, human resources, schedules and available technologies. Basically, these guidelines would serve as a road map for the water reuse program. Cost analysis must be included in the implementation plan, otherwise it will be very difficult to obtain funding and support from senior management. During the implementation period, suitable monitoring mechanisms should be established.

### **Feedback and improvements**

The transition towards an adaptive approach to the water resource management refers to a “learning by doing” processes is causing changes in the processes of decision-making, in which the outcomes of the implemented strategies are used to iteratively refine and improve the management policies. This process proceeds from the premise that policies can be treated as experiments in which monitoring and evaluating outcomes, and judging what has been learned are fundamental steps. The information cannot be considered just as an initial input, but it pervades the decision process in all phases. After the implementation of the designed alternatives, the monitoring information should support the decision-makers to assess the system responses and evaluate the efficiency of the management action. Furthermore, the monitoring information should support the decision-makers in revising selected policies and introducing some adjustments.

In the last stage, a continued review of stakeholders’ feedback and an update of the design or implemented project should be involved. This is required because in the production process, raw water quality, discharge limits and plant goals may change and affect the dynamics of wastewater reuse and water conservation. Technologies might be also need to be improved and become more cost-effective. The relevant information should be updated, new water reuse opportunities should be investigated and the implementation plan should be evaluated and revised.

## **9. Scenarios of decentralized wastewater management in a peripheral area of Beijing**

### **9.1 Introduction of Yang Song Township<sup>1</sup>**

#### **9.1.1 Location and geography**

Yong Song is a small town ship in Huai Rou County, 45 km northeast from the centre of Beijing (TianAnMen Square), and 25 km from the Beijing International Airport. The township covers a total area of 30.5 sq km and lies on a flat terrain. The urban district with a total area about 3 km<sup>2</sup> can be found in the northwest, the villages are located in the south and east of the Township.

The township of Yang Song has the typical Chinese rectangle form with strict separation of the different living functions (spheres). In general, the whole township is divided into two areas: 1) the northern part is mainly composed of new settlements, public places and living areas. The government is also developing the industrial and service zone in this part; 2) the south of the township is characterized by an older village structure and cultivated land. The older houses will be demolished and replaced by new houses and apartments, mainly for the resettlement rural population.

#### **9.1.2 Population**

The total population of Yang Song Township is 21,000. The urbanization rate was 46% in 1996 and 48% in 2000. The main reason for instructions from the government to have villagers increasingly settle in townships is to increase the urbanization rate and thus assumingly reduce resource consumption. And the average income in Yong Song Township is 5,300 Yuan/year/person (662.5 US\$/year/person)<sup>2</sup>.

#### **9.1.3 Agriculture**

Yang Song is still dominated by the agricultural sector, with 69% of the population working in agriculture. Concerning the plans of Yang Song Township, there will be a new regulation to strengthen development of the agriculture sector. To increase yield and financial benefit, the next important step will be to attract more companies that work in new technologies.

Today Yang Song total area for agriculture is 28,000 mu. The landscape is flat and the soil conditions are suited for agriculture. The water demand for irrigation is met by the groundwater derived from several wells. Various categories of agricultural production in Yang Song are presented as milk-production, grass and hay production, medical plants and other products like wheat, fruits and vegetables.

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<sup>1</sup> Section 9.1 & Section 9.2 are abstracted from Gallinat et al. (2003): Baseline study of application of closed-loop sanitation approaches in the township of Yang Song

<sup>2</sup> 1 US\$ = 8 Yuan (RMB)

At present, farmers still depend on night soil from village households and manure from farms with livestock. There is no social prejudice about excrement utilization, but over-fertilization with nutrients through artificial fertilizer, manure and night soil is assumed. Hence, there is an increasing demand of organic fertilizer for plantations.

#### 9.1.4 Types of settlements

Since being declared a model township for small-town-construction, the urban district developed very fast. The existing 15 villages will be reduced to 9 village units. The rest of the population will be resettled in the town. For this purpose, the construction of new apartment houses is a must and has been firmly decided.

##### In the town

In general, two different types of apartment houses can be distinguished in Yang Song, similar to the whole of China. Today more and more villa areas in suburbs are built up.

➤ *First category*

The apartment has a simple architecture with 6 floors and four entries (see Figure 9-1). Each block provides apartments for 12 families ( $4 \times 12 = 48$  unites). Every apartment unit consists of a living room and 4 bedrooms. The whole living area is about  $80 \text{ m}^2$ . The houses are connected to the central heating station, water supply and gas network. The buildings are characterized by bad building-substances.

➤ *Secondary category*

The apartment has an improved construction with a higher standard of equipment (see Figure 9-2). In Yang Song, those kinds of apartments are used in the trading and business area. The shops are in the ground floor and the upper floors are used as living areas.



**Figure 9-1** First category (Left)



**Figure 9-2** Secondary category (Right)

### **In the village**

The style of the houses in the villages and their sanitary equipment vary. In general, the houses of the settlements have the shape of a horseshoe, with 3 separated buildings and a courtyard; all surrounded by a wall (see Figure 9-3). The main residential building consists of a living room and 3~5 sleeping rooms, partly with power supply, TV, telephone and central heating. The adjoining buildings are the kitchen together with a food storage room and the sanitary room in form of a wet booth. The other buildings are small and simple lofts. The courtyard has a little garden for subsistence purposes.



**Figure 9-3** Settlement in the village (Left)

**Figure 9-4** Water park (Right)

## **9.1.5 Water for recreation**

### **Water parks**

In the middle of Yang Song Town, there is a water park, covering a total area of about 100 mu (see Figure 9-4). The water level will be filled at night, with water from a special pump station next to the lake. The fountain is operating with a water cycle.

### **Greenbelts**

The irrigation of the greenbelts in the town is done with groundwater, derived from the network. In the summer months the daily demand can increase to 500 m<sup>3</sup>/day or 16,000 m<sup>3</sup>/month.



## **9.2 Current water supply and sanitation**

Yong song is located in the major water shed area of Beijing. Surface water is coming from 3 small rivers in the Yang Song area. These are only serving as recreation areas, not as a fresh water source. There are 3 waterworks extracting groundwater for the town and village water supply. The water is now distributed via pipes in Yang Song. In recent years the population in the villages had to use conventional pumps. The majority of the households are not using the water for drinking; they buy potable water in bottles.

### **9.2.1 Current urban and rural water supply**

#### **9.2.1.1 Ground water**

Yang Song heavily relies on the groundwater resources, this even though they are the only source for drinking water supply. Groundwater can be found in 4 layers. The first layer is located in the depth of 18-19 meters, but water quality does not meet the drinking water standard. Potable groundwater, according to the national standards for drinking water supply, is derived from a depth of more than 100 meter. Over the past years, the groundwater level is decreasing about 1.5 meters per year forcing the waterworks to dig deeper by the year. Currently, there are no limiting regulations for groundwater withdrawal for the water works, and no organized groundwater recharge takes place in the area.

#### **9.2.1.2 Surface water**

In the area of Yang Song 3 rivers are located, with their springs in the northern mountain area. Chao Bai River at the east border of township, Huai River in the west and Yan Qi River. Figure 9-7 presents the dry riverbed of Chao Bai River. Currently all 3 riverbeds are dry. Yan Qi River is reported to have been dry since long time. The others run of water since approximately 1999, due to 3 dry years and the building of reservoirs in the upriver course. The Ruai Rou reservoir is located on the western side of Huai Rou city and the other reservoir is in Miyun County. Both have to guarantee the water supply for Beijing city and for the surrounding farmlands. However, increasing water demand for Beijing city means less for the surrounding county and their Townships.



**Figure 9-5** Dry riverbed of Chao Bai River in 2002 (Left)

**Figure 9-6** Dry riverbed of village (Right)

### 9.2.1.3 Rainwater

The climate in Beijing is semi-arid, with a cold, dry winter, low rainfall in spring and heavy rainfall during summer. The average precipitation is 600-700 mm per year, of which about 80 percent falls during June and September. The value is slightly higher than the Beijing city average, because of the mountains in the hinterland of Huai Rou County. In the whole township, rainwater is collected in rainwater pipes. In village areas the sewers are placed at one side of the smaller streets, and all the main streets in the town are sewered along both sides. The rainwater is transported and discharged into the nearby rivers or infiltrates into the ground. There are no specific applications and technologies for its further utilization, e.g. irrigation.

## 9.2.2 Current sanitation situation

### 9.2.2.1 Wastewater

Historically, the wastewater was discharged for a long time into the nearby river (for the town it was Yin Qi Rive) or infiltrates at the source. With the construction of the main roads and the coverage of new residential areas, wastewater and stormwater sewers were constructed.

#### **In the town**

Domestic wastewater from households, public facilities, public toilets and restaurants is collected in the sewer. There are 3 pipes, each with a diameter of 0.8 m, one for household wastewater only, one for storm water only, and the last one for combined wastewater or a storm water overflow. There are no facilities for the treatment of wastewater in Yang Song Township, not even the simplest treatment steps like screens, settlers, and sedimentation/collection tanks. The wastewater is now flowing from the existing pipes onto the fields next-door (see Figure 9-7). The field, which are used to cultivate corn and trees, are now flooded with wastewater, with a water level up to 20~30 cm.

### In the villages

Village households produce less wastewater, due to their lower fresh water consumption. There is no black water discharge. Wastewater from washing and cleaning, overspill from the toilet and other public facilities, is just flowing out of the house/courtyard and infiltrated into the ground (see Figure 9-8). There is no special drainage for this water, only an open gutter in the soil. Hence, there is no sewer or drainage system in most of the villages, though they are not connected to the main network.



**Figure 9-7** Wastewater discharge to field in the town (Left)

**Figure 9-8** Wastewater discharge to outside of the village house (Right)

### 9.2.2.2 Solid wastes

Before the implementation of the landfill construction, handling of municipal and village wastes was the same: organic wastes were mainly used to feed the pigs. Plastic waste and other leftovers were either brought to various wild disposal sites or burned with permission of the government.

#### In the town

Responsible for waste collection in the township is the Bureau of Sanitation. The waste collectors mainly have to clean the streets from dust, collect market refuse and to maintain and empty the public dustbins. In the town and the 4 associated villages, daily collection from households, public dustbins are brought to the landfill, about two kilometres northeast of the township. The landfill has been under operation since 1998. It covers a total area of 28 mu (1.87 ha).

### In the village

The households collect their solid wastes at home and have to bring it to the collection points, which can be found all over the village and with distances of about 300~400 m located to the streets. The waste mainly consists of organic waste, residues from food and courtyard farming. The waste would be collected and transported to the site of landfill every morning. Each village has a waste disposal site, located 1~2 km outside of the village. The site is an open pit with a size of about 5~6 mu and a depth of 4~6 meters.



**Figure 9-9** Landfill in the town (Left)

**Figure 9-10** Landfill in the village (Right)



### 9.3 Strategic proposal for new development

As a Model township, Yang Song has to reach or even to set economical and environmental standards. In order to attract further investments, first priority is to improve that urban infrastructure. In principle, further development should be handled through investment by the private sector. At present the Yang Song Government is offering to develop a construction-plan for a new housing area in the northwest of the township, namely **Feng Ri Yi** and **Feng Heng Yi** area. The total area is **1018 mu** ( $\approx$  **68 hectare**)<sup>1</sup>, the construction area is **400 mu** ( $\approx$  **27 hectare**). In this district, **3000** people are planned to be settled.



Figure 9-11 New model of YangSong development plan

#### 9.3.1 Key study objective

Strategically placed decentralized treatment systems can be a valuable component of a more sustainable approach to wastewater treatment. The evaluation of decentralized treatment options needs to consider the requirements and demand for recycled resources (water, nutrient, energy) in Yang Song Township. Constructions of a reclaimed water system provide benefits for irrigation and non-portable building uses (e.g. toilet flushing). This is a typical graph of decentralized wastewater system by establishing “satellite” decentralized plants. All the wastewater generated from Feng Ri Yi and Feng Heng Yi area will be transported to decentralized plants by small-diameter pipelines and treated on site. The following key assumption will be followed in the design of decentralized wastewater system in Feng Ri Yi and Feng Heng Yi area<sup>2</sup>:

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<sup>1</sup> 1 Mu = 1/15 hectare (ha)

<sup>2</sup> The following concept of Yang Song Township is referred Feng Ri Yi and Feng Heng Yi area.

### 9.3.2 Predicted quantity of organic solid waste

In Yang Song Township, around 1,500 kilogram organic solid waste is produced per day. The calculation is shown in Table 9-1.

**Table 9-1** Amount of organic solid waste produced in Yang Song Township

	Organic waste (kg/d*c)	Number of inhabitants	Organic waste amount (kg/d)
Production of solid waste	0.5	3,000	1,500

Assumption

- The inhabitants would produce 1,0 kg solid waste per day (Li, et.al, 2004).
- 50% solid waste is for organic solid waste is assumed.

### 9.3.3 Mass balance analysis for both scenarios

According to Wang (2003), the general mass balance for a system consists of several components and it describes the accumulations of mass in the system as function of mass input into the system, mass output from the system and mass transportation in the system:

**Accumulation = Input – Output – Transformation**

This principle is based on the neglect of the influences of groundwater and surface water. And it is based on the assumption that all infiltrated storm water can be consumed by the plants, also based on the assumption that there is no water/nitrogen/phosphorus loss during transformation processes, the meaning of each factor are described as following:

**For water flow balances:**

- The “Input” is described as the flow of supplied water.
- The “Output” is described as the flow of the discharged water.
- The “Transformation” is described as the water consumption of water by plants in Yang Song Township.
- The “Accumulation” term is zero, since only steady state situation is considered.

**For nitrogen (or phosphorus) balances:**

- The “Input” is described as the amount of nitrogen produced by inhabitants in Yang Song Township.
  
- The “Output” is described as the amount of nitrogen discharged in Yang Song Township.
- The “Transformation” is described as the amount by nitrogen consumed by plants in Yang Song Township.
  
- The “Accumulation” term is zero, since only steady state situation is considered.

