



HÖGSKOLAN I HALMSTAD
För utveckling av verksamhet, produkter och livskvalitet

A General Investigation of Shanghai Sewerage Treatment System



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Summary

As a modern metropolis, Shanghai has a registered population of 18.8 million in 2011, and the permanent population has been more than 20 million. As a result, Shanghai produces more than 6.3 million cubic meters of sewage per day which is considered as a massive test for Shanghai's sewerage treatment system. Given the high proportion of time spent on the literature review, this study has investigated how the whole system works in Shanghai. To do this, Shanghai sewerage systems were divided into two parts – the drainage system and the sewage treatment system, and they were introduced respectively following the track of history development process. It was done by combining previously published theses, study reports, governmental documents, overt information by companies and news reports. It showed that, in 2009, Shanghai's government established a basic formation of six centralized sewage treatment systems in co-existence with 52 sewage treatment plants. In the same year, the sewage treatment rate reached 78.9%, which can be considered a leap compared with the 62.8% figure in 2003. In spite of that, the gap between sewage treatment in Shanghai and that in developed countries still exists. By comparing Shanghai Bai Longgang sewage treatment plant with Halmstad Västtra stranden's waste water treatment plant, it can be concluded that the gap was embodied in differences of inflow condition, relative low discharge standards and poor treatment capability.

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Index

<i>1 Introduction</i>	<i>1</i>
<i>1.1 Urban and social profile</i>	<i>1</i>
<i>1.2 Water resources</i>	<i>3</i>
<i>1.2.1 The Yangtze River</i>	<i>4</i>
<i>1.2.2 The Huangpu River</i>	<i>5</i>
<i>1.2.3 Suzhou Creek</i>	<i>5</i>
<i>1.3 Water consumption and water quality</i>	<i>6</i>
<i>1.4 National Environmental Quality Standards for Surface Water (GB 3838-2002)</i>	<i>8</i>
<i>1.4.1 Scope</i>	<i>8</i>
<i>1.4.2 Water features and standard classification</i>	<i>9</i>
<i>2 Aim of my study</i>	<i>10</i>
<i>3 Methodology</i>	<i>11</i>
<i>4 Literature review</i>	<i>13</i>
<i>4.1 Brief introduction of the development of the Shanghai sewerage treatment system</i>	<i>13</i>
<i>4.2 Drainage system</i>	<i>16</i>
<i>4.2.1 Complete combined drainage system</i>	<i>16</i>
<i>4.2.2 Based on combined and in assistance with separated drainage system</i>	<i>17</i>
<i>4.2.3 Complete separated and co-existence with combined drainage system</i>	<i>17</i>

4.2.4 Intercepting combined as the main drainage system	18
4.2.5 Intercepting combined and co-existence with separated drainage system.....	23
4.3 Sewage treatment system	26
4.3.1 The historical evolution of Shanghai sewage treatment system	26
4.3.2 Current Shanghai sewage treatment system (based on 2009).	32
4.3.3 Case study.....	34
4.3.4 Shanghai suburban domestic sewage treatment.....	41
Combined biological process/ ecological process	44
5 Conclusion.....	46
6 References.....	48
Appendix 1	53
Appendix 2	54

1 Introduction

1.1 Urban and social profile

Shanghai, with a registered population of 18.8 million in 2011 (City Population, 2011), is located on east coast of the nation and on the eastern boundary of the Yangtze River Delta with East China Sea in the east (shown in figure 1.1). The city of Shanghai covers a total area of 6340.5 km² and consists of seventeen districts and one county (shown in figure 1.2) (SMG, 2009). Shanghai's population, area and GDP world ranking is shown in table 1.1 below.

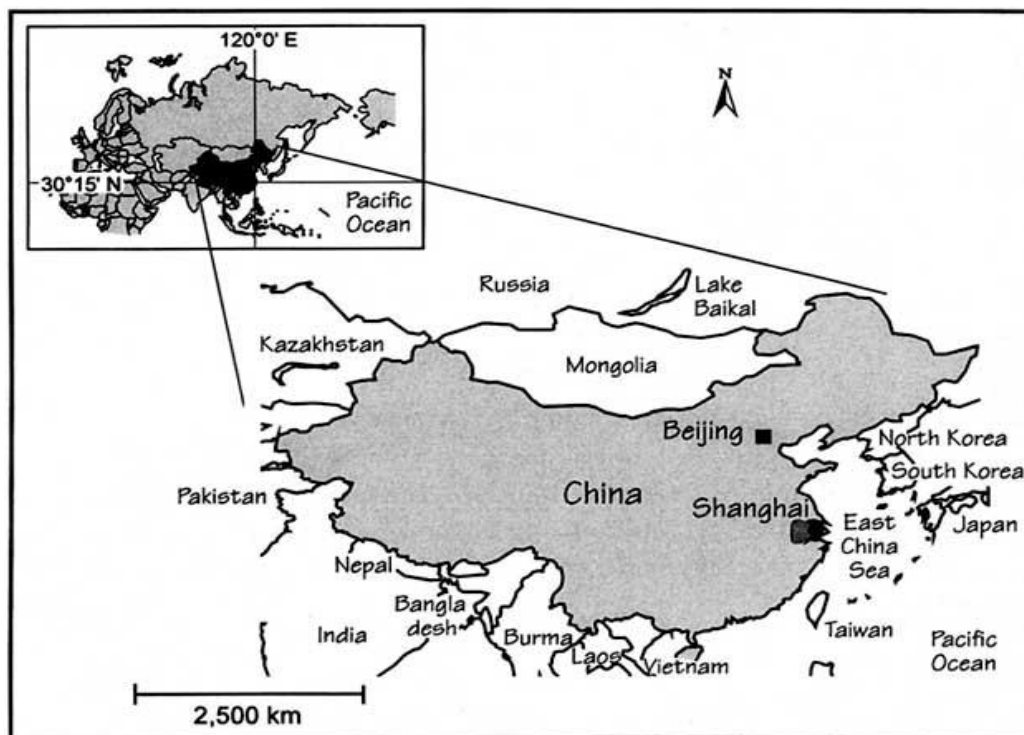


Figure 1.1 The map of China and showing the location of Shanghai (Helmer and Hespanhol 1997)

Table 1.1 Shanghai's population, area and GDP world ranking

	Shanghai	Rank in the world cities
Registered Population (2011) ^a	18,800,000	10 th
Area (2010) ^b	6,340 km ²	18 th
Population density (2011) ^c	3503/km ²	13.3/km ² (World average)
GDP per capita (2009) ^d	\$233	25 th

a: 'The Principal Agglomerations of the World', 2011; b: 'Wikipedia', 2010; c: 'NetEase News', 2010;

d: 'Wikipedia, 2009'



Figure 1.2 The distribution of 17 districts and on county in Shanghai (Google Image 2011)

In 2009, reported from the Shanghai government, the average annual precipitation was 1322.5 mm and flooding season lasted from June to October. The amount of shallow groundwater resource is 992 million m³ and city surface runoff is 3.46 billion m³ (SMOB, 2009).

Shanghai, a part of alluvial plain of the Yangtze River Delta, is one of the most low-lying regions in China with an average altitude of 4 meters (above sea). In addition to some hills standing in the southwest parts, it is mostly flat in the city. Land terrain

shows an overall low inclination from east to west of Shanghai. A high efficiency of drainage system and flood control system was demanded due to flat terrain, abundant rainfall and intensive streams and rivers of Shanghai. In 2003, Shanghai government conducted the “Regulations of Shanghai Flood Control”. It is clearly put forward a thought that establishing a "four lines of defense" as the main system of flood control facilities which are “thousands of miles of seawall”, “thousands of miles of river embankment”, “urban drainage” and “regional waterlogging control” (SWA, 2003). A photo of seawall in Shanghai is shown in figure 1.3.



Figure 1.3 A photo of seawall in Jinshan district, Shanghai (The People's Government of Jinshan District 2004)

1.2 Water resources

Shanghai is a water-rich city (shown in figure 1.4). It is a region with intensive distribution of rivers, canals, drains and lakes (He and Han, 2005). The main water bodies in Shanghai are as follows.

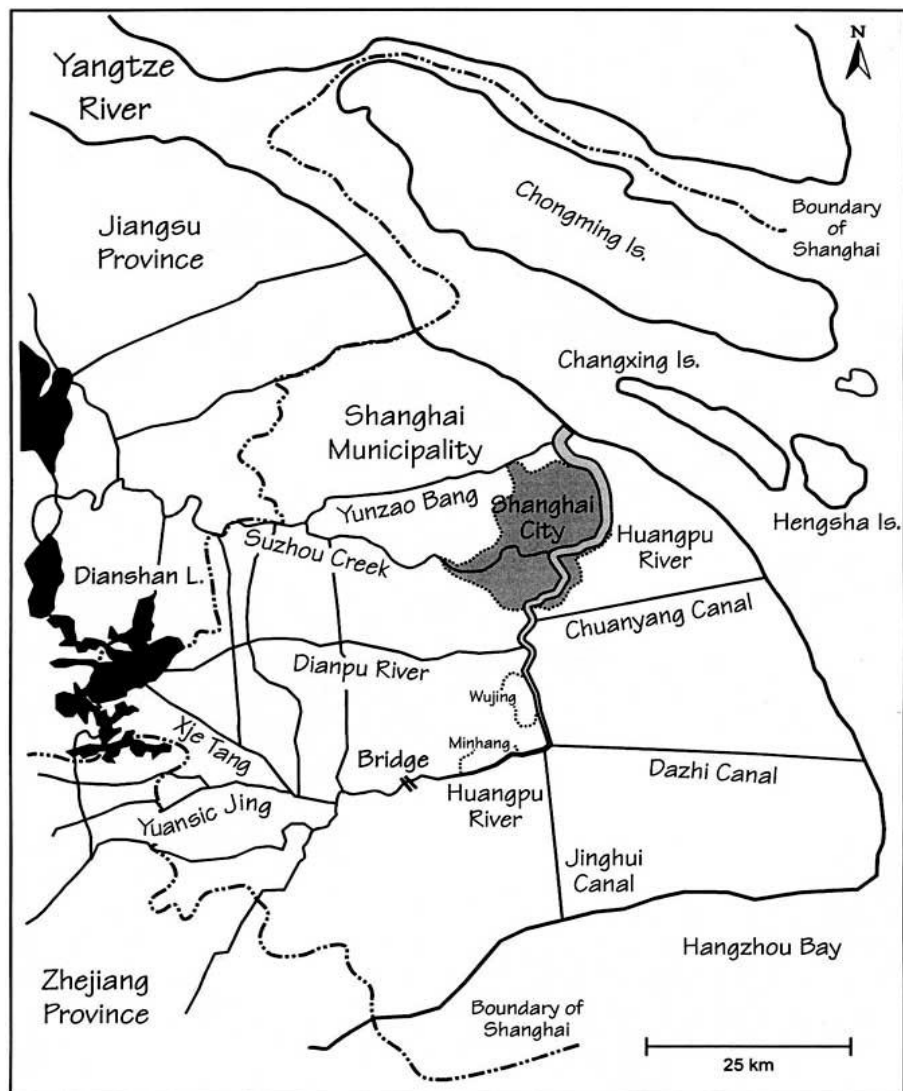


Figure 1.4 The distribution of rivers, canals and lakes in and around Shanghai (Helmer and Hespanhol 1997)