Due to “Transformation” in Yang Song Township means the water/nitrogen/phosphorus is transformed into plants, the direction of “Transformation” is negative. The formula is corrected as follows:

**Output = Input – Transformation.**

## 9.4 Two scenarios for decentralized wastewater system in Yang Song Township

### 9.4.1 Introductions for both scenarios

#### 9.4.1.1 Predicted domestic water consumption in Yang Song Township

In chapter 9, two scenarios are designed. The first scenario is based on traditional “end-of-pipe” concept and all the wastewater flows are combined. After treatment the treated wastewater will be discharged to nearby Yan Qi River. The second scenario adopts the concept of decentralized wastewater management based on ecological sanitation, which means urine diversion toilets are needed to be installed in each household to realized source separation. After treatment, the treated greywater will be used for garden irrigation and the nutrients from yellow water and brown water (e.g., nitrogen and phosphorus) will be used as liquid/solid fertilizer in agriculture.

The average time of domestic water consumption activity in Yang Song Township are shown in Table 9-2. The domestic water consumption amount depends also on water equipment. That means if water saving equipments are used, the water consumption should be less than conventional one. Additionally, in both scenarios, the domestic water consumption amount should be different, because the different types of toilets would be equipped. The low-flush urine diversion toilets are recommended in scenario 2.

**Table 9-2** The estimated average times of different domestic water uses for inhabitant in Yang Song Township (time/capita\*day)

Activities	Drinking	Cooking	Urine flush	Faeces flush	Hand wash	Face clean	Bath/shower	Laundry	Other
Use of time	8	3	4	1	8	2	1	0.2	1

#### Explanation

- Average times for water consumption is assumed based on daily knowledge in China, such as: most of people need eat three times per day, take 4 urines and 1 faeces per day, clean hands after toilet and before eating, wash faces before and after the sleep, take showers/bath once per day, wash cloths once per week.
- Above „Cooking“ includes all activities related with cook, such as food cleaning, and dishes washing.



### 9.4.1.2 Quantity of storm water in Yang Song Township

#### Catchment's area for rainfall in Yang Song Township

There are two types of surface area in Yang Song Township: building area and open-space area, e.g., green field, garden and park. As shown in Table 9-3, the area of buildings is 27 ha (270,000 m<sup>2</sup>), the area of green-land is 41 ha (410,000 m<sup>2</sup>)<sup>1</sup>, and the total catchment's area distribution is 68 ha (680,000 m<sup>2</sup>).

**Table 9-3** The catchment's area distribution of Yang Song Township (m<sup>2</sup>)

	Buildings (m <sup>2</sup> )	Open space (m <sup>2</sup> )	Total (m <sup>2</sup> )
<b>Area</b>	270,000	410,000	680,000

#### Predicted quantity of storm water in Yang Song Township

The estimated amount of rainfall is around 435,200 m<sup>3</sup> per year in Yang Song Township (see Table 9-4).

**Table 9-4** Predicted quantity of rainfall in Yang Song Township (m<sup>3</sup>)

	A (m <sup>2</sup> )	p (mm/y)	r	Q (m <sup>3</sup> /y)	Q <sub>c</sub> (m <sup>3</sup> /y)
<b>Building area</b>	270,000	640	0.7	172,800	120,960
<b>Green-field, garden, park</b>	410,000	640	0.2	262,400	52,480
<b>Total</b>	680,000	640	-	<b>435,200</b>	<b>173,440</b>

#### Explanation

- The catchment's area (A) can be obtained from Table 9-3.
- The annual precipitation (p) in Beijing is 640 mm (Chapter 7).
- Run off coefficient (r) can be obtained from Table 9-5.
- Rainfall/catchment's storm water calculation equations are shown on below.

$$Q = A * p$$

Q: Estimated total amount of rainfall

A: Catchment's area

p: Annual precipitation

$$Q_c = A * r * p$$

Q<sub>c</sub>: Catchment's rainfall amount

A: Catchment's area

r: Run off coefficient

p: Annual precipitation

<sup>1</sup> 1ha = 10,000 m<sup>2</sup>

**Table 9-5** Run off coefficients for selected surfaces (Zhu, 1998)

Roof catchments	Run off coefficient	Ground catchments	Run off coefficient
Sheet metal	0.8~0.9	Concrete lined	0.75
Cement tile	0.6~0.7	Cement soil mix	0.3~0.4
Clay tile (machine-made)	0.3~0.4	Buried plastic sheet	0.3~0.35
Clay tile (hand-made)	0.25~0.3	Compacted soil	0.1~0.2

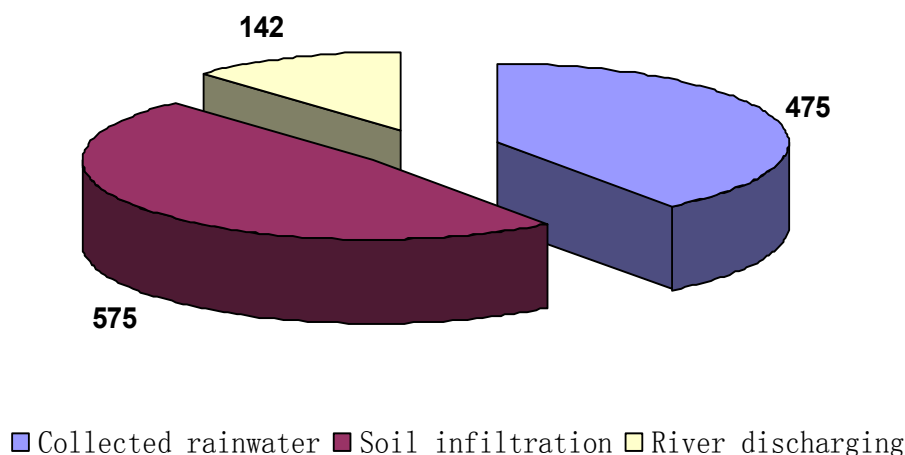
The rainfall catchment's area is the building area plus the open-space area (e.g. green filed, garden and park) in Yang Song Township. Therefore, the catchment's rainfall amount (collected rainwater or drainage water under the consideration of runoff coefficient) is **173,440** m<sup>3</sup>/year, which is equal to 120,960 m<sup>3</sup>/y in building area plus 52,480 m<sup>3</sup>/y in green-land area (see Table 9-4).

In the open-space area, most of storm water would infiltrate into soil. Based on ignoring the ground water influence, the infiltrated storm water is **209,920** m<sup>3</sup>/year, which is equivalent to  $Q$  (262,400 m<sup>3</sup>) minus  $Q_c$  (52,480 m<sup>3</sup>).

Except for catchment's storm water and infiltrated storm water, the rest is uncollected storm water – **51,840** m<sup>3</sup>/year, which is equal to total  $Q$  (172,800 m<sup>3</sup>/y) minus  $Q_c$  (120,960 m<sup>3</sup>/y). The uncollected storm water will be discharged into surface water directly or indirectly.

Therefore, the total storm water can be divided into three parts. Approximate 173,440 m<sup>3</sup>/year (40%) rainwater storm water could be collected by pipes in all building areas. Approximate 209,920 m<sup>3</sup>/year (48%) rainwater would infiltrate into the soil in green-land area, and another 51,840 m<sup>3</sup>/year (12%) would be discharged into the surface water body.

As shown in Figure 9-12, in order to simplify the calculation, assume the average daily rainfall equal annual rainfall divided by 365. That means there is **1,192** m<sup>3</sup>/day rainfall, including **475** m<sup>3</sup>/day collected storm water, **575** m<sup>3</sup>/day infiltrated storm water, **142** m<sup>3</sup>/day discharged storm water in Yang Song Township.



**Figure 9-12** The storm water distribution (m³/d)

#### 9.4.1.3 Predicted water consumption for garden irrigating in Yang Song Township

In general, the water quantity used for irrigating the garden and the irrigating frequency are varied by types of grass and flowers, also they are varied by seasons, and water irrigation habits. Therefore, average daily water consumption for garden irrigation would be used for calculation in this paper.

Based on average water consumption for garden irrigation is 35 m³/ha\*d (Waskom and Neibauer, 2005), **1,435** m³/day water are needed in the 41 ha open-space area (35 m³/ha\*d \* 41 ha = 1,435 m³/d) (see table 9-3). Fortunately, the infiltrated storm water could water garden as well as irrigating water. Thus approximately **860** m³/d irrigating water from municipal drinking water supply is only needed for green field. (Needed irrigating water from municipal drinking water supply = total water amount for irrigating garden – infiltrated storm water = 1,435 m³/d – 575 m³/d = 860 m³/d).

#### 9.4.1.4 Nitrogen production in Yang Song Township

As calculated in Table 9-7, approximate **43.5 kg/day** nitrogen, namely 15,878 kg/year nitrogen (=43.5 kg/d\*365d), can be produced in Yang Song Township.

According to the principle that garden area normally need nitrogen 100 kg/ha/y and agricultural area need 112 kg/ha/y (Pinsem and Winneras, 2003), 43.5 kg/d nitrogen (equal to 15,878 kg/year) can be used for **158.78** ha garden area or 141.77 ha agriculture area. Hence, around 5.3 kg nitrogen, which is produced by one habitant per year (see Table 9-6) ( $365 * 14.5\text{g/c}\cdot\text{d} = 5.3 \text{ kg}$ ), can be used for 530 m<sup>2</sup> garden area or 470 m<sup>2</sup> agriculture area.

As shown in Figure 9-13, around 76% nitrogen comes from urine (yellow water), while the faeces (brown water), the greywater, and the organic solid waste (bio-waste) are only contributing 10.3%, 3.4%, and 10.3% nitrogen respectively.

**Table 9-6** Characteristic of the main components of household wastewater (g/capita\*day) (Otterpohl et al, 2001)

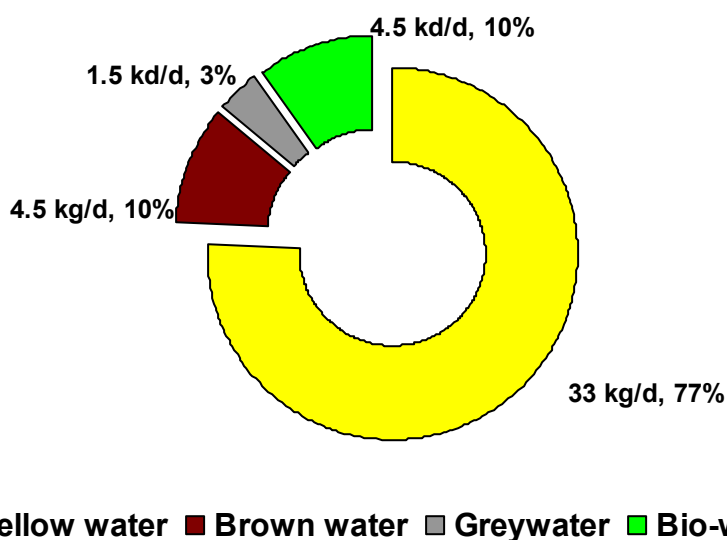
Loads (g/capita*day)	Yellow water	Brown water	Greywater	Biowaste	Total
Nitrogen (N)	11	1.5	0.5	1.5	14.5
Phosphorus (P)	1	0.5~0.8	0.2~0.5	0.3	2~2.6
Potassium (K)	2.5	0.6~1.0	1.6	0.2	4.9~5.3

**Table 9-7** The amount of human nitrogen production (kg/d)

Water types	Yellow water	Brown water	Greywater	Bio-waste	Total
<b>N-production</b>	33	4.5	1.5	4.5	<b>43.5</b>

#### Explanation

- The amount of nitrogen production per capita is shown in Table 9-6.
- The daily estimated amount of human nitrogen production (kg/d) = Unit load (g/capita\*day)(see Table 9-6) \* Number of inhabitants (3,000 inhabitants in Yang Song Township).



**Figure 9-13** Nitrogen production in Yang Song Township (kg/d)

#### 9.4.1.5 Phosphorus production in Yangsong Township

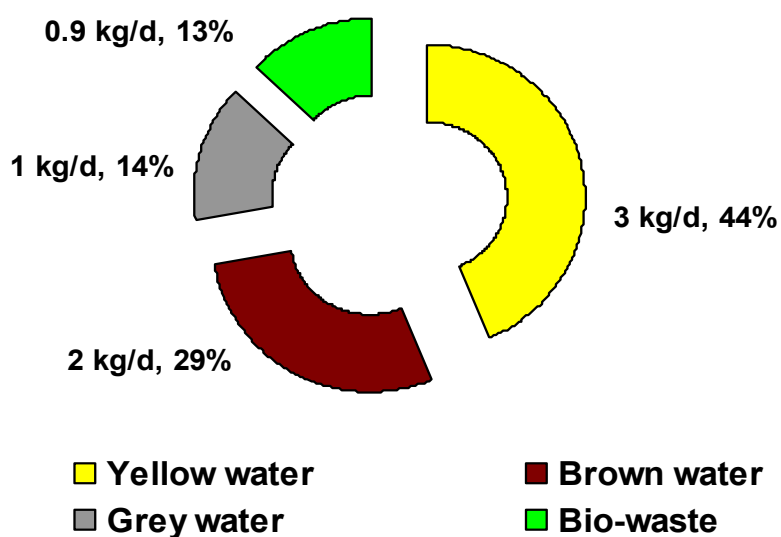
As calculated in Table 9-8, approximate **6.9 kg/day** nitrogen, namely 2.519 kg/year phosphorus (=6.9 kg/d\*365d), can be produced in Yang Song Township.

**Table 9-8** The amount of human phosphorus production (kg/d)

Water types	Yellow water	Brown water	Grey water	Bio-waste	Total
<b>P-Production</b>	3.0	2.0	1.1	0.9	6.9

#### Explanation

- The amount of phosphorus production per capita is shown in Table 9-6. And 0.65 g/capita\*d for brown water are 0.35 g/capita\*d for greywater are selected respectively.
- The daily estimated amount of human phosphorus production (kg/d) = Unit load (g/capita\*day)(see Table 9-6) \* Number of inhabitants (3,000 inhabitants in Yang Song Township).



**Figure 9-14** Phosphorus production in Yang Song Township (kg/d)

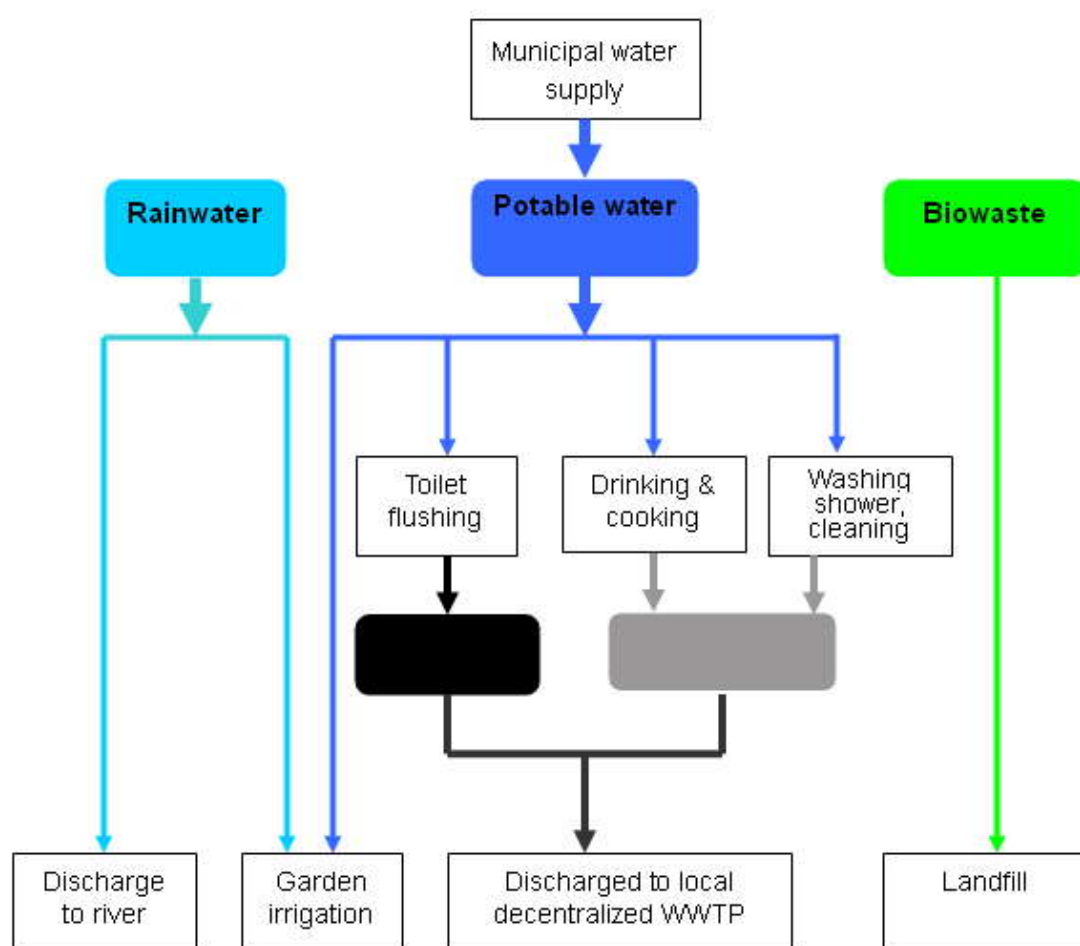
As shown in Figure 9-14, around 76% nitrogen comes from urine (yellow water), while the faeces (brown water), the greywater, and the organic solid waste (bio-waste) are only contributing 10.3%, 3.4%, and 10.3% nitrogen respectively.

According to the principle that garden area normally need nitrogen 100 kg/ha/y and agricultural area need 112 kg/ha/y (Pinsem and Winneras, 2003), and generally in northern China the N:P ratio is equal to 1:0.5, therefore 50 kg/h/y phosphorus are needed for garden area. 6.9 kg/d (equal to 2,518 kg/year) can be used for 25.18 ha garden area.

## 9.4.2 Scenario 1 – Conventional system

### 9.4.2.1 Design of water flow

The conventional system will be designed that the different types of household wastewater are mixed and then transported by small-diameter pipelines to decentralized facilities/plants. After primary and secondary treatment, treated wastewater will be discharged into the Yan Qi River. Storm water can be conveyed by storm water pipes to nearby streams or channels. These storm water pipes would be connected with the roof cutters of building and the surfaces of roads, pathways. As shown in Figure 9-15, besides using for drinking and cooking, the potable water is also used for toilet flushing, washing, shower and irrigation, while wastewater and storm water is discharged to the Yan Qi River.



**Figure 9-15** Schematic diagram for water flow of Scenario 1

### 9.4.2.2 Water flow balance

When a small community needs to choose a suitable treatment technology, they are required to get to know the local daily consumption of fresh water, and daily wastewater quality and quantity, and then compare to the design-flow of different technologies.

#### Predicted water consumption

The total volume of domestic water consumption is calculated in Table 9-10, and around 633 m<sup>3</sup>/d domestic potable water is needed in Yang Song Township.

**Table 9-9** Domestic unit water consumption for scenario 1 (litre/capita\*time)

Activities	Drinking	Cooking	Urine flush	Faeces flush	Hand wash	Face cleaning	Bath/shower	Laundry	Other
Volume	0.25	5	9	9	2	3	100	60	15

Explanation

- Based on Trifunovic (2003), the domestic unit water consumption is assumed as shown above.
- Above "cooking activity" includes the food preparation and dish washing.
- Above "other" is un-mentioned water consumption in this table.

**Table 9-10** Water consumption for domestic use in scenario 1 (litre/capita\*day)

Activities	Drinking	Cooking	Urine flush	Faeces flush	Hand wash	Face cleaning	Bath/shower	Laundry	Other	Total
Volume	2	15	36	9	16	6	100	12	15	<b>211</b>

Explanation;

- The water consumption for each activity (litre/capita\*day) = Domestic unit water consumption (litre/capita\*time) \* times of each activity (time/capita\*day).
- Domestic unit water consumption is based on Table 9-9.
- Times of each activity are shown in Table 9-2.



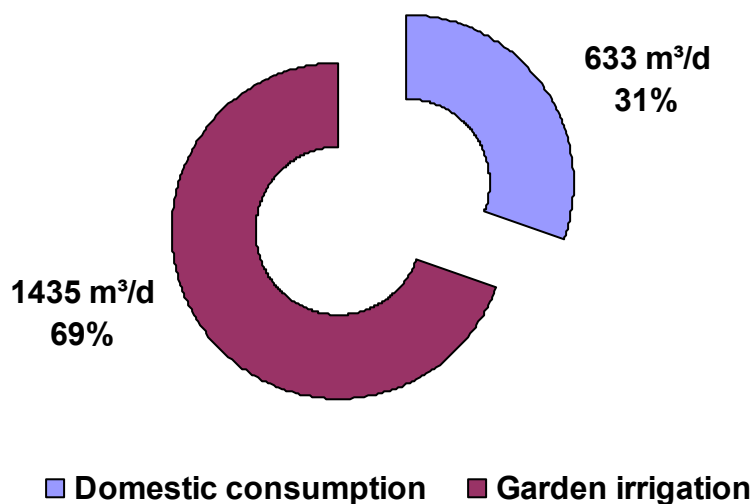
**Table 9-11** Domestic water consumption for scenario 1 (m<sup>3</sup>/day)

Number of inhabitants	Domestic water quantity (litre/capita*day)	Total water quantity (m <sup>3</sup> /day)
3,000	211	633

Explanation:

- Domestic water quantity per person comes from Table 9-10.
- Total water quantity (m<sup>3</sup>/day) = Number of inhabitants \* Domestic water quantity (litre/capita\*day).

Compared with domestic uses, the water consumption for garden irrigation would be much higher than domestic water. As shown in section 9.4.1.3, around **1,435 m<sup>3</sup>/day** potable water for garden irrigation is needed. Hence, the water consumption pattern in Yang Song Township is drawn in Figure 9-16.



**Figure 9-16** Estimated distribution of total consumption for scenario 1 in Yang Song Township (m<sup>3</sup>/d)

**Predicted wastewater production quantity and quality**

Estimated wastewater production quantity is 633 m<sup>3</sup>/day, which is equal to the domestic water consumption. The typical wastewater includes all domestic wastewater for toilet flushing, face & hand cleaning, shower/bath, clothes washing, cooking, dish washing and room cleaning.

The wastewater quality of Yang Song Township is calculated as following Table 9-11, based on the assumption of 633 m<sup>3</sup>/day wastewater production and daily 3,000 PE (the unit of Population Equivalent expresses the volume of wastewater produce, 1 PE is equal to daily 80g COD, 60g BOD<sub>5</sub>, 70g TSS, 13g TN, 2g TP (Lens *et al.*, 2001)).

**Table 9-12** Estimated wastewater quality in Yang Song Township for scenario 1 (mg/l)

Parameters	COD	BOD <sub>5</sub>	TSS	TN	TP
<b>Wastewater quality (Yang Song Township)</b>	<b>379</b>	<b>284</b>	<b>332</b>	<b>62</b>	<b>9</b>
Concentrated domestic wastewater	560	350	450	80	23
Pre-treated household wastewater (typical)	500	210	210	35	7
Pre-treated household wastewater (range)	250~1000	110~400	100~350	20~85	4~15

## Explanation

- The calculation of estimated wastewater quality in Yang Song Township (mg/l) = PE (3,000) \* Parameter (g) / Total wastewater quantity (633 m<sup>3</sup>/day)
- Concentrated domestic wastewater is based on Lens *et al.*, 2001
- Pre-treated household wastewater (typical) is based on Crites, 1998
- Pre-treated household wastewater (range) is based on Crites, 1998

### **Water flow balance**

The water flow balance explanation for scenario 1 is presented as below:

- The input water flow is 2,685 m<sup>3</sup>/d, including 1,493 m<sup>3</sup>/d from municipal water supply and 1,192 m<sup>3</sup>/d storm water flow.
- The output flow is 1,250 m<sup>3</sup>/d, including 633 m<sup>3</sup>/d wastewater and 617 m<sup>3</sup>/d uncollected storm water.
- The transformation water flow is 1,435 m<sup>3</sup>/d, which is consumed by the plants in Yang Song Township.

The details are drawn in Figure 9-17 and explained is as following.

As shown in Figure 9-16, the total water consumption for garden irrigation is approximate 1,435 m<sup>3</sup>/d. The infiltrated storm water could contribute to 575 m<sup>3</sup>/d (see Figure 9-12). Therefore, the municipal water supply needs to offer 860 m<sup>3</sup>/d for garden irrigation (= 1435 m<sup>3</sup>/d - 575 m<sup>3</sup>/d).

As presented in Figure 9-16, the total water consumption for domestic use is around 633 m<sup>3</sup>/d, and the municipal supply for garden irrigation is 860 m<sup>3</sup>/d, therefore the total municipal supply would be 1,493 m<sup>3</sup>/d.

As a consequence, there are two types of water input, including 1,493 m<sup>3</sup>/d potable water from municipal water supply and 1,192 m<sup>3</sup>/d from rain water flow (see Figure 9-12).

And the output water flow is 1,250 m<sup>3</sup>/d, including 633 m<sup>3</sup>/d from wastewater flow and 617 m<sup>3</sup>/d from uncollected rainwater that will be discharge into river.

### **Nitrogen flow balance**

There are around 43.5 kg nitrogen is produced in Yang Song Township per day (see Figure 9-14). 39 kg nitrogen mixed with wastewater is discharged to decentralized treatment plant. After primary and secondary treatment, the effluent is discharged into Yan Qi River, and the sludge is used for agriculture.

Additionally, 4.5 kg nitrogen coming from organic solid bio-waste is conveyed to local solid wastewater treatment plant and then is filled in the land.

Figure 9-18 presents the nitrogen balance flow in Yang Song Township. In summary, there is no nitrogen recycled for scenario 1 in Yang Song Township.