1.2.1 The Yangtze River

The Yangtze River is the largest river in China and third largest river in the world. The Yangtze River rolls on eastwards and joins the East China Sea in the Shanghai region (Zhang, 1997). Shanghai belongs to the alluvial plain of the Yangtze River Delta (also shown in figure 1.4).

1.2.2 The Huangpu River

The Huangpu River, which is called the “Mother River” and a tributary of the Yangtze River, is the main water source for agriculture, industry and household use in Shanghai. It runs from the south west to the north east of the city and finally enters the Yangtze River. The Huangpu River also pertains to the Tai Lake water system and plays a vital role in discharging runoff water from the Tai Lake (Zhang, 1997).

1.2.3 Suzhou Creek

Suzhou Creek is the main branch of the Huangpu River. At present, it provides many functions like flood prevention, navigation, industrial water supply, irrigation, and aquatics breeding. However, from the 1950's onwards, Suzhou Creek has been gradually polluted due to the direct discharge of untreated water from industries. At that time, the deterioration of Suzhou Creek was heavy and the citizens who live close to the Creek had to close their windows because of the bad odour. The water was black and there were no fish or plants in it (ICD, 2006).

From 1998, the first, second and third phases of the Suzhou Creek Rehabilitation Plan were launched by the Shanghai government (SWEB, 2009). The main contents of the plans included sewage interception, pollution treatment, flow augmentation, river regulation, river bank improvement and the settlement of a flood control wall. After the comprehensive renovation of Suzhou Creek, the black water and odour phenomenon no longer exist today. The water quality could reach class V (National environmental quality standard for Surface water is given in subsection 1.4 below), making it suitable for agricultural use and for general sightseeing (Zhu, 2008).

1.3 Water consumption and water quality

Shanghai is a large water consumption city. In 2009, a total 12.52 billion m^3 of water was used in Shanghai, and which equivalent to an average daily water consumption of 1.79 m^3 per person. Divided by the purposes of water usage, agricultural use was 1.711 billion m^3 ; thermal power industries use was 7.334 billion m^3 ; general industry use was 1.082 billion m^3 ; urban public water supply use was 1.13 billion m^3 ; residents supply use was 1.263 billion m^3 , and the percentages of the total water consumption are 13.7%, 58.6%, 8.6%, 9.0% and 10.1%, respectively (as shown in figure 1.5 below). In the same year, the total volume of Shanghai municipal wastewater was 2.301 billion m^3 , which was equivalent to an average daily volume of 6,304,900 m^3 (as shown in figure 1.6). Thereinto, the industrial wastewater was 654 million m^3 and household sewage volume was 1.647 billion m^3 (SMOB). If the daily volume of sewage divided by the permanent population in 2009, the daily amount of sewage produced would be 0.33 m^3 per person per day.

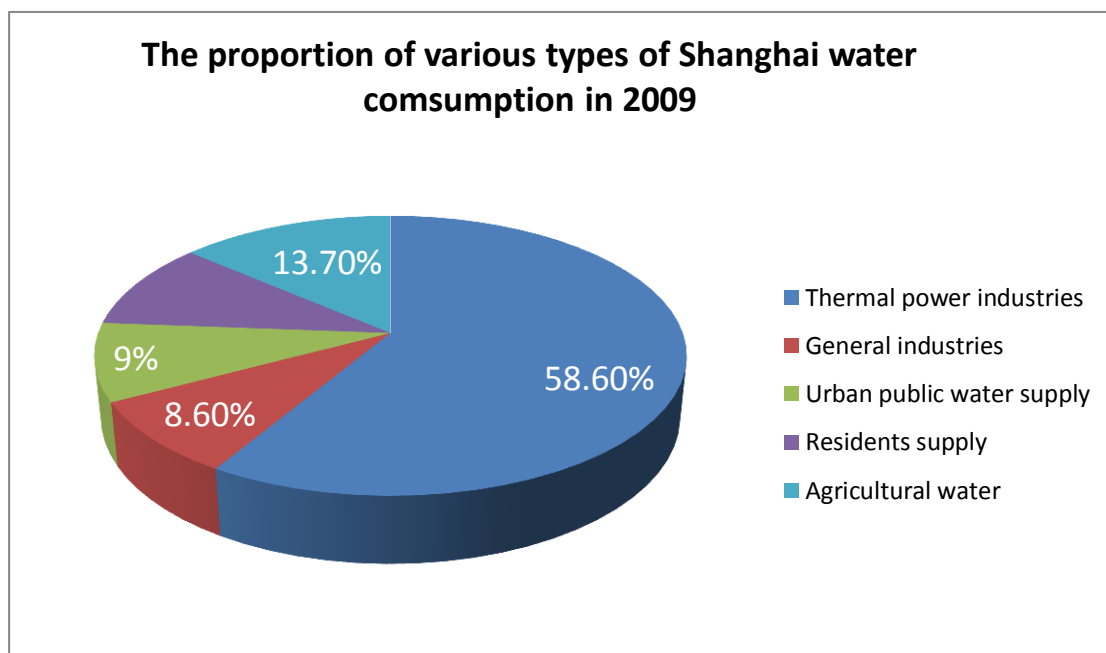


Figure 1.5 The proportion of various types of Shanghai water consumption in 2009 (data from SMOB)

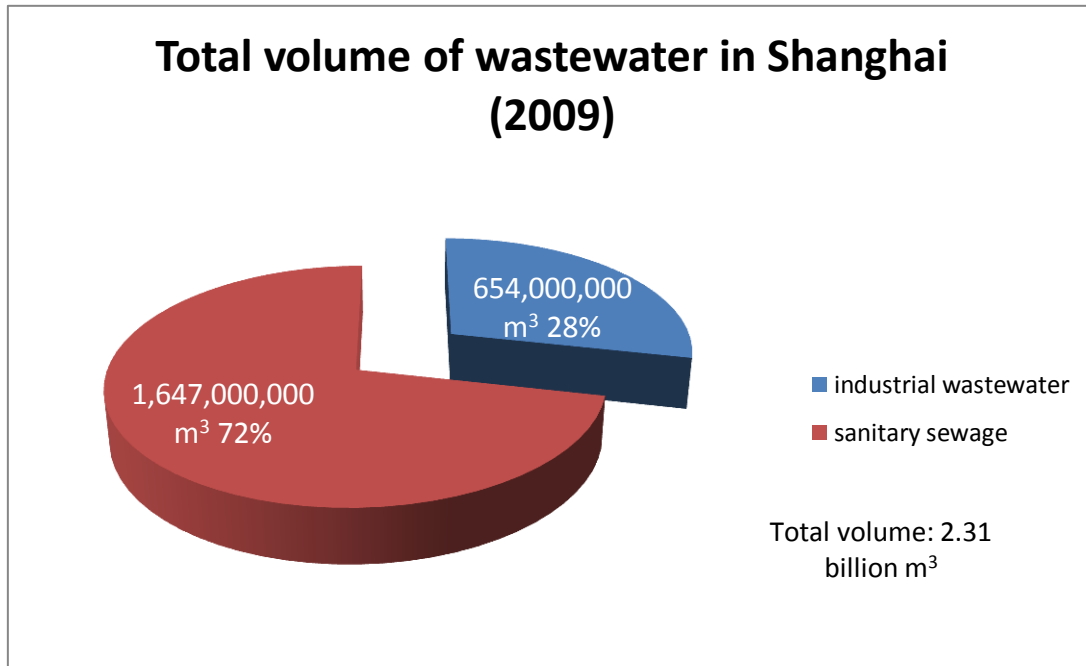


Figure 1.6 The proportion of industrial wastewater and household sewage in total volume of wastewater in 2009, Shanghai (data from SMOB)

Among total 719.8 km rivers in 2009, the sections attaining class I to class III accounted for 28.7%, class IV 27.2% and class V 8.5%. And the sections are worse than class V reached 35.6% (SMOB, 2009). The classification of rivers is shown in figure 1.7.