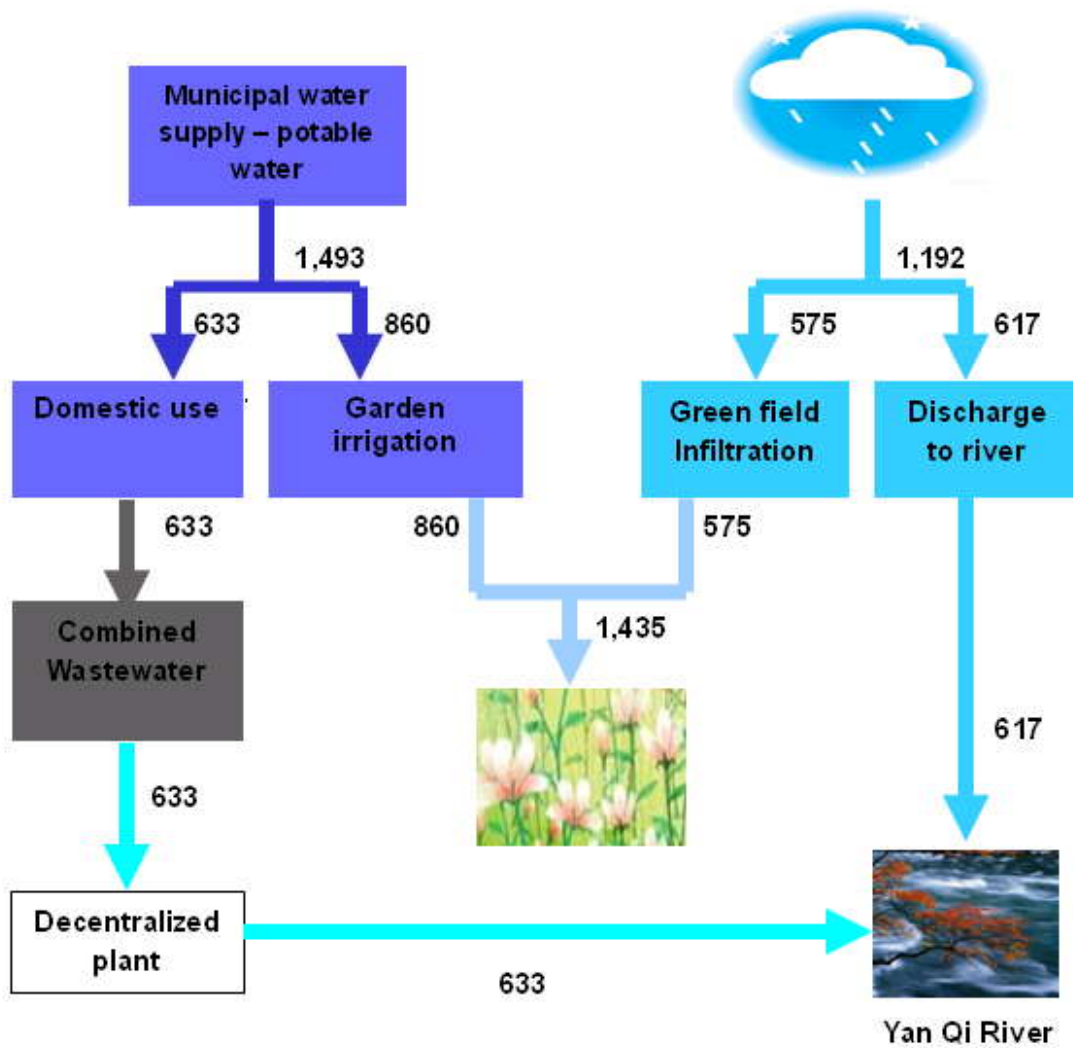
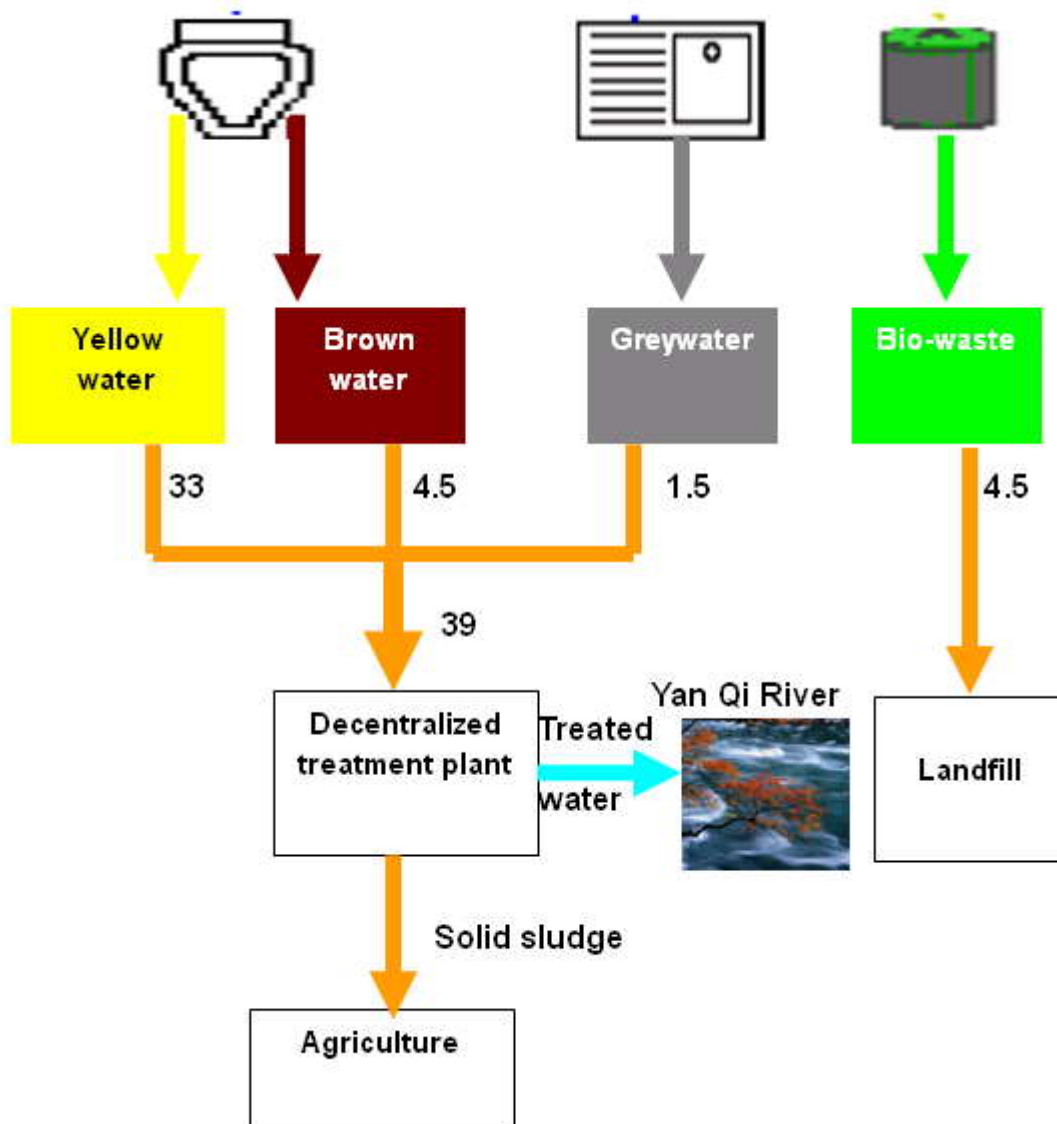


Figure 9-17 Water flow balance for scenario 1 in Yang Song Township (m<sup>3</sup>/d)



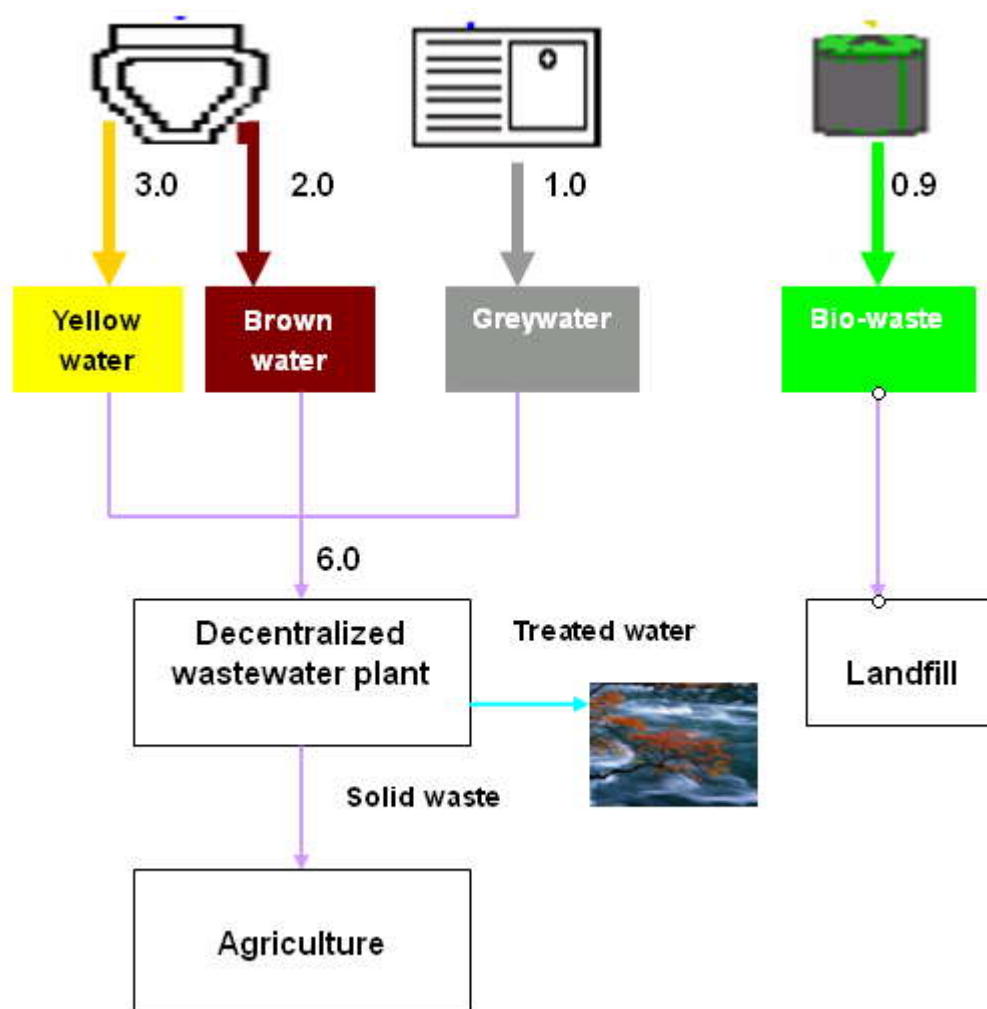
**Figure 9-18** Nitrogen balance in Yang Song Township for scenario 1 (kg/d)

### Phosphorus flow balance

There are around 6.9 kg phosphorus is produced in Yang Song Township per day (see Figure 9-14). 6.0 kg phosphorus mixed with wastewater is discharged to decentralized treatment plant. After primary and secondary treatment, the effluent is discharged into Yan Qi River, and the sludge is used for agriculture.

Additionally, 0.9 kg phosphorus coming from organic solid bio-waste is conveyed to local solid wastewater treatment plant and then is filled in the land.

Figure 9-19 presents the nitrogen balance flow in Yang Song Township. In summary, there is no nitrogen recycled for scenario 1 in Yang Song Township.



**Figure 9-19** Phosphorus balance in Yang Song Township for scenario 1 (kg/d)

### 9.4.3 Scenario 2 – Ecological sanitation

#### 9.4.3.1 Proposal design

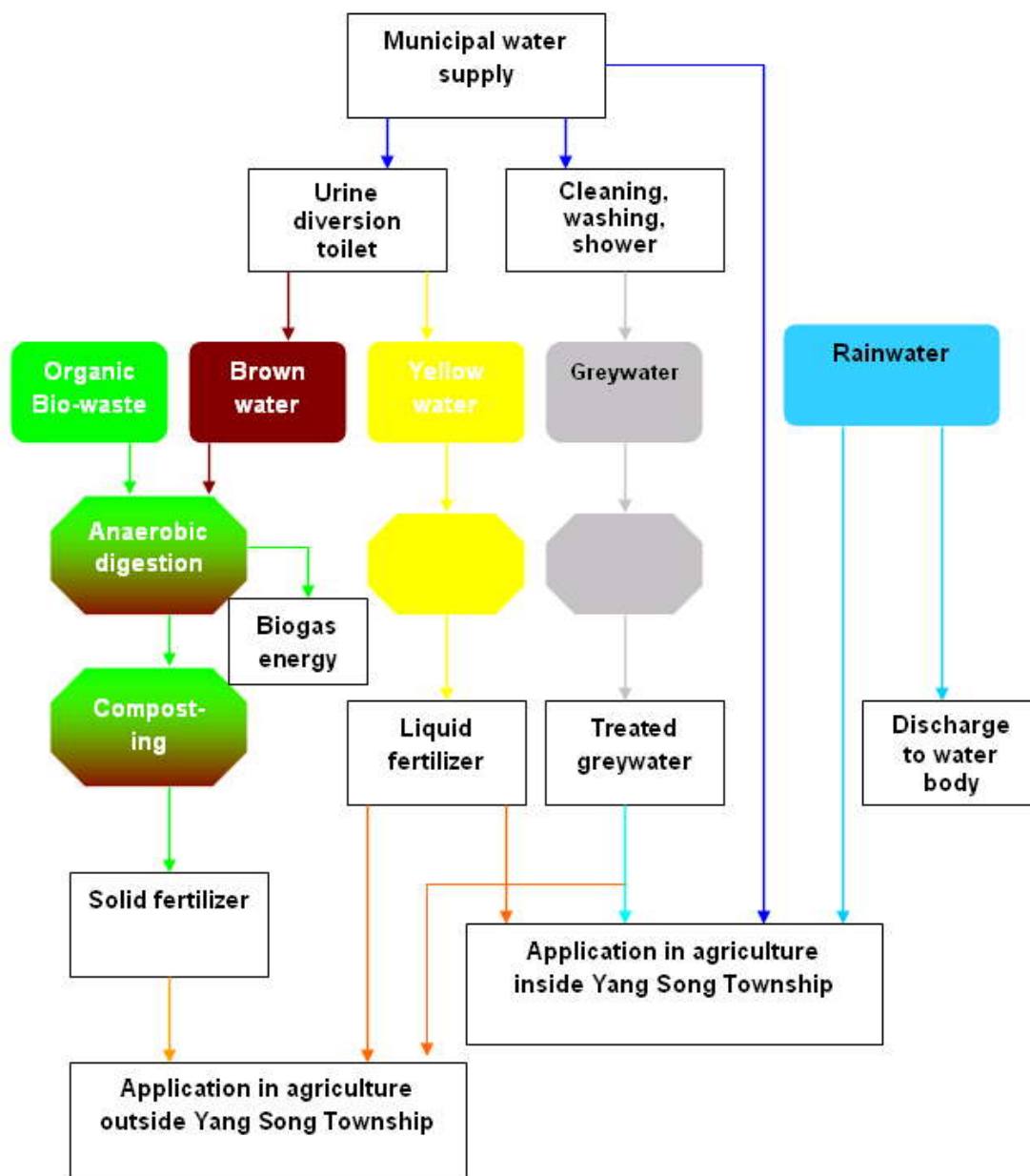
In order to achieve ecological wastewater management, a closed-loop treatment system is recommended. The traditional linear treatment systems should be transformed into the cyclical treatment to promote the conservation of water and nutrient resources. The development of ecological wastewater management strategies will contribute to the reduction of pathogens in surface and groundwater to improve public health. Source control and reuse of treated wastewater is the basic prerequisite for sustainable wastewater development. Sustainable concept listed below will mostly have to leave the path of traditional wastewater management:

- Source separation of black water as basic step towards flexibility.
- Adequate treatment and utilization of the waste and wastewater contents.
- Integration of agriculture as service provider (treatment, transport) and as users of the end product.
- Connection to energy concepts. Utilization of the energy content of black water and bio-waste, loss of energy by aeration of composting toilets, energy needed for aerobic treatment.
- Reutilization of separated flows (e.g. rainwater as groundwater-recharging and laundry water, treated greywater for toilet flushing).

An applied strategy for ecological sanitation in practice is based on a separate collecting, treating and reuse the different wastewater flows to optimize the potential for reuse and for cost-efficient solutions. Separate collection and treatment of wastewater streams simplifies the treatment process, while increasing opportunities for beneficial reuses, whereas flush-toilets contribute the highest volume of water to the waste stream.

Scenario 2 for the sustainable sanitation system, under the EcoSan system there will be a „Wastewater Processing Facility” (WWPF). The WWPF is a treatment center for yellow-, brown-, greywater and green bio-waste. All types of wastewater in Yang Song Township are conveyed to WWPF, and then are treated to reclaim or discharge into water body. The WWPF is composed of a yellow water storage tank, a brown water digestion/composting plant and a grey water treatment plant (namely constructed wetlands). Although the WWPF is a wastewater treatment place, it would look totally different to the conventional wastewater treatment plant.

Figure 9-20 presents the schematic diagram of wastewater management systems based on ecological sanitation in Yang Song Township.



**Figure 9-20** Schematic diagram of wastewater management systems based on ecological sanitation in Yang Song Township



### 9.4.3.2 Water flow balance

#### Predicted water consumption

The total volume of domestic water consumption is divided into two parts: 51m<sup>3</sup>/d potable water, and 465 m<sup>3</sup>/d non-portable water (see Table 9-16)

Table 9-13 illustrates flush water consumption daily per capita of different types of toilet. EcoSan toilets can be “dry” or “wet” (with flush water). Based on literature review, “wet” toilets are focused, because these will be more acceptable for the users. On the contrary, “Dry” toilets have the disadvantage that ash or lime has to be added after defecation to remove moisture.

Table 9-14 presents domestic unit consumption for scenario 2. And Table 10-15 shows the daily water consumption in scenario 2 is 172 litre/capita\*day.

**Table 9-13** Flush water consumption daily per capita of different types of toilet (Otterpohl, 2001)

Toilet types	Conventional without water saving measurement	Urine diversion toilets with low flush	Dry toilet without flush
Water consumption per flush faeces (l/time)	9	5	0
Water consumption per flush urine (l/time)	9	0.15	0.1
Water amount (l/c*d)	45	5.6	0.4

**Table 9-14** Domestic unit water consumption for scenario 2 (litre/capita\*time)

Activities	Drinking	Cooking	Urine flush	Faeces flush	Hand wash	Face cleaning	Bath/shower	Laundry	Other
Volume	0.25	5	<b>0.15</b>	<b>5</b>	2	3	100	60	15

## Explanation

- Based on Trifunovic (2003), the domestic unit water consumption is assumed as shown above.
- According to urine diversion toilet, toilets flushing water consumption is 0.15l/flush for urine, 5l/flush for faeces (Table 9-13).
- Above “cooking activity” includes the food preparation and dish washing.
- Above “other” is un-mentioned water consumption in this table.

**Table 9-15** Water consumption for domestic use in scenario 2 (litre/capita\*day)

Activities	Drinking	Cooking	Urine flush	Faeces flush	Hand wash	Face cleaning	Bath/shower	Laundry	Other	Total
Volume	2	15	<b>0.6</b>	<b>5</b>	16	6	100	12	15	<b>172</b>

## Explanation

- The water consumption for each activity (litre/capita\*day) = Domestic unit water consumption (litre/capita\*time) \* times of each activity (time/capita\*day).
- Domestic unit water consumption is based on Table 9-14.
- Times of each activity are shown in Table 9-2.

**Table 9-16** Potable and non-potable water consumption for scenario 2 (m<sup>3</sup>/d)

	Number of inhabitants	Potable water		Non-potable water	
		(l/c*d)	(m <sup>3</sup> /d)	(l/c*d)	(m <sup>3</sup> /d)
Water consumption	3,000	17	<b>51</b>	155	<b>465</b>

## Explanation

- Potable water (l/c\*d) = drinking water (l/c\*d) + cooking water (l/c\*d) (see Table 9-15).
- Non-potable water (l/c\*d) = Total (l/c\*d) – Potable water (l/c\*d) (see Table 9-15).
- Potable/non-potable water (m<sup>3</sup>/d) = Potable/non-potable water (l/c\*d) \* Number of inhabitants.

### Predicted yellow-, brown- and greywater production quantity and quality

Based on the assumption calculated in Table 9-18, the total yellow, brown and greywater is estimated at 6 m<sup>3</sup>/d, 15.42 m<sup>3</sup>/d and 492 m<sup>3</sup>/d respectively.

**Table 9-17** Domestic wastewater production for scenario 2 (litre/capita\*day)

	Yellow water	Brown water	Greywater
<b>Domestic wastewater production</b>	2.0	5.14	164

#### Explanation

- The assumption that the volume of pure urine and faeces in 500 litre and 50 litre per capita per year (Otterpohl, 2001), also assume 4 urine and 1 faeces per capita per day, therefore pure urine and faeces amount is 0.34 litre/capita\*time (500liter/365/4), 0.14 litre/capita\*time (50liter/365).
- Yellow water (0.49 litre/capita\*time) = Pure urine (0.34 litre/capita\*time) + urine flush water (0.15 litre/capita\*time) (see Table 9-14)
- Brown water (5.14 liter/capita\*time) = Pure faeces (0.14 liter/capita\*time) + faeces flush water (5 liter/capita\*time) (see Table 9-14)
- Times of each activity come from Table 9-2.
- The yellow-/brown water production (litre/capita\*day) = yellow-/brown water production (litre/capita\*time) \* times of each activities (time/capita\*day).
- The greywater quantity (litre/capita\*day) = Total water consumption (litre/capita\*day) – urine flush water (litre/capita\*day) – faeces flush water (litre/capita\*day) – drinking water (litre/capita\*day) (172-5-0.6-2=164 litre/capita\*day) (see Table 9-15).

**Table 9-18** Domestic wastewater production for scenario 2 (m<sup>3</sup>/d)

	Number of inhabitants (c/d)	Yellow water quantity (m <sup>3</sup> /d)	Brown water quantity (m <sup>3</sup> /d)	Grey water quantity (m <sup>3</sup> /d)
<b>Wastewater production</b>	3,000	6	15.42	492

#### Explanation

- Domestic wastewater production per person comes from Table 9-17.
- Total wastewater production (m<sup>3</sup>/d) = Number of inhabitants (c/d) \* domestic wastewater production per person (l/c\*d).

The wastewater quality of Yang Song Township for scenario 2 is predicted as following Table 9-19, based on the calculation of 492 m<sup>3</sup>/d greywater production (see Table 9-18), and also based on the assumption of daily 3,000 PE ((The unit of Population Equivalent expresses the volume of greywater produce, 1 PE is equal to 55g COD, 35g BOD<sub>5</sub>, 45g TSS, 0.5g TN, and 0.3g TP, (Lens *et al.*, 2001)).

**Table 9-19** Estimated greywater quality in Yang Song Township for scenario 2 (mg/l)

Parameters	COD	BOD <sub>5</sub>	TSS	TN	TP
Greywater	335	213	274	3.0	1.8
Domestic wastewater	200~700	100~400	-	8~30	2~7

Explanation

- Estimated greywater quality (mg/l) = 3,000 \* Unit of population Equivalent (e.g. 55g COD, 35g BOD<sub>5</sub>) / 492 m<sup>3</sup>/d.
- Above "Domestic wastewater" is based on Lens *et al.*, 2001.

### Water flow balance

Water flow balance explanation for scenario 2 is presented:

- The input water flow is 1,708 m<sup>3</sup>/d, including 516 m<sup>3</sup>/d water flow from municipal water supply and 1,192 m<sup>3</sup>/d storm water flow.
- The output water flow is around 270.42 m<sup>3</sup>/d, including 142 m<sup>3</sup>/d uncollected storm water flow, approximate 21.42 m<sup>3</sup>/d water flow from yellow water and brown water, and 107 m<sup>3</sup>/d treated greywater.
- The transformation water flow is 1,435 m<sup>3</sup>/d, which is consumed by the plants in Yang Song Township.

The details are drawn in Figure 9-21. Explanation is as following.

As presented in Table 9-16, the potable water consumption in scenario 2 is 51 m<sup>3</sup>/d. Also from Table 9-17, the domestic wastewater water quantity for yellow-, brown- and greywater is 6 m<sup>3</sup>/d, 15.42 m<sup>3</sup>/d and 492 m<sup>3</sup>/d.

The total water demand for garden irrigation is 1,435 m<sup>3</sup>/d (see Chapter 9.4.1.3), apart from the infiltration amount 575 m<sup>3</sup>/d (see Chapter 9.4.1.2), approximate 860 m<sup>3</sup>/d water is still needed, which can be supplied by treated greywater 492 m<sup>3</sup>/d and collected rainwater 475 m<sup>3</sup>/d. Therefore, around excessively 107 m<sup>3</sup>/d (= 492 m<sup>3</sup>/d + 475 m<sup>3</sup>/d - 860 m<sup>3</sup>/d) treated water will be discharged in Yan Qi River.

According to Table 9-15, around 516 m<sup>3</sup>/d (172 l/c\*d \*3,000c) potable water is need for Yang Song Township for daily consumption. Since total rainfall is 1,192 m<sup>3</sup>/d, the total input flow is therefore 1,708 m<sup>3</sup>/d (=516 m<sup>3</sup>/d+1,192 m<sup>3</sup>/d).

The output water flow is around 270.42 m<sup>3</sup>/d, including 142 m<sup>3</sup>/d from uncollected rainwater (see Figure 9-12), around 21.42 m<sup>3</sup>/d from yellow water and brown water (see Table 9-18), and 107 m<sup>3</sup>/d treated water that will be discharged in Yan Qi River.

The total transformation flow is 1,435 m<sup>3</sup>/d, which consists of 575 m<sup>3</sup>/d infiltration flow from rainwater, 492 m<sup>3</sup>/d treated greywater from decentralized plant, 368 m<sup>3</sup>/d (= 475 m<sup>3</sup>/d -107 m<sup>3</sup>/d)collected storm water. The transformed flows are used for garden irrigation inside Yang Song Township.

In scenario 2, all types of wastewater are separated at source, and then are sanitized. Hence, yellow, brown and greywater is treated and discharged respectively. As shown in Table 9-18, 6 m<sup>3</sup>/d, 15.42 m<sup>3</sup>/d and 492 m<sup>3</sup>/d of yellow-, brown- and greywater is produced. The yellow and brown water is treated in anaerobic process after sanitation. They could be used as liquid or solid fertilizer for inside and outside Yang Song Township, while the greywater is treated by constructed wetlands before reuse for garden irrigation.

In summary, there are water reuses in scenario 2. The greywater is reused for garden irrigation after treatment, while yellow- and brown water is reused for liquid and solid fertilizer.

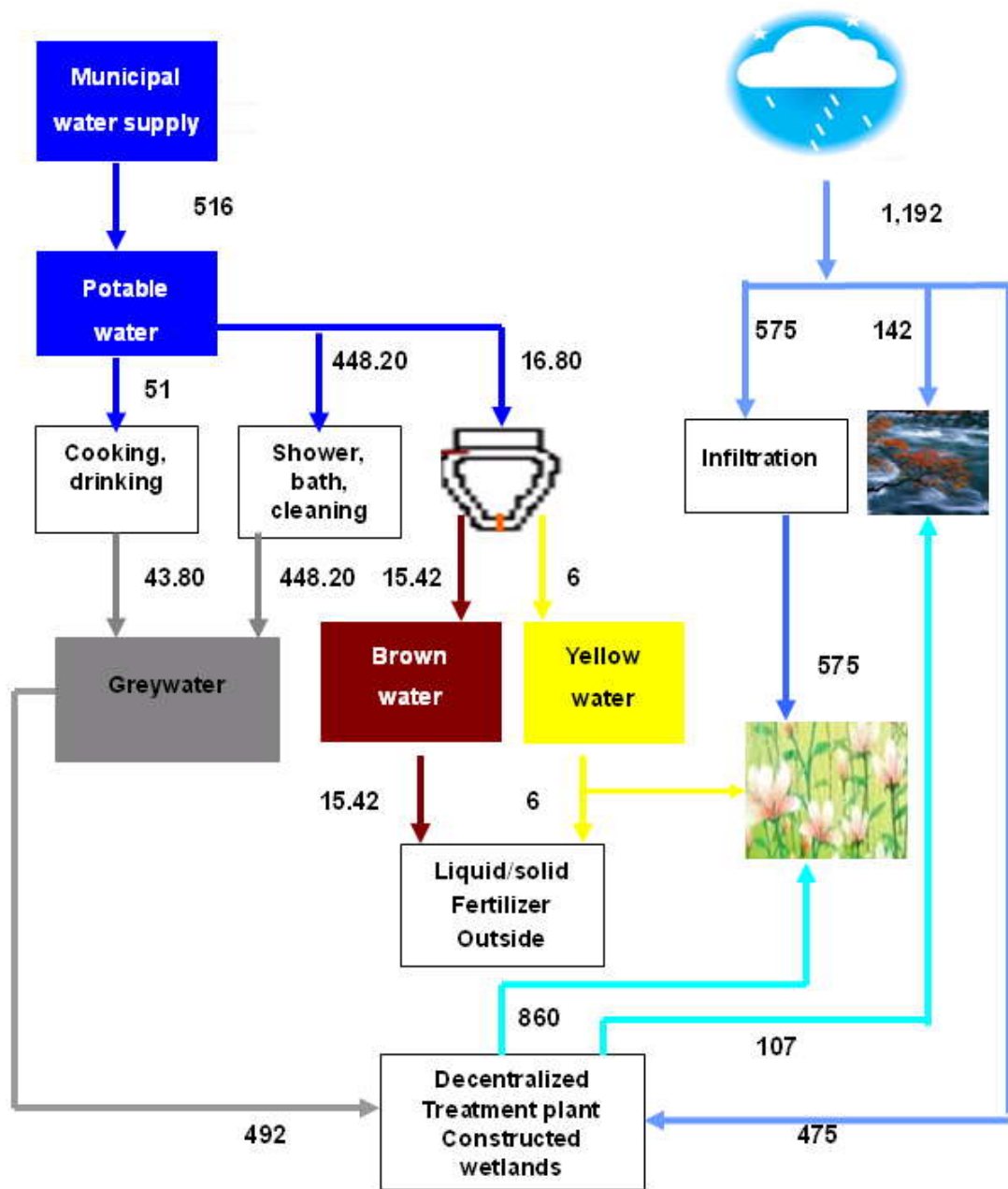


Figure 9-21 Water flow balance in Yang Song Township for scenario 2 (m<sup>3</sup>/d)

### Nitrogen balance

The EcoSan concept emphasizes the recovery of nutrients from the urine, faecal sludge, greywater and organic solid waste. The nutrients benefit local agriculture and to a certain degree can substitute artificial fertilizer. Ideally EcoSan systems enable the complete recovery of all nutrients from wastewater.

In Yang Song Township, only the nitrogen and phosphorus balance is discussed, because nitrogen is the main nutrient from wastewater and organic waste.