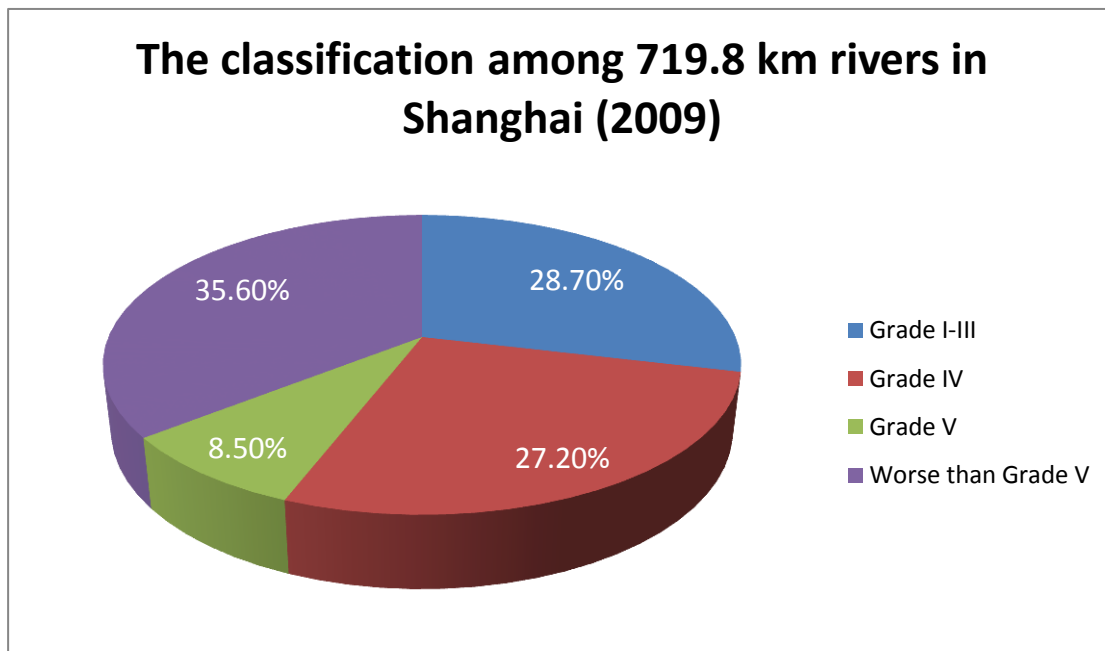


Figure 1.7 The classification among 719.8 km rivers in 2009, Shanghai (data from SMOB)

1.4 National Environmental Quality Standards for Surface Water (GB 3838-2002)

1.4.1 Scope

The standard is applicable within the territory of rivers, lakes, canals, irrigation channels, reservoirs and other surface water features in China.

This standard was implemented in June 1, 2002. According to functional classification and surface conservation objectives, it provides for the items and its limitations that should be controlled, and also for assessment and supervision of the implementation and water quality analysis.

1.4.2 Water features and standard classification

Water quality was divided into five categories or classes based on surface water features and water environment protection targets.

- Class I: mainly applicable for the source of water or the State Nature Reserve;
- Class II: mainly applicable for first-grade surface sources protection zones for domestic and drinking water, habitats of endangered aquatic organisms, fish and shrimp spawning grounds and feeding grounds etc.;
- Class III: mainly applicable for second-grade surface sources protection zones for domestic and drinking water, fish and shrimp wintering grounds and migration channels, aquacultural grounds of fish, shrimp, shellfish and aquatic plants, swimming areas and etc;
- Class IV: mainly applicable for general industrial use and recreational water areas for human indirect contact with;
- Class V: mainly applicable for agricultural and general landscape requirement use.

In terms of the many types of specific water use, the highest standards of appropriate categories should be applied (China's EPA, 2002).

2 Aim of my study

The aim of this study is to investigate the whole picture of Shanghai's sewerage system. To do this, Shanghai's sewerage system was divided into two parts – the drainage system and the sewage treatment system. In the first step, a historical review of both drainage and sewage treatment systems was made mainly to get a general historical evolution of Shanghai's sewerage system. Secondly, I have investigated the current status of both drainage and sewage treatment systems in Shanghai. In terms of drainage system, what I focused on are the sewage collection and transportation status. And in terms of sewage treatment system, I mainly paid attention to both the capability and capacity of wastewater treatment plants in Shanghai. Last but not least, I have made several comparisons between Shanghai sewerage system and that in developed countries and this including two cases of study on Shanghai Bai Longgang sewage treatment plant and Halmstad Västtra stranden's waste water treatment plant. Basing on those above, finally, I have put forward some gaps or differences and suggestions in my conclusion.

3 Methodology

Due to lack of information in English about Shanghai's sewerage system, most of references I found were published in Chinese, including academic papers and study reports. The rest information mainly came from governmental documents, generally available information by companies and news reports.

All academic papers and literature were selected from CNKI (China National Knowledge Infrastructure) database. 108 pieces of literature were initially selected from CNKI database. And through scientific and comprehensive information integration, 41pieces of them were used as references in this study.

The key words I mainly used in searching were Shanghai drainage system, Shanghai wastewater (sewage) treatment, Shanghai treatment plants, Shanghai piping system, distribution of pipe network in Shanghai, separated drainage system, combined drainage system, sewage treatment rate in Shanghai, Shanghai urban sewage treatment, Shanghai suburban sewage treatment and so on.

The processes of literature review in my study were as follows:

- Searching from CNKI database with relevant keywords
- Reading and thinking the initial pieces of literature and reports carefully to find most relevant ones
- After establishment of the main structure of this study, re-searching new keywords and re-thinking processes were done.

- Collecting relevant data, table and figures from governmental documents, generally available information by companies and news reports to support my study.
- Putting forward my comments and own suggestions basing on obtained information.

4 Literature review

4.1 Brief introduction of the development of the Shanghai sewerage treatment system

The Shanghai sewerage treatment system consists of a drainage system and a wastewater treatment system. The Shanghai sewerage treatment system has undergone enormous changes in the past 30 years, which made a considerable contribution to Shanghai being considered a modern international metropolis.

In the late 80's, the daily emission of Shanghai sewage was more than 5 million m³, of which 4 million of untreated sewage being directly discharged into Suzhou Creek, the Huangpu River and the Yangtze River estuary, which resulted in Shanghai being included in China's 36 "Water shortage due to water quality" cities (Shen, 2008). There are relatively abundant water resources available, but due to various forms of pollution of water resources, this has resulted in the deterioration of water quality, which cannot be used.

In this regard, from the late 1980's Shanghai has spared no effort when engaged in the treatment of the water environment. Among these, three main events have played an important role in the history of Shanghai sewage treatment. These events were the Shanghai Sewage Project Phases I, II and III (abbreviate: SSPI, SSPII and SSPIII).

In 1988, the daily amount of Shanghai sewage was 5.3 million m³ (Shen, 2008). In order to solve the problem of growing amount of sewage comprehensively and systematically, Shanghai municipal government invested 1.6 billion yuan in starting the SSP I. This was the first battle, and the project included the rehabilitation of 44 river

closure facilities and old pumping stations; the laying 20.48 km of sewage connection pipes and 33.39 km of closure main. It also included the construction of one large sewage pumping station, one export pumping station and one sewage treatment plant, serving an area of 70.57 km² and a population of 2.55 million (Gong et al., 1989).

In 1996, Shanghai started the second stage, and made an investment of 6.3 billion yuan in the SSP II. The completion of this project succeeded in accomplishing the transmission and the centralized disposal of 1.7 million m³ wastewater which was generated in the southern, western and eastern parts of Shanghai. The area and population benefited were 272 km² and 3.56 million, respectively. In addition, the project also provided the effective protection of the upstream and midstream sections of the Huangpu River. In 2001, the SSP II was awarded as "China Human Settlement Environment Award" by China's Ministry of Construction (Zhang and Xu, 2003).

At the end of 2003, a total investment of 46 billion yuan in the SSP III started, including the sewer main project, the sewage collection system, the building of the second Zhu Yuan sewage treatment plant and the rehabilitation of SSP I. The sewage collection system covered the areas of Bao Shan, Yang Pu, Pu Dong, Hong Kou and northern regions. By the year 2007, the main project was completed and water was transferred. Moreover, the project also succeeded to realize sewage collection in the north and northeast parts of Shanghai (Lin, 2008). The area that benefited was 172 km² and a population of 2.43 million was covered (Yu and Yang, 2004). The water quality of Suzhou Creek and the Huangpu River has been further improved.

In 2009, the total amount of urban sewage in Shanghai came to 2.301 billion m³, of which 654 million m³ was industrial wastewater and 1.647 billion m³ was household sewage (shown in figure 1.6). The daily sewage treatment volume of city's sewage

treatment increased to 4,975,900 m³, and the sewage treatment rate was 78.9% (SMOB, 2009).

The rising total amount of sewage in Shanghai during 2000 to 2009 is presented in table 2.1 and figure 2.1 below.

Table 2.1 Total amount of sewage in Shanghai during 2000 to 2009 (SMOB, 2009)

Year	Amount of industrial wastewater (unit: million m ³ /year)	Amount of household sewage (unit: million m ³ /year)	Total amount of sewage (unit: million m ³ /year)	(unit: million m ³ /day)
2000	896	1,087	1,983	5.43
2001	680	1,270	1,950	5.34
2002	649	1,272	1,921	5.26
2003	795	1,182	1,977	5.42
2004	691	1,363	2,054	5.62
2005	759	1,414	2,173	5.95
2006	731	1,485	2,216	6.07
2007	743	1,509	2,252	6.17
2008	727	1,604	2,331	6.39
2009	654	1,647	2,301	6.30

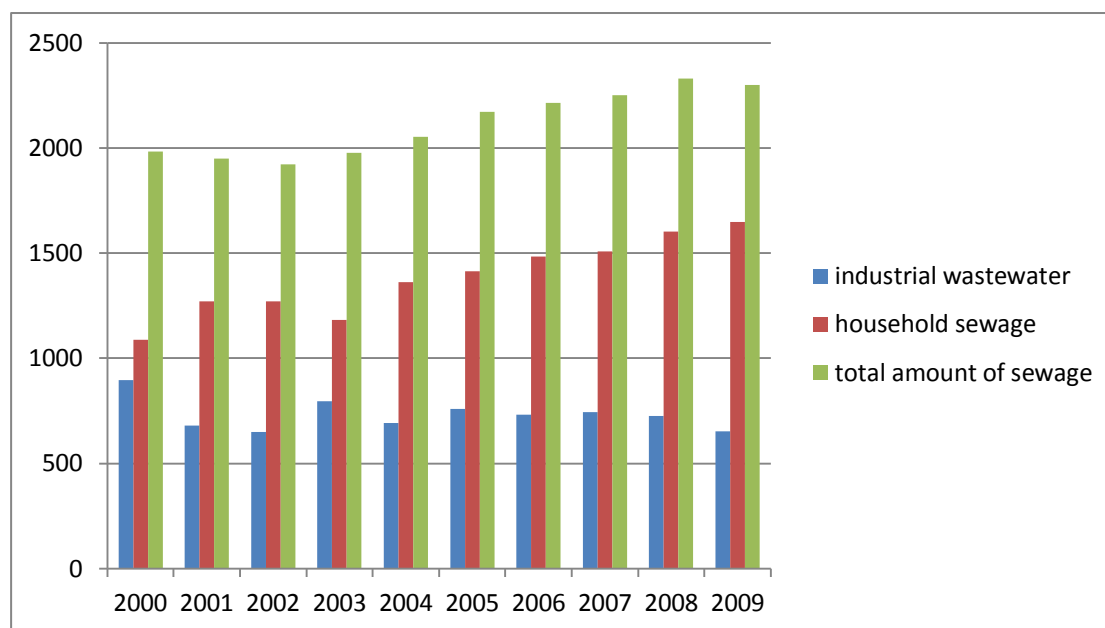


Figure 2.1 A diagram of total amount of sewage in Shanghai during 2000 to 2009 (SMOB, 2009)

4.2 Drainage system

The urban drainage system is an important part of the whole sewerage treatment system. For domestic sewage, industrial waste water and storm water, the Shanghai drainage system can be generally divided into combined and separated systems (Tang, 2007). Storm water and sewage collected separately are referred to as the separated drainage system while combined drainage system collects them altogether in one sewer main (Tang, 2007). Dramatic changes and developments in the Shanghai drainage systems can be seen clearly from past to present, which showed that Shanghai has been committed to finding the most suitable drainage patterns by itself.