Nitrogen balance for scenario 2 is explained as follows:

- The input nitrogen amount is 43.5 kg/d (see Table 9-7), including 33 kg/d nitrogen from urine, 4.5 kg/d from faeces, 1.5 kg/d from greywater and 4.5 kg/d from bio-waste.
- The output nitrogen amount is around 31.27 kg/d nitrogen, including 9 kg/d from solid fertilizer (from both brown water and bio-waste), and 23.27 kg/d liquid fertilizer from urine.
- The transformation nitrogen is 11.23 kg/d (from treated greywater and partial yellow water), which will be consumed by garden plants in Yang Song Township.

The detail is drawn in Figure 9-22. And explanation is as following. As calculated in section 9.4.1.4, 43.5 kg/d nitrogen that is produced in Yang Song Township can be used for 158.78 ha garden-area irrigation.

There are around 41 ha open space (e.g., green-field, garden, part) in Yang Song Township (see Table 9-3). According to the principle that garden area normally need nitrogen 100 kg/ha/y (Pinsem and Winneras, 2003), the green-field inside Yang Song Township require approximately 11.23 kg/d (26%) nitrogen ( $=100 \times 41 / 365$ ). These amounts of nitrogen can be achieved from yellow water. And the rest of amount of nitrogen will be distributed to outside nearby for irrigation, which includes brown water 4.5 kg/d, greywater 1.5 kg/d, bio-waste 4.5 kg/d and yellow water 21.77 kg/d ( $33 \text{ kg/d} - 11.23 \text{ kg/d} = 21.77 \text{ kg/d}$ )

Figure 9-23 presents the nitrogen distribution for scenario 2.

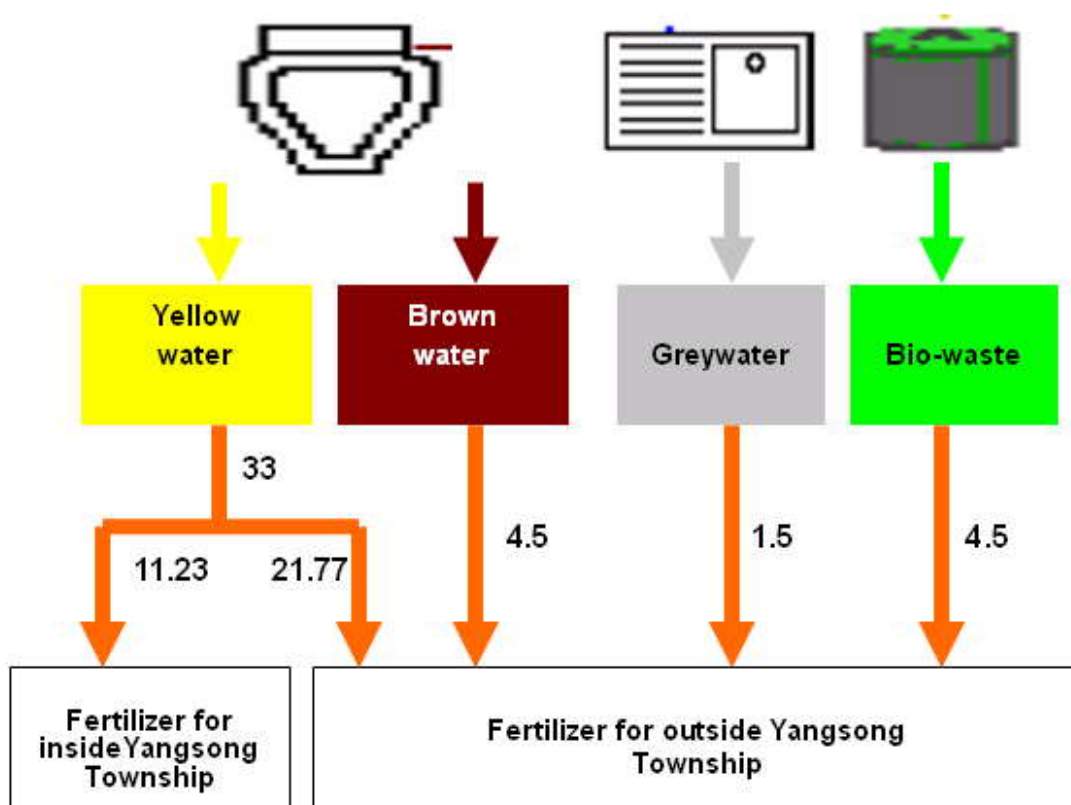


Figure 9-22 Nitrogen balance in Yang Song Township for scenario 2 (kg/d)

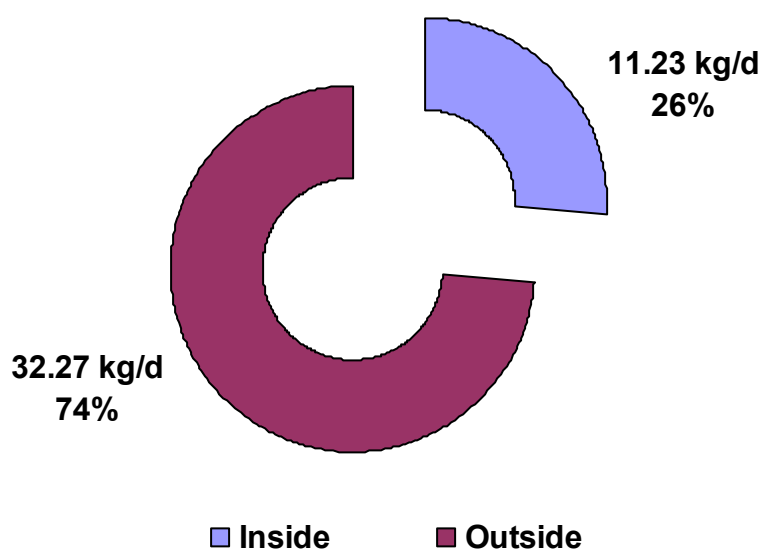


Figure 9-23 Nitrogen consumption distribution for scenario 2 (kg/d)



### Phosphorus balance

Phosphorus balance for scenario 2 is explained as follows:

- The input phosphorus amount is 6.9 kg/d (see Table 9-8), including 3.0 kg/d phosphorus from urine, 2.0 kg/d from faeces, 1.0 kg/d from greywater and 0.9 kg/d from bio-waste.
- The output amount is around 1.28 kg/d phosphorus, which comes from greywater and bio-waste and will be reused as fertilizer outside Yangsong Township.
- The transformation phosphorus is 5.62 kg/d, which comes from yellow water, brown water and greywater and will be consumed by garden plants in Yang Song Township.

The detail is drawn in Figure 9-24. And explanation is as following.

There are around 41 ha open space (e.g., green-field, garden, part) in Yang Song Township (see Table 9-3). According to the principle that garden area normally need nitrogen 100 kg/ha/y (Pinsem and Winneras, 2003), and generally in northern China the N:P ratio is equal to 1:0.5, therefore 50 kg/h/y phosphorus are needed for garden area. 6.9 kg/d (equal to 2,518 kg/year) can be used for 25.18 ha garden area (see section 9.1.1.5).

Therefore, the green-field inside Yang Song Township require approximately 5.62 kg/d phosphorus ( $=50 \times 41 / 365$ ). These amounts of nitrogen can be achieved from yellow water, brown water and greywater. And the rest of amount of phosphorus will be distributed to outside nearby for irrigation ( $6.90 \text{ kg/d} - 5.62 \text{ kg/d} = 1.28 \text{ kg/d}$ )

Figure 9-25 presents the phosphorus distribution for scenario 2.

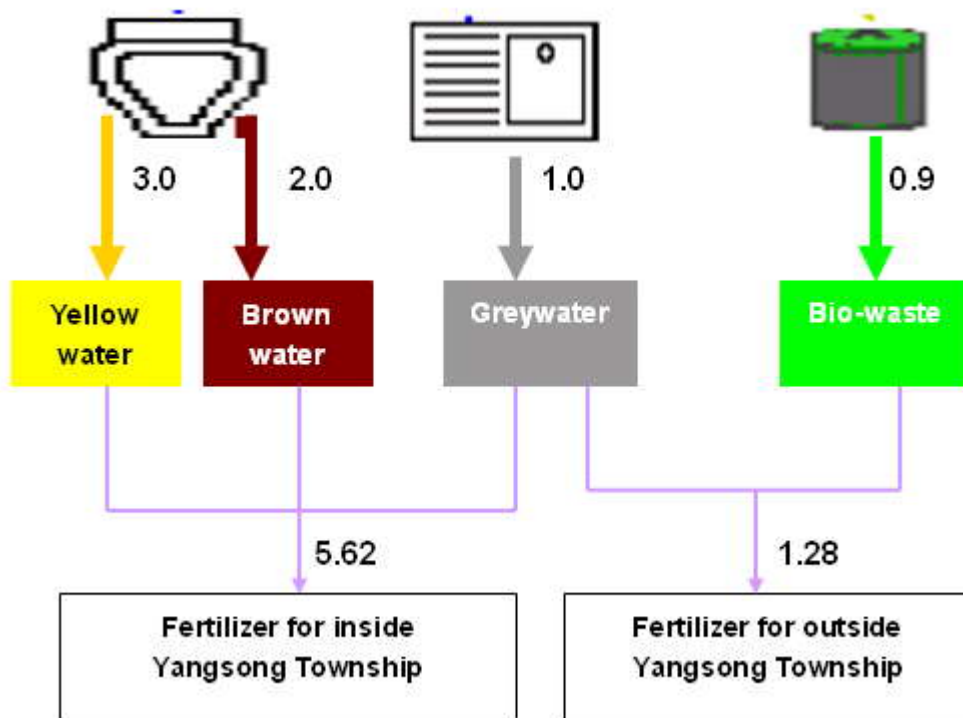


Figure 9-24 Phosphorus balance in Yang Song Township for scenario 2 (kg/d)

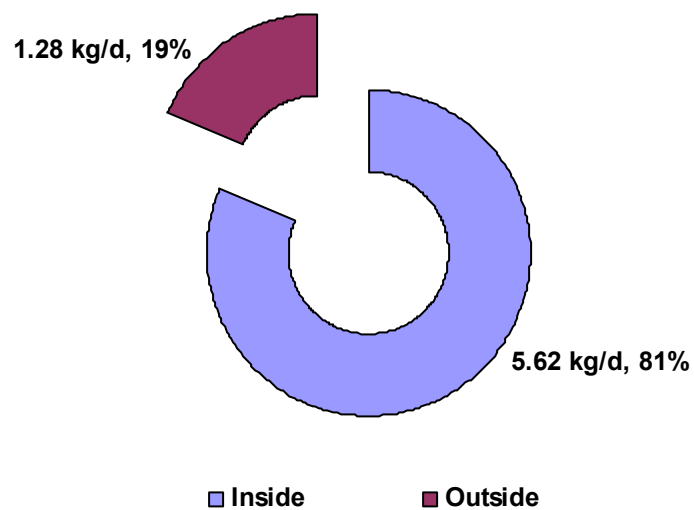


Figure 9-25 Phosphorus consumption distribution for scenario 2 (kg/d)

### 9.4.3.3 Construction and implementation

New urban development is to be found when new dwellings or development areas are being constructed either by the authorities (national, regional or local government) or by private developers (these are normally private businesses, but may sometimes also include citizens groups who wish to build their own homes in an ecological way). The dwellings come equipped with EcoSan systems, and these systems are therefore considered from early on in the planning stage, facilitating considerably the consideration of all relevant aspects of town planning, land use, urban agriculture, and management. Because of the urban location and the favourable planning conditions, all the treatable resources (urine, faeces, grey water, rainwater and organic waste) may be integrated into these sanitation systems.

#### **Recommended sanitation technologies:**

➤ *Yellow water*

Urine diversion toilets are proposed for Yang Song Township. All urine is collected from each toilet and piped separately to the collection tank, from where the urine mixture is transported to the storage tank and kept long enough to be sanitised and reused in agriculture. Urine tanks are put in the basements of each building and connected with urine pipes. Every week, the urine would be emptied and conveyed to Wastewater Processing Facilities (WWPF). In WWPF, there are special urine storage tanks to store urine around 6 months before irrigation as liquid fertilizer. This can provide a simple collection of urine and treatment possible.

➤ *Brown water*

With the sorting toilet, faeces are flushed with 5 l water to the faeces tank, where the solid and liquid phase are separated and treated separately. In Yang Song Township, the faeces just like urine, can be collected by indoor brown water pipes, and then stored in faeces tank for one week before transported by faeces truck to WWPF. In WWPF, faeces are anaerobic digested or composted with the organic solid waste.

Anaerobic digestion is being considered as a promising approach for brown water combined with bio-waste, due to many benefits, e.g., low energy demand, low investment costs and low space requirements, and low production of excess sludge. The most important of all, the end-product methane can be reused as an alternative energy source (biogas), which is beneficial for heat and power generation.

➤ Storm water design

In scenario 2, the storm water in Yang Song Township can be collected from the roof cutters of each building or surface roads. Even if storm water can be regarded relative clean, it can also be contaminated by roofs and gutters made from zinc-plated metal or copper, as well as air pollution. After filtration and treatment in the constructed wetlands, the storm water is reclaimed to irrigate garden, park and green-fields in Yang Song Township.

➤ Greywater

In Yang Song Township, greywater can be transported by greywater sewerage to WWPF, and then passed through screen, membrane bio-reactor (MBR) and disinfection tank. Besides MBR, there are various options for greywater treatment, e.g., Rotating Biological Contactor (RBC), Constructed Wetland (CWs), Sequencing Batch Reactor (SBR) and so on. Finally, the treated effluent will be discharged to garden area inside Yang Song Township for irrigation.

When come to technological options for greywater treatment, one of significant factors needed to consider is space requirement. The following Table 9-20 summarized the space requirements for different technological options.

**Table 9-20** Space requirements for different technological options

Space Demand (m <sup>2</sup> )	Sand Filter	Lagoon (Anaerobic)	Trickling Filter	SBR	RBC	CW	MBR
<b>Connection Grade</b>	>50	-	4~1,000	4~5,000	>200	4~1,000	4~5,000
<b>1E</b>	1~2.5	10	0.5	0.3	0.1~0.3	2~3	0.05~0.5
<b>50E</b>	50~125	500	25	15	5~15	100~150	2.5~25
<b>100E</b>	100~250	1,000	50	30	10~30	200~300	5~50
<b>500E</b>	500~1,250	5,000	250	150	50~150	1,000~1,500	25~250
<b>1,000E</b>	1,000~2,500	10,000	500	300	100~300	2,000~3,000	50~500
<b>3,000E</b>	3,000~7,500	-	1,500	900	300~900	6,000~9,000	150~1,500
<b>5,000E</b>	5,000~12,500	-	2,500	1,500	500~1,500	10,000~15,000	250~2,500

Explanation:

- The table and data is summarized from Schütze (2005), Li (2004), Otterpohl (2002).