4.2.1 Complete combined drainage system

Before Shanghai was opened to foreign trade in 1843, the city only had conventional drainage ditches, thus raw storm and waste water was discharged into nearby rivers. In early opening stages of foreign trade, ditches or culverts were dug in the street. From 1862, the British and French concession started the planning and constructing of rain water pipes. Basically, the Huangpu River, Suzhou Creek, Hongkou and Zhaojiabang were used as the discharge channels for those pipes. At that time, due to regional fragmentation, design principles and standards of pipe network varied much, which resulted in low design standards, poor drainage and severe storm flooding in many areas (Wang, 2007).

4.2.2 Based on combined and in assistance with separated drainage system

In the early 20th century, water closets were brought into use in western-style architectures. Thus plenty of untreated sewage was discharged into rivers, which caused serious water pollution. In 1921, the International Settlement buried fecal sewage pipes and constructed three sewage treatment plants which adopted an activated sludge process. In most parts of the city, a combined drainage system was applied while the incomplete separated drainage system was used in some parts of the city. By 1949, there were 521 km of rainwater pipes, eleven storm water pumping stations, a drainage capacity of 16 m³/s, 117 km of sewage pipes, three sewage treatment plants and a daily treatment capacity of 3.55 million m³ (Wang, 2007).

4.2.3 Complete separated and co-existence with combined drainage system

In the 1950's, the Shanghai government completed development of new residential areas, suburban industrial areas and satellite towns, and the separated drainage system was implemented for those areas. After ten years, six drainage systems were built in new residential areas, and six small sewage treatment plants and three sewage systems were established in the new industrial areas. Meanwhile, technological transformation was done for the original three sewage treatment plants (Wang, 2007). In 1983, the municipal government proposed the policy of “comprehensive and simultaneous management and governance” and adopted the combined co-existence with separated drainage system in Shanghai. A combined drainage system was constructed as the main style. In order to serve new residential areas, four medium-sized sewage treatment

plants were built or rebuilt and another four small sewage treatment plants were constructed (Li, 2008).

4.2.4 Intercepting combined as the main drainage system

In the 1980's, owing to the rapid development of the national economy, the urban sewage amount was about 4.9 million m³ per day. More than 70% of untreated sewage was directly discharged through the combined pipes into the Huangpu River, Suzhou Creek and other rivers, which resulted in serious pollution of the river water (Shen, 2008). Thus, the first and second phases of the Shanghai Sewage Project have been commenced, respectively. These two phases of projects have contributed to intercept the combined and domestic sewage along the Huangpu River and Suzhou Creek, and then discharge into the Yangtze River for volume diffusion and dilution (Liu et al., 2003).

- **During the Shanghai Sewage Project I**

In August of 1983, Shanghai formed a special group to further study wastewater treatment, and the results showed that the most cost-effective approach of governance of Shanghai sewage is to build a main pipe for sewage interception which could block and pretreat existing sewage in the areas of combined sewage (industrial wastewater must be pretreated before being discharged into the main pipe). For new regional wastewater, they were collected separately and then sent into the water bodies through secondary treatment (Gong et al., 1989).

The total length of main pipe for sewage interception was about 34.4 km. The location of the main pipe was decided upon the following major factors (Gong et al., 1989).

- a) Because of the original sewage being discharged into the Suzhou Creek, so the location of the new interceptor mains should be as close as possible to the Suzhou Creek in order to reduce the length of connecting pipes as well as make the best use of existing pumping stations;
- b) underground utility lines, facilities of land acquisition and relocation should be as less as possible;
- c) the distance from the interceptor main to sewage outfall should be as short as possible;
- d) and it should facilitate the construction and maintenance of an intercept main.

By comparison, the first phase of the sewage discharge outlet locations was selected in Zhu Yuan, and the position is shown in figure 2.2 below.

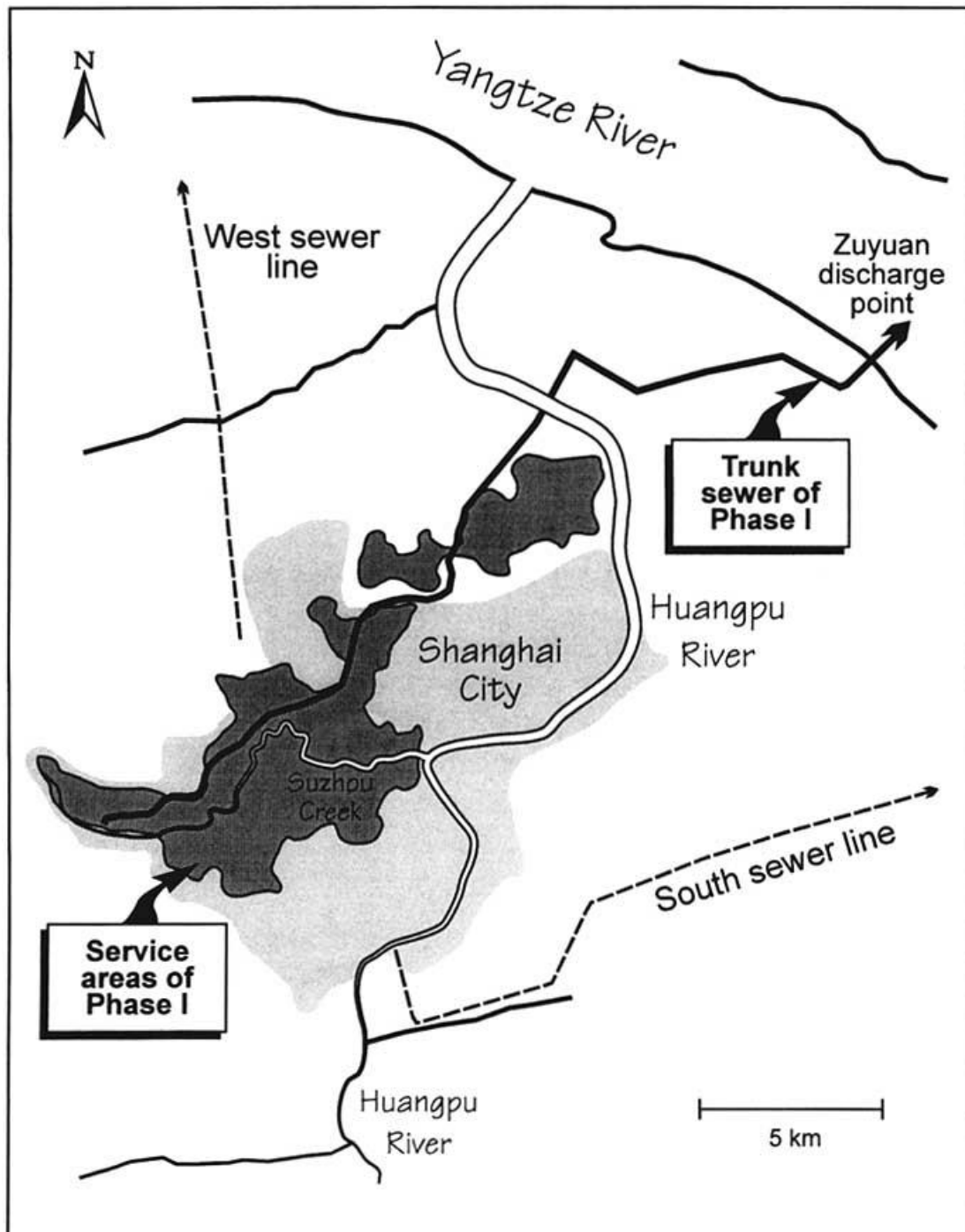


Figure 2.2 A map showing the service areas of SSP1 and a main pipe with a bold line (Zhang, 1997)

- During the Shanghai Sewage Project II

In the project, three main pipes were built to solve the wastewater issues in the upper Wu Jing, Min Hang, Xu Hui, Lu Wan Districts and Pu Dong New Area. The combined

wastewater in the Xu Hui and Lu Wan districts were transported together with wastewater in Wu Jing, Min Hang and Pu Dong districts after being pumped through the Huangpu River to Bai Longgang which was near the Yangtze River estuary. Before being discharged to the sea, wastewater would be merged with the sewage in the original south trunk (Zhang, 1997).

The total length of main pipes was about 24.48 km and two inverted siphon pipes were constructed for the length of 610 meters for each (Zhang and Xu, 2003). A figure below shows the location of main pipe in SSP II.

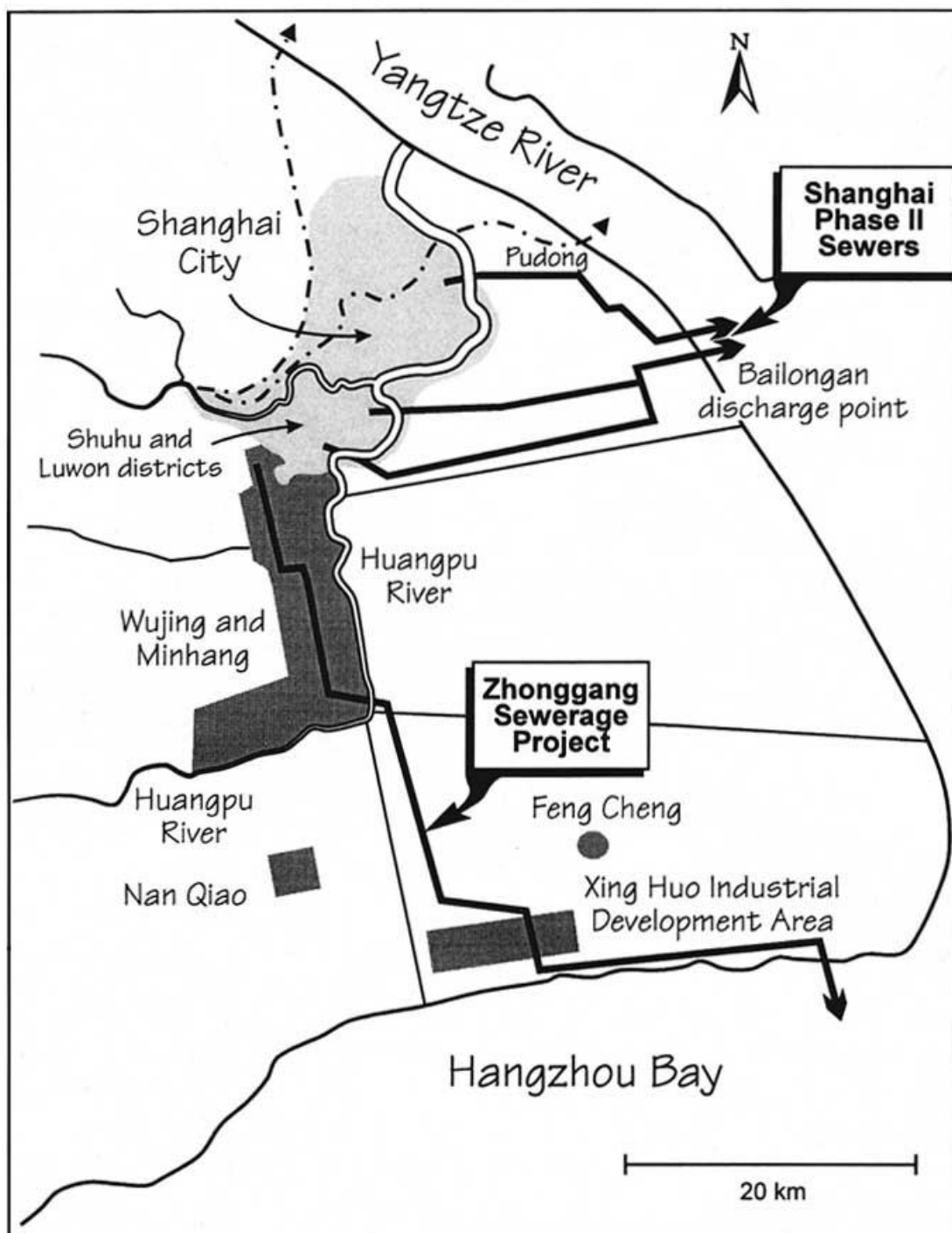


Figure 2.3 A map showing the service areas of SSP1 and main pipe of SSP II (Zhang, 1997)

4.2.5 Intercepting combined and co-existence with separated drainage system

With the economic development of Shanghai, a third main pipe was built and three sewage treatment plants had been built at the end of three largest efflux systems, to meet the requirement for sewage to be discharged into the water bodies. In order to take advantage of the new sewage collection system, Shanghai retained or rebuilt eight sewage treatment plants which were distant from the main sewer collection and the de-nitrogen and phosphorus removal process were enhanced (Wang, 2007).

- During the Shanghai Sewage Project III

From the year 2003, Shanghai began to improve the sewer mains system to address existing gaps of land water way out in the central city. The new main pipe served the north of Suzhou Creek in Pu Xi and Pu Dong districts and other parts of the urbanized areas. The total service area was of 171.68 km and the length of new pipeline was 24.48 km (Yu and Yang, 2004).

Unfortunately, no figure or map was found that showing the exact location of main pipe of SSP III.

In 2005, the city's total number of pumping stations was 500 and the total design flow was $2467.657 \text{ m}^3 / \text{s}$. Since 2004, the Shanghai Water Authority had spent more than two years to complete a census of the city's water sources and found 36,823 wastewater pollution sources. And about one third of which did not enter the sewage collection pipe network. Therefore, Shanghai Water Authority tightened the construction and development of sewage removal and pipe laying (Shen, 2008). In 2005, there were 67 combined drainage systems and 114 separated drainage systems, which covered the

areas of 114.47 km² and 301.11 km², respectively. In addition, there were 39 combined mixing with separated drainage systems, which covered an area of 104.49 km². The distribution of areas of combined or separated drainage systems in 2005 is shown as figure 2.4 (SWA, 2005). By the year 2008, the total length of pipeline in Shanghai was 9,732 km which had been realized the entire pipe network coverage of the urban area (Tian, 2008).

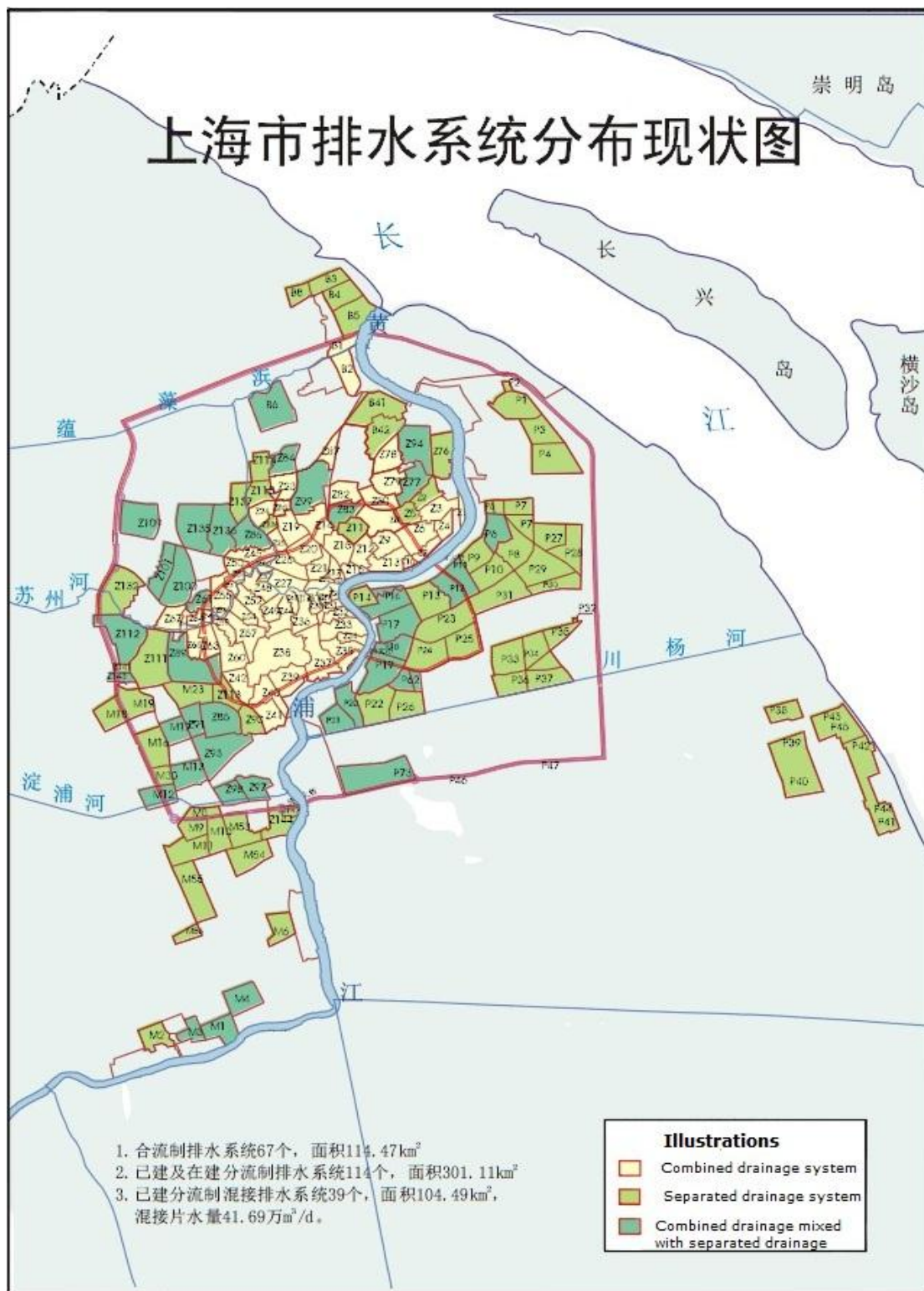


Figure 2.4 The distribution of combined and separated drainage system of Shanghai in 2005 (SWA, 2005)

4.3 Sewage treatment system

4.3.1 The historical evolution of Shanghai sewage treatment system

Shanghai was the first city that used septic tanks for domestic wastewater treatment in China. In 1921, the first municipal wastewater treatment plant was built in Shanghai – The northern sewage treatment plant (Zhu and Tang, 2003).

The daily capacity of northern sewage treatment plant in the early liberation period (Shanghai was liberated in 1949) was 4700 m³. After several periods of expansion and reconstruction, when abolished in the early 90's, the north sewage treatment plant reached a daily capacity of 18,000 m³. The eastern and western sewage treatment plants were constructed in turn around 1926, while the eastern sewage treatment plants are still working now (Zhu and Tang, 2003).

In the 1950's, with the construction of residential areas and industrial zones, three secondary sewage treatment plants (which are the Cao Yang, Peng Pu and Min Hang) and two primary sewage treatment plants (which are the Dong Chang and Ri Hui) were built.