### **Recommended diversion methods**

The recommended diversion methods in scenario 2 are:

- Install low flush urine diversion toilets in each family;
- Equip indoor yellow- and brown water pipes for each single building. These pipes will collect the separated urine/faeces because they are the links between the urine diversion toilets and the urine/faeces tanks in each basement. The urine/faeces tanks can be emptied or transported to WWPF once a week;
- Build the greywater sewerage, which can collect and convey the greywater to WWPF in Yang Song Township;
- Construct the sewerage for collecting and conveying storm water to a WWPF.
- Equip the organic waste separation rubbish bin, and then transporting them to solid waste treatment centre in WWPF.

### **Recommended recycling approaches**

The recommended recycling approaches in scenario 2 are:

- Liquid fertilizer coming from yellow water: use as fertilizer for flowers, trees and grass inside Yang Song Township or its surrounding areas;
- Biogas coming from brown water anaerobic digestion: use as energy in Yang Song Township (e.g., lighting, cooking);
- Solid fertilizer coming from brown and green waste composting: irrigation for surrounding farmer lands;
- Treated water comes from greywater: irrigation for flowers, trees and grass inside Yang Song Township;
- Treated water coming from storm water: irrigate flowers, trees and grass inside Yang Song Township;

## 9.4.4 Comparisons for both scenarios

### 9.4.4.1 Summary of two scenarios

EcoSan is a holistic approach towards sustainable sanitation and typical elements of EcoSan are wastewater/waste separation, sanitization and recycling.

- Estimated amount of rainfall is approximate 435,200 m<sup>3</sup>/year in Yang Song Township. The maximum volume for collected storm water is around 40 percent of total rainwater, named 173,440 m<sup>3</sup>/year.
- In scenario 1: conventional system, also can called as flush-and-discharge systems, requires large amounts of fresh water for flushing. The all of wastewater coming from each toilet, kitchen and shower is collected by small-diameter sewer system Yang Song Township, and then be transported to decentralized wastewater treatment plant. The storm water collected from roofs and roads is discharged into nearby streams and channels directly.
- In scenario 1: 1,493 m<sup>3</sup>/d potable water is required from municipal water supply; 633 m<sup>3</sup>/d wastewater is discharged to decentralized wastewater treatment plant. And 43.5 kg/d of nitrogen and 6.9 kg/d of phosphorus are generated and discharged to municipal treatment plants.
- In scenario 2, “Wastewater Processing Facility” (WWPF) is needed to set up, where greywater and storm water could be treated by MBR (or other options), after treatment, the treated water will be recycled to garden irrigation inside Yang Song Township; the yellow water can be sanitized in the yellow water storage tanks; the brown water can be sanitized with organic waste by anaerobic digestion/composting processes before they are irrigated as fertilizers for the agriculture and garden area.
- In scenario 2, only 516 m<sup>3</sup>/d potable water is required from municipal water supply, because of the greywater and storm water recycling and reuse. Approximate 492 m<sup>3</sup>/d greywater is produced and can be reused for irrigating the garden area inside Yang Song Township. Only 142 m<sup>3</sup>/d uncollected storm water is discharged to the surface water body nearby – Yan Qi River. 6 m<sup>3</sup> yellow water and 15.42 m<sup>3</sup>/d brown water is treated in WWPF, and then is used inside and outside Yang Song Township.
- In scenario 2, approximate 11.23 kg/d of nitrogen is recycled inside Yang Song Township as irrigation fertilizer and approximate 32.27 kg/d liquid and solid fertilizer will be recycled outside Yang Song Township.
- In scenario 2, around 5.62 kg/d of phosphorus is recycled inside Yang Song Township and 1.28 kg/d of phosphorus can be recycled as fertilizer outside Yang Song Township.

#### 9.4.4.2 Cost comparison for capital investment

In both scenarios, the differences are presented as follows:

- The urine diversion toilets in scenario 2 will replace the conventional toilets in scenario 1;
- The yellow water pipes, which convey the urine with low flush water from the urine diversion toilet to the sewerage in the basements, are needed in scenario 2;
- In scenario 2, the urine tanks are needed for storage the urine in each building basement;
- In WWPF of scenario 2, the yellow water storage tanks should be constructed;
- In Scenario 2, like the urine tanks, the faeces tanks are also required;
- In WWPF of scenario 2, the brown water digester/composted tanks also need to be equipped.

Therefore the capital investment of scenario 2 is likely to be higher than scenario 1, due to the additional cost that would be spent in constructing equipments and units.

#### Cost comparison for water consumption and wastewater discharge fee

Based on indicative cost comparisons of both scenarios, the capital investment of scenario 2 is likely to be higher than scenarios 1. However, around 63,145 Euro per year of water/waster fee is saved in scenario 2 compared with scenario 1. Moreover, the valuable liquid/solid soil fertilizer is produced in scenario 2.

In scenario 1, all water consumption comes from municipal water supply and the classic wastewater is considered as wastewater. Therefore, the expenditure for 1,493 m<sup>3</sup>/d water supply and 633 m<sup>3</sup>/d wastewater treatment is charged.

However, in scenario 2, the expenditure for 516 m<sup>3</sup>/d municipal water supply and 492 m<sup>3</sup>/d wastewater treatment is charged.

As calculated in Table 9-21, approximate 142 Euro/d is needed for water supply and wastewater treatment in scenario 2, while 315 Euro/d is needed for water supply and wastewater treatment in scenario 1. In another words, around 63,145 Euro can be saved per year (173 Euro/day) if applying scenario 2.

**Table 9-21** The estimated expenditure for municipal water supply and wastewater treatment in both scenarios

	Unit Price (Euro/m <sup>3</sup> )	Scenario 1		Scenario 2	
		Amount	Cost	Amount	Cost
		(m <sup>3</sup> /d)	(Euro/d)	(m <sup>3</sup> /d)	(Euro/d)
<b>Water supply</b>	0.16	1,493	239	516	83
<b>Wastewater treatment</b>	0.12	633	76	492	59
<b>Total</b>	-	-	315	-	142

**Explanation**

- 1 Euro = 10 RMB (Chinese currency).
- At present, the unit price for municipal water supply is 1.6 RMB/m<sup>3</sup> and for municipal wastewater treatment is 1.2 RMB/m<sup>3</sup> in China.
- Cost (Euro/d) = Amount (m<sup>3</sup>/d) \* (Euro/m<sup>3</sup>).

**9.4.4.3 The criteria comparison for sustainability**

The criteria comparison can be derived from several aspects: health, environment, economy, socio-culture and technical function. Because up to date there are no clear indicative factors for the criteria, everyone use their own interpretation of sustainability. In practice the indicators with the highest priority should be given the highest indicative factors. Hence, all categories are considered over the entire life circle of the sanitary system – from resource extraction for its construction to eventual service at the end of its useful life. The detailed explanations for sustainability criteria are shown in the followings.

**Environment**

- *Use of natural resources for construction:* both scenarios are equal.
- *Use of natural resources for operation and maintenance:* both scenarios are equal.
- *Discharge to water bodies (COD):* In scenario 2, minimum pollutants are maintained due to separating and sanitizing different types wastewater, much less COD that is discharged to rivers than scenario 1.
- *Resources recovery:* In scenario 2, the potential of saving fresh water by recycling of greywater is much greater than that in scenario 1. Also nutrients are recycled in nature. Water flow and nutrients are both recycled.



### Health

- *Risk of infection:* It is not safe using of urine/faeces, if they are treated properly due to operation mistake in scenario 2.
- *Risk of exposure to harmful substances:* more manure is needed to be sanitized in scenario 2, thus the risk is relative high.

### Economy

- *Total costs of capital:* In scenario 2, urine diversion toilets are needed to install. And separating pipes for yellow water and brown water transportation are needed to set up. Therefore more investment and more complex technology are needed.
- *Total cost of maintenance:* In scenario 1, the cost of maintenance seems to be greater than that in scenario 1, due to more complex technology (e.g., biological treatment for nutrients removal).
- *Contribution to local development:* In scenario 2, more income from biogas generation and liquid/solid fertilizer production can be realized. Also, due to the deduction of fresh water consumption and the reduced amount of greywater treatment in scenario 2, the cost saving potential is greater than that in scenario 1.

### Socio-culture

- *Willingness to use:* Most of people do not know about the concept of EcoSan and urine diversion in scenario 2.
- *Convenience:* There is no difference for users since the convenience level of using flush-and-discharge toilets and urine-diversion toilets is identical.
- *Institutional requirement:* Scenario 2 demands new institutional issues.
- *Current legal acceptability:* Legal support for scenarios 2 is urgently needed, e.g., the formulation of treatment standard for small decentralized wastewater treatment plant.
- *System perception (complexity, compatibility):* Urine diversion toilets or vacuum toilet are a little bit complicated than conventional toilets.

### Technical function

- *System robustness:* Scenario 2 is a pilot project and new technology should be less robust than conventional one.
- *Possibility to use local competence for construction:* Scenario 1 needs less capital investment.
- *Possibility to use local competence for system monitoring:* Scenario 2 is more complex because urine diversion, thus it is not easier monitored than scenario 1.
- *Durability/life time:* Both scenarios are same.
- *Complexity of construction and O&M:* Both scenarios are same.
- *Flexibility/adaptability:* Because urine and faeces is separated in scenario 2, the greywater quality is less various than scenario 1.

All in all, based on sustainable criteria analysis, important results was that applying scenario 2 for integrated wastewater management in Yang Song Township should bring benefits of holistic development, such as conserves water and environment by minimum contaminants for separating and sanitizing different types of wastewater, saving water for reuse storm water and greywater, recovers and recycles nutrients and organic materials, bring income for biogas, and liquid/solid fertilizer production.

In summary, scenario 2 is a sustainable approach for the future.

## **10. Impediments, challenges and perspectives for the future development**

### **10.1 Impediments**

It is likely through, that decentralized concepts may become established in certain niches, such as urban areas or regions where a high investment need coincides with a dramatic decrease in water demand. This would, for example, apply to newly constructed or newly rebuilt areas, which would not have to be connected to the existing sewage system, but would function as nearly zero wastewater producers, using a combination of approaches such as recycling of process water, separation of wastewater streams, decentralized treatment of rainwater, and small community treatment plants.

However, it appears unlikely at this point in time that the centralized water and wastewater systems will be replaced entirely by decentralized alternatives in the short- to mid-term. Even if other challenges with regards to the implementation of EcoSan approaches have been overcome, scientists and researchers predict that a comprehensive realization of these approaches will still take at least some 30 to 50 years. Until then, conventional systems and EcoSan systems would exist in parallel, even within one city or community.

Taking into consideration of decentralized projects promoted by other organizations in different parts of the world, several key issues should be highlighted which will be crucial for the broad application of decentralized approaches based on ecological sanitation and for which we do not yet see solutions. With regards to environmental, social and economic sustainability, major impediments especially in the following:

#### **Lack of high level acceptance**

The common misunderstandings have led to a main barrier to development of decentralized approach: the decentralized systems are inferior, old-fashioned, less technologically advanced, and not as safe as centralized wastewater treatment system. Decentralized system and other decentralized technologies serving small portions of a community are often seen as suitable only in low-density and rural areas, as well as then only as temporary solution until such time as local growth allows these areas to be served by sewers and connected to central treatment plants.

With respect to decentralized systems based on EcoSan, one of the main difficulties is that the closed loop approach to sanitation is still relatively unknown, not only amongst the general public, but also among planners, engineers, consultants, politicians and local authorities. Since the concept of EcoSan remains relatively unknown, the single most apparent barrier to stimulating this concept is lack of knowledge. That means the majority of potential exponents of decentralized systems based on EcoSan were unaware of the overall concept. Despite the numerous, mainly

academic reports available, far too few are reaching, or are accessible to the potential customer of the concept.

Too often, in developing countries, decision makers strongly prefer standards and project concepts which are applied in the industrialized countries. Engineers are familiar with conventional techniques. They are reluctant to accept new approach. For instance, the acceptance in Chinese circles, particularly politicians for such as source control measures in urban construction is also very low. One of the typical concern is that they are learning European well-proved experiences and concepts, and these are centralizes plants with deeply excavated pipelines.

In addition a low level of acceptance often occur amongst customers, since they would generally be faced with an increasing handling time or higher handling cost in comparison to conventional systems. This is due to the fact that EcoSan systems are by its definition decentralized systems posing a higher burden on the end users. Up to now only a few private investors have shown a readiness to invest in closed loop sanitation systems.

### **Lack of financial incentive and feasibility**

With regards to financial feasibility, system already constructed in an existing settlements need to be taken into account for any new investment, may it be a replacement of the existing system. Thus it will usually not be financially feasible to replace an existing conventional system by a decentralized system based on EcoSan in the case that the existing centralized system has not yet been fully depreciated. Since most of the large cities do have existing conventional sanitation systems, also in the developing countries, these systems can only be gradually replaced.

In general, decentralized projects based on EcoSan can be applied to all areas, from informal settlements to luxury multi-storey apartment or office blocks, where the existing infrastructure is to be upgraded to EcoSan systems. The implementation of such projects generally tends to be much more complex than those in areas of new development, for several reasons. The use of existing infrastructure may still be foreseen in the project and EcoSan solutions must be built around this system, which may cause a considerable degree of technical difficulty.

Therefore, private households may also only reluctantly agree to convert their sanitary facilities to EcoSan, as they will most likely have to pay the bill for the change over. Private investors may also not be willing to participate in such projects as there is a considerably smaller opportunity for them to make a profit. Additionally, these built up areas may have very little space for the installation of decentralized solutions. Projects in this context may therefore have to adopt a long term approach to the completion of an EcoSan system, with innovations being introduced gradually over many years.

### **Lack of systematic analysis**

Another fact is that the delimitation of centralized vs. decentralized solutions in city outskirts, slums and scattered settlements can be very difficult. The same holds true for design parameters and for treatment standards and well as treatment performance. Existing information and standard in most developing countries currently do not allow the introduction of such approaches based on decentralized systems. The result of this is not only a general lack of information as to how such a system might function in a given circumstance, but also a complete lack of experience among all those involved in implementing such system.