In 1960's, with the help of foreign aid, the northern suburb sewage treatment plant was constructed (Ward and Liang, 1995).

During 1970's, based on reducing river pollution and making use of the idea of environmental capacity in large water bodies - two trunk lines were built to be sewage conveyance route (the south main and the west main), which could be seen in figure 2.2 (Ward and Liang, 1995). The wastewater was transported to Bai Longgang and Shi

Dongkou (two discharging outfalls) through these two main pipes and then discharged into the Yangtze River. At the same time, another sewage treatment plant was built in the Jia Ding district (Yan et al., 2005).

In the 1980's, large-scale sewage treatment (or purification) plants were built one after another (which are Quyang, Tianshan, Longhua, Sitang, Wusong, Chengqiao and Longqiao). With the development of suburban urbanization, several suburban sewage treatment plants have gradually been built (which are Qing Pu, Jin Shan, Zhu Jing, Zhou Pu, Nan Hui, Nan Qiao, Song Jiang, Jia Ding, An Ting and others). At the same time as the changes of history, some aging facilities and old sewage treatment plants gradually have been abolished (Zhu and Tang, 2003).

In the 1990's, Shanghai Tao Pu industrial wastewater treatment plants and the phase II expansion of Song Jiang sewage treatment plant have been accomplished. At the end of 20th century, there were 31 sewage treatment plants in Shanghai with a design and actual processing capacity of 1,006,500 m³ / d and 793,000 m³ / d, respectively (Shao, 2001).

After SPP I and SPP II in 2003, Shanghai government established the basic formation of six centralized sewage treatment systems (shown in Appendix 1) in co-existence with 34 sewage treatment plants (shown in Appendix 2). The total design and actual processing capacity of sewage treatment plants was 1,446,200 m³ / d and 1,168,300 m³ / d, respectively. The sewage treatment rate was 62.8% and secondary rate of which was only 19.8% (calculated after deducting the amount of groundwater infiltration) (Yan et al., 2005).

Although Shanghai had 34 sewage treatment plants with secondary biological treatment (in 2003), most of them are small-scale, obsolete and have a low level of

technology which cannot meet the water quality standards (Zhu and Tang, 2003). The gap between Shanghai and some cities in China as well as some developed countries are mainly in three aspects.

Firstly, there has been a big gap in sewage treatment rates. The daily amount of Shanghai sewage has reached 5.43 million m³ in 2003, and the secondary sewage treatment of which was only 1.2 m³ / d, the actual rate of secondary treatment was only 19.8%. The sewage treatment rate was 62.8% which was lower than some cities like Shen Zhen and Bei Jing in China and even lower than the level of developed countries. Even in 2007, the sewage treatment rate in Shanghai was just over 70%. Sewage in Europe and other developed countries had already been highly treated (Swedish EPA, 2006). The comparison is shown in table 2.2 and figure 2.5.

Table 2.2 Sewage treatment rate in big cities of China and European countries in 2003 (Zhu and Tang, 2003)

Sequence number	Countries or cities	Wastewater treatment rate%	Sequence number	Countries or cities	Wastewater treatment rate%	Sequence number	Countries or cities	Wastewater treatment rate%
1	National average	36.5	15	Netherlands	98	29	Greece	69
2	Bei Jing	70	16	Switzerland	96	30	Poland	68
3	Shen Zhen	68	17	Luxemburg	93	31	Spain	68
4	Xia Men	61.8	18	Sweden	93	32	Portugal	65
5	Nan Jing	60.8	19	Germany	92	32	Belgium	65
6	Zhu Hai	60	20	Danmark	89	33	Bulgaria	62
7	Tian Jin	58	21	U.K.	84	34	Hungary	59
8	Hang Zhou	54.6	22	Austria	81			
9	Chong Qing	42.9	23	Finland	80			
10	Ji Nan	41.5	24	France	79			
11	Chang Chun	32	25	Italy	75			
12	Shen Yang	31.7	26	Norway	73			
13	Guang Zhou	29.3	27	Czech	72			
14	Wu Han	29.3	28	Ireland	70			

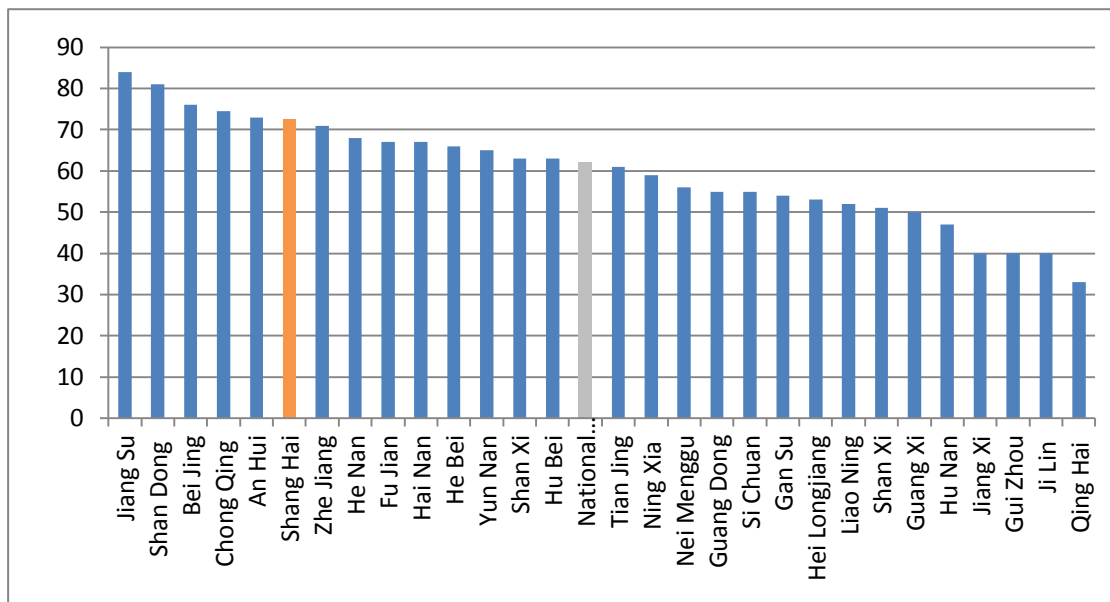


Figure 2.5 Sewage treatment rate in every province of China in 2007 (China's Yearbook of Environment Statistics, 2007)

Secondly, there has been a big gap in treatment levels. The main purpose for sewage treatment is only to remove organic matter (carbon sources), which cannot meet the new domestic requirements of "Cities Sewage Treatment Plant Pollutant Discharged Standard "(GB18918-2002). While the removal of nitrogen and phosphorus in developed countries was relatively high, even in developed countries, the removal of non-biological COD have been set as goals. This part will be discussed in detail in section 4.3.3 based on two cases of study.

Thirdly, there has been a large gap in sludge reduction, stabilization and detoxification. Large quantities of sludge from Bail Longgang were produced during sewage treatment process, but most of them had been concentrated and mechanically dehydrated only or even just concentrated. Very small amounts of sludge had been used during the process of stabilization with anaerobic digestion. So the sludge had been discharged without stabilization and sanitation (Yang, 2003). Most of the sludge has been used as fertilizer or landfill. But in recent years, fertilizer use and river management are subject to certain restrictions, so how the final sludge will be treated is

becoming one of the factors that restrict the running of sewage treatment plants. In many developed countries, sludge has been treated through a series advanced disposal system since the 1960's. For example, sludge digestion, sludge dewatering, sludge drying incineration, biogas utilization, high-temperature composting sludge system, sludge solidification industries, wet oxidation technology and so on have been widely used as final sludge disposal technologies (Zhu and Tang, 2003).

After nearly 20 years of continued and concentrated efforts (especially from 1988 to 2009), Shanghai has completed a solid foundation of long-term battle with water treatment. A detailed comparison of Shanghai sewage treatment in last two decades is shown in table 2.3 and figure 2.6 below.

Table 2.3 The growing of total volume of sewage, number of sewage treatment plants daily capacity of sewage treatment and sewage treatment rate from late 1980's to 2009 in Shanghai (SMOB, 2009; SWEB, 2009)

	Total volume of sewage (unit: million m ³ / day)	Amount of sewage treatment plants	Daily capacity of sewage treatment (unit: thousand m ³)	Sewage treatment rate (%)
Middle and Late 1980's	Around 5	No data	No data	< 20
In 1988	5.3	8	106	24.6
In 1996	No data	31	793	No data
In 2003	5.43	34	1,450	62.8
In 2004	5.62	38	4,190	65.3
In 2006	6.07	45	4,298	70.8
In 2007	6.17	48	4,511	73.1
In 2008	6.39	50	4,812	75.5
In 2009	6.30	52	4,976	78.9

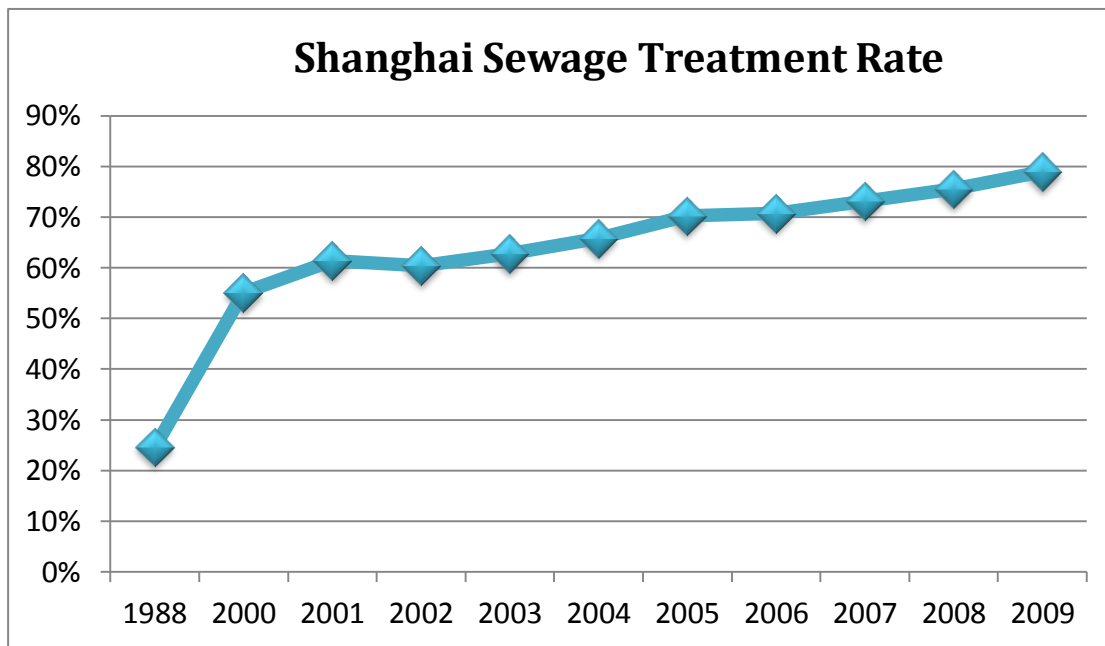


Figure 2.6 Trend of sewage treatment rate in Shanghai from 1988 to 2009 (SWEB, 2009; SMOB, 2009)

It can be seen from the table and figure above that although the total amount of sewage in Shanghai were rising every year, the sewage treatment rate was also in a rising trend (except for a slim fall in 2002). According to that trend, as predicted by Zhang in 2008, sewage treatment rate will reach 90% in 2020 which considered a slight difference in sewage treatment compared with developed countries (Zhang, 2008).