Since decentralized wastewater management based on EcoSan is designed and suitable for individual household or community, the technological options and combinations of greywater and blackwater treatment differ largely from case to case. In the view promoting “appropriate technology” implies that we focus on the every problem that should be solved depending on individual conditions. In principle a wide range of technical solutions from simple latrines to sophisticated treatment facilities may emerge as being appropriate. However, in any case, there are no universal solutions. Thus the treatment performance and accordingly cost analysis cannot be concluded in a uniform package.

### **Lack of experiences in urban areas on a large scale**

At present there are many people living in metropolitan areas due to urbanization. Urban areas with their rapidly growing populations and high population densities are in particular need of closed-loop waste and wastewater management system, not only to protect human health, but also out of an increasing need to efficiently use available resources (e.g., water, nutrients, energy and organics). Therefore, faced with rapid urbanization world-wide there is a pressing need for solutions in built up areas.

Up to date, most applications of the concept of EcoSan have been well implemented and proved in rural and less densely populated peri-urban areas, whereas experience with urban and peri-urban areas remains rather limited. And there are many choices and appropriate designs at very low prices in many cases for such applications. In urban areas, there are also some promising approaches for those situations, but little experience exists so far. Solutions for reusing treated wastewater and sewage sludge to close water and nutrient cycles are gaining priority, specifically in very densely populated arid regions. Also very small peri-urban or urban pilot installations do have the problem that there is no fertilizer demand yet. Based on the experience, this undertaking can be highly complex and challenging from a technical, socio-economic, legal and institutional point of view.

## 10.2 Perspectives and challenges

Decentralized wastewater system based on Ecological Sanitation is a relatively new concept in many parts of the world, although in the last few years this promising approach has assumed an increasingly prominent position in the international discourse on sanitary provision and is recognized as an innovative approach which could play an important role in achieving sustainable development. Much process has been made, but much more is still needed before this approach will be recognized as the standard approach.

### **Enhance political execution and creating demand**

Political will is becoming one of the greatest concerns in the promotion of EcoSan concept. Politicians and other government officials have to be convinced that the concept can work and is good for the economy if properly promoted and executed. All efforts to promote the concept of EcoSan might meet great resistance unless the politicians and other government officials embrace the concept. For this reason accepting EcoSan as a technical sanitation within governmental policy solution is a vital first step in convincing the public that the concept is workable.

The increasing number of alternative systems based on EcoSan being installed around the world is proof to the fact that there is an increased awareness amongst many different groups leading to a greater demand. Pilot projects allowing stakeholders to actually experience how the alternative system works have also served to create demand all around the world. However, further advocacy is needed to help mainstream of EcoSan, and there remains an urgent need of setting up showcase at municipal or large neighborhood level to convince decision makers. The leaders of a nation have a tremendous influence on the people they govern. Also, the leadership at the lowest levels in the community should also not be taken for granted. These should be acknowledged before any promotion activities are started.

### **Integrate the implementation into early urban planning**

In order to find legal and technological ways of implementation, it is necessary to be involved in an early stage of urban planning. Resource recycling and reuse needs to be integrated into sanitation planning process from the very beginning. When the settlements and dwellings come to be equipped with EcoSan systems, these systems should be considered from early on in the planning stage and integrated into the processes of urban planning, facilitating considerably the consideration of all relevant aspects of town planning, land use, urban agriculture, and management. Even with reliable and proven systems, EcoSan requires integrated planning for implementation.

Help will probably come from the changes in energy supply to more decentralized structures where synergies can be found for semi-central installations in urban areas. It is very obvious that cooperation with city planners is a key issue. Therefore, besides the urgent need for expanding education of engineers and capacity building in the region city planners must get basic knowledge about alternatives. Based on urban location and the favorable planning conditions, all the treatable resources (urine,

faeces, grey water, rainwater and organic waste) should be integrated into urban sanitation systems.

### **Establish technical standards, cost analysis and risk comparisons**

In order to enable a successful implementation of the concept of EcoSan, the future efforts will be focused on generating the necessary data, technology and policies required to affect a major change in the way human settlements relate to the environment, with an emphasis on testing, research and development and social marketing, as well as cultural, financial, legal and institutional issues. Some decision makers and planners remain an information deficit, which limits the range of choices available to them. Even when information is available, it is not often insufficient, leading to wrong assumption. The lessons learnt from existing systems must be therefore better documented and disseminated. More practical knowledge on system construction, operation and maintenance and on the safe use of the products, as well as cost evaluation needs to be developed and given to more attention.

### **Promote agricultural use**

The acceptance of the agricultural reuse by farmers of the fertilizer products of EcoSan systems has proven to be unproblematic, and the need to carefully manage limited resources will be an extra impetus to the necessity of nutrient recovery. In particular in China the concept of EcoSan is evolved predominantly due to the need by the local farmers to recycle the nutrients in human excreta for agriculture.

Although there is an active ongoing debate, compared to the risk posed by discharging substances (e.g., micro-pollutants) into our water bodies and the risk of drinking water contamination in the conventional centralized systems, the practices of applying treated faeces and urine to topsoil can be considered a much safer practice. In the soil the substances are exposed to a greater amount of oxygen and biological activity, thus their degradation can be expected much more quickly than in water. However this must be confirmed by further practice oriented research. Reuse options for EcoSan fertilizers also need further field testing at medium- and large-scale. Appropriate treatment and distribution as well as guidelines for the safe handling and use for different local conditions need to be developed or optimized. Existing legal frameworks may also need to be reviewed to enable nutrient recovery particularly from urine.

### **Accelerate the implementation of large scale urban projects**

Although there are now quite a number of relatively large-scale EcoSan systems either being planned or in implementation in urban areas around the world, most of them are implemented in relatively homogenous contexts, and complex systems covering a range of household types, income levels, cultural and geographical conditions within one urban area are still extremely rare. These complex systems are needed to develop a variety of technological, organizational and economically viable solutions for densely populated urban areas and to obtain results concerning the costs and performances of different systems in both industrialized and developing nations. Up to now only a few private investors have shown a readiness to invest in

closed loop sanitation systems for urban area - which would be an important pre-condition for these systems being widely applied and accepted as standard.

In order to have EcoSan systems introduced on a large scale, their functioning and acceptance would still have to be proven. To achieve the latter, it is of utmost important to successfully hold the dialogue with decision makers. And EcoSan systems are going to be introduced in developing countries on large scales probably only when they have been introduced and operated in the industrialized countries in a much wider scale, showing clearly the advantages to the existing conventional systems, especially in urban and semi-urban areas.



## Summary

Currently in most of the developing world like China, dramatically economic development, rapid industrialization, and fast growing agricultural demand have resulted in excessive water consumption and deterioration of water contamination, as well as environmental degradation. Nearly all the water resources which are easy to be developed geographically and technologically have been over-exploited. In addition, the accelerating rates of urbanization have generally far exceeded the limited capacities of the national and the local governments to soundly manage the demographic transition processes efficiently, equitably and sustainably. Those problems are the major driving forces that challenge the water resource and wastewater management of China's in the few decades to come.

Historically, traditional centralized sewer systems have been regarded as the optimal solution for water pollution control and prevailed in many industrial countries. However, to solve the multifold water-related problems in China, completely replication of centralized water-, energy- and cost-intensive technology has been proved extremely limited and not feasible. Planning for sustainable development and utilization of the limited water resources is therefore essential for sustainable socioeconomic development. In addition, proper decisions on where to connect houses to a sewerage system and where to build small decentralized facilities are the key issue for the economics of the whole wastewater infrastructure.

The main objective of integrated decentralized wastewater management based on Ecological Sanitation is a sustainable alternative and is aimed to achieve maximum reuse and recycling useful nutrients and water from wastewater. Thus the concept of decentralized wastewater management is far beyond traditional thinking and solution. Wastewater should be recognized as a significant, growing and reliable water resource. As a closed-loop and holistic alternative, it results in beneficial reuse of rainwater and greywater, enable the maximum recovery of nutrients for the benefit of agriculture, thus helping to preserve soil fertility, assure food security for future generations, minimize water pollution and recover bio-energy.

This paper investigated the state-of-art technological options for decentralized wastewater treatment based on source control. It demonstrated the implementation of rainwater harvesting and greywater recycling, as well as investigated the water- and cost-saving potentials in a semi-urban area of Beijing. Moreover, through a case study in an industrial park in Tianjin, the formation of eco-industrial chain aiming at the reuse of by-products and waste/wastewater of upstream enterprises as resource for the new production was established. In addition, this paper also presented and compared two scenarios based on conventional systems and decentralized systems in a peripheral area of Beijing. The water-flows and nitrogen mass balances of both scenarios were performed and important results are that applying integrated decentralized water management is significant benefit for holistic and sustainable development.

The reasons why these three case studies were selected for this paper are because these case-studies take place in the relatively high-density urban area and in the fast growing agglomerations of urban fringe of Beijing:

- Decentralized wastewater management based on ecological sanitation has been widely implemented in rural areas or urban fringe in many places worldwide, where the demand of agricultural reuse and fertilizer products are usually immense (typical case study - Yang Song Township);
- Comparing rural areas, the implementation of decentralized wastewater management in urban areas are rather rare. Urban areas with their rapid growing populations and high population densities are in particular need of closed-loop sanitation systems, not only to protect human health, but the most important of all to make maximal use of available resources including water, nutrients, energy and organics efficiently (typical case study – Tianxiu Garden);
- In order to demonstrate the implementation of decentralized wastewater management in an industrial park and to present the regeneration and utilization of water resources in industrial park TEDA was selected since this industrial zone is one of the largest in China, therefore its demonstration affect on other Chinese industrial parks is great. Hence, most of the tenants in TEDA are completely foreign-owned enterprises which are interested in having a higher level of environmental awareness. Additionally, TEDA was suitable for the research study given their environmental challenges, especially their increasingly severe water crisis.

Furthermore, the conclusion of three case studies can be drawn as follows:

- In the case study of Tianxiu Garden, according to the roof drainage and the amount service water for toilet flushing, only 29% of service water can be achieved by using rainwater harvesting. However, to relieve pressure on the drainage system and to avoid flooding, rainwater harvesting in relatively high-densely populated semi-urban area can be well-achieved, if measures against air pollution are undertaken in Beijing. Greywater recycling installation was designed for a daily volume 10 m<sup>3</sup>, and the calculated service water requirement for toilet flushing is 6 m<sup>3</sup>. Therefore an over-production of greywater may be used for laundry and shower. In addition, the total amounts of water- and cost-savings per year by greywater-recycling are 3,650 m<sup>3</sup> and 14,000 Euros, and there is no much difference between RBC and other biological options in energy consumption. Because greywater recycling is independent on seasonal change in water volume and is therefore a more suitable technique for saving water in Beijing;

- In the case study of TEDA, focusing on modern industry, TEDA takes industrial development as its economic mainstay, and formed an eco-industrial structure with different industrial features, including four key industries: electronic information, biological pharmacy, automobile and food & beverage. In these eco-industrial systems, downstream enterprises used the byproducts or waste of upstream enterprises as raw material for the production of new products. This process of forming a products chain is so-called Eco-industrial Chain. In this process, primary products increase in value along with the extension of industrial chain, so that materials and energies can reach maximal utilization. The industrial chain enables products recycling and wastewater reclamation, which are important characteristics of eco-industry;
- In the case study of Yangsong Township, comparing with two scenarios, scenario two is a sustainable approach in keeping the harmony of social, economic and environmental development. Although in the initial stage, high investment are also required for scenario two to install urine diversion toilets, separating pipeline systems, anaerobic digestion and biogas facilities, approximate 63,145 Euros pro year could be soon achieved by the saved wastewater treatment cost. Additionally, cost recovery can be achieved by fertilizer generation that can replace chemical fertilizer and biogas production that can generate combined heat and power. From environmental point of view, emissions and waste/wastewater amount can be tremendously reduced by the recycling of water- and material flows. Around 11.23 kg and 32.27 kg nitrogen could be reused as fertilizer inside and outside Yang Song Township. Hence, surface water and ground water will no longer be contaminated and nutrients will no longer lead to eutrophication during wastewater discharge. It also facilitates the nutrients and organic material as well as trace elements contained in wastewater recycled and back to the agriculture.

In addition, a shift from central sewer systems to decentral eco-sanitation systems involves a socio-technical transition. The social scientific component in the implementation of ecological sanitation addresses social problems, such as social acceptance of such eco-sanitation systems and the changing behaviour/attitude of provider and customer dealing with ecological sanitation. For this reason, we need to explore not only the technical lay-out, but also the changes in social practices around the building, use and management of these systems. Especially, the social organization around the design, implementation, operation and maintenance should be kept as local-tailored as possible.

Since decentralized wastewater management based on ecological sanitation is designed, tailored and suitable for individual household or community, the technological options (e.g., the combinations of greywater and blackwater treatment) differ largely from case to case. In the view promoting “appropriate technology” implies that we focus on the every problem that should be solved depending on individual conditions. In principle a wide range of technical solutions from simple latrines to sophisticated treatment facilities may emerge as being appropriate. However, in any case, there are no universal solutions. Thus the treatment

performance and accordingly cost analysis cannot be concluded in a uniform package.

Moreover, worldwide there is currently lack experience of greywater treatment especially the treatment performance in different climate, and greywater treatment has been usually conducted on laboratory scale. For yellow water treatment, further investigations are needed to find out about the effect of parameters such as temperature and pressure conditions in the stabilization and acidification process to reduce ammonia losses. Hence, energy balance of different techniques like freezing and evaporation are needed to be studied. For black water treatment, the determination of bio-gas production rates with time and how to optimize the adaptation phase of anaerobic reactor where biowaste and black water are co-fermented are needed.

In principle, decentralized projects based on ecological sanitation can be applied to all areas, from informal settlements to luxury multi-storey apartments or office blocks. If decentralized sanitation and reuse infrastructures and techniques should be applied at household level, its concepts should be involved in the earliest stages of urban planning and the urban planners have therefore responsibilities to support the design by allocating extra space within the requirements for the architect of building. At present, experiences are still extremely rare in large settlement and in dense-populated urban areas. From the point stand of urban planner, there remains an urgent need of setting up showcases in other projects at municipal or large neighbourhood level, which should cover different household types, settlement structure, population density, income levels, cultural and geographical conditions within one urban area.

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