4.3.2 Current Shanghai sewage treatment system (based on 2009)

At the end of 2009, there were 52 sewage treatment plants (shown in figure 2.7 below). The total design treatment capacity was 6,865,000 m³ / day, compared with a net increase of 142,500 m³/ day with that of last year. The actual capacity of sewage treatment plant was 4,975,900 m³ / day, which rising 164,100 m³ / day year-on-year (SMOB, 2009). Following table 2.4 shows the survey of Shanghai sewage treatment in 2009.

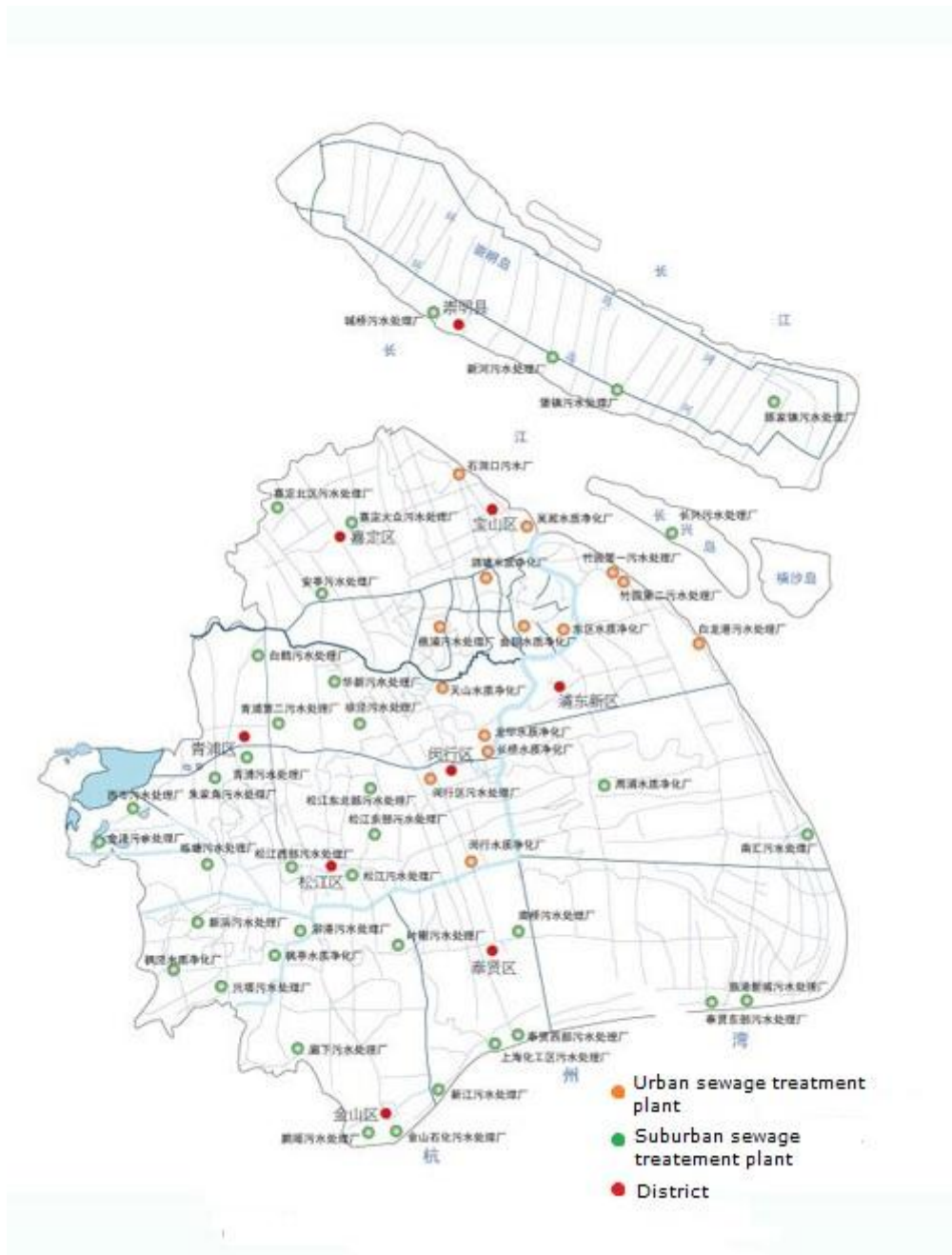


Figure 2.7 The distribution of 52 sewage treatment plants of Shanghai in 2009 (SMOB, 2009)

Table 2.4 A survey of Shanghai sewage treatment in 2009 (SMOB, 2009)

	Total	Urban area	Suburban area
Amount of sewage treatment plants	52	14	38
Design capacity of sewage treatment plants (unit: thousand m ³ /d)	6,865	5,107	1,758
Actual capacity of sewage treatment plants (unit: thousand m ³ /d)	4,975.9	3,790.3	1,185.6
Amount of sewage produced (unit: thousand m ³ /d)	6,304.9	4,365.4	1,939.5
Sewage treatment rate (unit: %)	78.9	86.8	61.1
Abatement of COD (unit: thousand tonnes)	403.6	291.6	112.0

4.3.3 Case study

a) Shanghai Bai Longgang sewage treatment plant

(1) Brief background

The Shanghai Bai Longgang sewage treatment plant is one of the key projects in the second phase of SSP II. The plant was built in 1999. Both combined and separated sewage was collected (Xu et al., 2003). In 2003, the daily capacity of the plant was 1.72 million m³ which served an area of 271.17 km² and a population of 3,557,600 (Yang, 2003). However, with the rapid increase in the amount of sewage in 2006, the actual inflow of sewage has been stabilized at 1.5 to 1.8 million m³/d and the peak inflow reached 2.0 million m³/d, which exceeded the design capacity. As a result, the plant was expanded and upgraded in 2007. After transformation, the design capacity of the plant was 3.45 million m³/d and the actual capacity (in 2008) was 2.0 million m³/d (Zhang et al., 2008). This enabled Bai Longgang sewage treatment plant to be the largest sewage treatment plant in Shanghai as well as in Asia (Tian, 2008).

(2) Treatment process

Contrary to the conventional AA/O process (wastewater will pass through Anaerobic-Anoxic-Oxic reactors in turn), an inverted AA/O process (wastewater will pass through Anoxic-Anaerobic-Oxic reactors in turn) was applied in Bai Longgang sewage treatment plant (Zhang et al., 2008). A schematic diagram of the process is shown below.

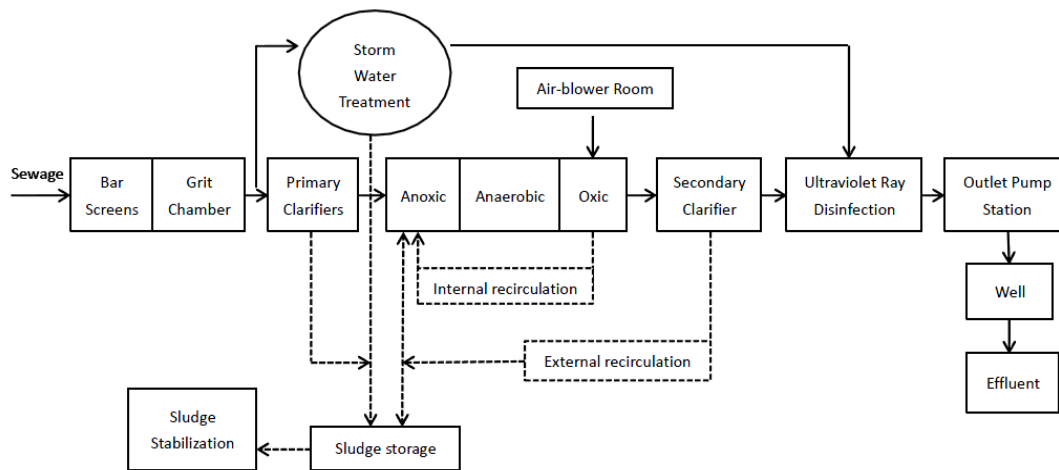


Figure 2.8 A schematic diagram of treatment process in Shanghai Bai Longgang sewage treatment plant (Zhang et al., 2008)

In the process, the bar screens, grit chamber and primary clarifiers considered as primary treatment process. And the conventional activated sludge treatment system and secondary clarifiers are secondary treatment processes. The final step of secondary sewage treatment process is disinfection, which purpose is to kill residual bacteria in the water.

The design water quality indexes of sewage inflow and outflow in 2007 are shown as a table below.

Table 2.5 The design water quality indexes of sewage inflow and outflow of Bai Longgang in 2007

(Zhang et al., 2008)

Items	COD _{cr} (unit: mg/L)	BOD ⁵ (unit: mg/L)	SS (unit: mg/L)	NH ³ -N (unit: mg/L)	Total P (unit: mg/L)
Design influent (Range)	250 - 320	100 - 150	120 - 200	20 - 30	3 - 5
Design effluent	100	30	30	25	3
Removal rate (%)	60 - 68.75	70 - 80	75 - 85	Maximum 16.7	Maximum 40

b) Halmstad V ästra stranden's wastewater treatment plant

Information and data in this section was acquired directly from Halmstad V ästra stranden's wastewater treatment plant.

(1) Brief background

V ästra stranden's waste water treatment plant, with the average daily treatment capacity of 30,240 m³ (140,000 population equivalents, abbreviate: p.e.), is one of the biggest tertiary treatment plants in Sweden. It serves an area of 4,595 hectares (45.95 km²).

(2) Treatment process

The treatment process of V ästra stranden's waste water treatment plant is shown below.

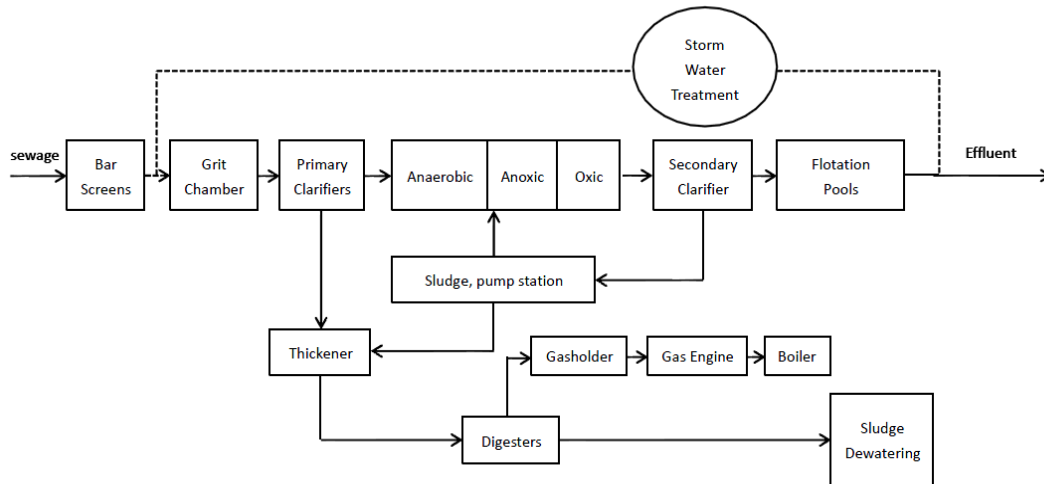


Figure 2.9 A schematic diagram of treatment process in Västtra stranden's waste water treatment plant

In this plant, a conventional AA/O process was applied. The raw sewage is roughly cleaned mechanically by three grids. After the mechanical treatment, water will be input into the biological stage with both nitrogen and phosphorus removal. Biological stage consists of two reactors in series and three parallel lines that can run in different ways. In subsequent sedimentation process, bio-sludge will be separated from the water. Most of the bio-sludge will be return to the activated sludge basin as return sludge, and excess sludge will be taken out for further sludge treatment. After the biological treatment, water will be fed into flotation pools where chemical precipitation is undertaken. In subsequent steps, flotation pools will separate chemical sludge and lead to sludge oxidation and sludge thickener. Dosage of precipitation chemicals is controlled by means of the phosphorus results produced by the biological phosphorus separation. Finally water will be discharged into a pond system (wetland), where a further treatment is done. The reduction of some important pollutants in 2010 is show below.

Table 2.6 The design water quality indexes of sewage inflow and outflow of Västtra stranden's waste water treatment plant

Items	COD _{cr} (unit: mg/L)	BOD ₇ (unit: mg/L)	SS (unit: mg/L)	NH ₃ -N (unit: mg/L)	Total N (unit: mg/L)	Total P (unit: mg/L)
Incoming influent	/	218	/	/	31	5.2
Outgoing effluent	38	3.4	5.3	2.2	2.2	0.28
Removal rate (%)	/	98.44	/	/	92.90	94.62

Although the capacity, working conditions and pollutants concentration of influent are different between the Shanghai Bai Longgang sewage treatment plant and V ästra stranden's waste water treatment plant, and even though the data was not collected in the same year, there have been sharp contrasts of pollutants concentration in the effluent between two plants. The big gaps are mainly reflected in three aspects – differences of inflow condition, discharge standards and treatment capability.

Due to the absence of detailed inflow data of V ästra stranden's waste water treatment plant, the comparison of inflow condition cannot be made. But it is certain that Bai Longgang sewage treatment plant receives much more industrial water (nearly 30%) than that in V ästra stranden's waste water treatment plant (Yang, 2003).

The effluent of Bai Longgang sewage treatment plant meets the II-class of Nation Discharge Standard of Pollutants for Municipal Wastewater (GB18918-2002) implemented in 2006 (Zhang et al., 2008). While Swedish sewage treatment plants have to meet the Standards of Urban Wastewater (91/271/EEC) of European Union Directives which was implemented in 1991 (Swedish EPA, 2006). These two criteria are shown in comparison below.

Table.2.7 Comparison of requirements for discharges from urban waste water treatment plants in China and European Union (The Council of the European Communities, 1991; China's EPA, 2002)

Items	Secondary class of Nation Discharge Standard of Pollutants for Municipal Wastewater (China) (unit: mg/L)	Standards of Urban Wastewater (91/271/EEC) of European Union Directives (unit: mg/L)
BOD ₅ at 20 °C	30	25
COD _{cr}	100	125
Total suspended solids	30	35
TP	3	➤ 2 (10,000 – 100,000 p.e.) ➤ 1 (more than 100,000 p.e.)
TN	/	➤ 15 (10,000 – 100,000 p.e.) ➤ 10 (more than 100,000 p.e.)
NH ₃ -N	➤ 25 (the temperature from the effluent is superior to 20 °C) ➤ 30 (the temperature from the effluent is inferior or equal to 20 °C)	/

From the table above, there is no significant difference of requirements of BOD₅, COD_{cr} and total suspended solids between two criteria. But for removal of nitrogen and phosphorus, standards of EU Directives are stricter than that of China. Furthermore, there is no explicit limitation of discharging total nitrogen in China, which should be improved in the future.

The effluent discharging from Bai Longgang sewage treatment plant just met the secondary class of Nation Discharge Standard of Pollutants for Municipal Wastewater, while in V ästra stranden's waste water treatment plant, the concentrations of effluent were considerably lower than Standards of Urban Wastewater (91/271/EEC) of European Union, especially for total nitrogen and total phosphorus. The difference in treatment process may be the key reason. Bai Longgang is a secondary treatment plant while V ästra stranden is a tertiary one. A secondary treatment is inadequate in

effectively reducing the concentration of nitrogen and phosphorus in sewage (Nathanson, 2007). Another difference between two plants is the different secondary treatment process.

A conventional AA/O process was implemented in V ästra stranden's waste water treatment plant which considered being the most worldwide used as a biological sewage treatment process. It is not only good to remove COD, and also achieve a higher nitrogen removal. However, the removal of phosphorus is not very satisfactory (Nathanson, 2007). In order to get a high phosphorus removal, chemical treatment in V ästra stranden is needed. The precipitation and floatation process in flotation pools (as figure 2.9 shows) could remove phosphorus at large. It is the reason that the removal rate of nitrogen and phosphorus were highly effective in V ästra stranden's waste water treatment plant.

In the Bai Longgang sewage treatment plant, the inverted AA/O process contributed to remove both ammonia nitrogen and total phosphorus. Owing to the location exchange of anaerobic and anoxic tanks, the recirculation of nitrate nitrogen will be completely removed in denitrification process, and the anaerobic environment will not be disturbed by other factors. As a result, the phosphorus removal rate will increase compared with that in conventional AA/O process. But for the removal of nitrogen, there is no significant increase compared with that in conventional AA/O process (Gao, 2011). But if lower concentrations of pollutants in effluent are demanded, upgrade and enhancement have to be done, for example, tertiary treatment process should be added.

4.3.4 Shanghai suburban domestic sewage treatment

(1) Brief background

The amount of suburban domestic sewage has become larger and larger. But due to the low treatment rate, the pollution was heavy. According to statistics in 2003, of the 232 river courses in the villages and towns (total length of a river should be more than 0.5km) in Pu Dong districts, 55.2 % were worse than class V (National environmental quality standard for surface water) (Zhang and Tan, 2009). Due to scattered wastewater pattern in the suburban area, centralized sewage treatment is not feasible (Gao et al., 2008). For this reason, Shanghai developed the "Shanghai Rural Sewage Treatment Technology Guide" (abbreviate: Guide) aiming at suburban sewage treatment systems (Zhang and Tan, 2009).

(2) Sewage collection

In terms of suburban sewage collection, the "Guide" clearly mentioned that sewage should be collected in separated systems. Among them, the fecal sewage must be treated by septic tanks or bio-gas pools before it is used for agriculture or entering sewage collection and treatment system; and sewage of bath, laundry, kitchen and etc., should directly enter into the sewage collection and treatment system (Zhang and Tan, 2009).

Considered the characteristics and the actual situation in suburban areas of Shanghai, the "Guide" put forward the principles of sewage collection in suburban areas of Shanghai (Zhang and Tan, 2009).

- For the suburban domestic sewage that could directly access to municipal sewers network, it can be incorporated into the urban sewage piping system.

- For the suburban domestic sewage that could not access to municipal sewers network, a separate sewage treatment system could be created. Water will be treated before being discharged in situ.
- Sewage of premises or business in suburban areas could both directly access to urban sewers network and been treated alone or treated with sewage with surrounding sewage treatment system.

(3) Applicable treatment processes and techniques

According to the Shanghai economic level, technology and natural conditions of suburban areas, the "Guide" identified several suitable treatment processes and techniques for sewage treatment which are presented in table 2.8 below.

Table 2.8 Technical scheme of rural domestic sewage treatment in Shanghai (Zhang and Tan, 2009)

Items	Service scope (unit: household)	Capacity (unit: m ³ /d)	Technique process	Standards for discharge	Applicable condition	Construction cost (Unit: Yuan /household)	Operational cost (Unit: Yuan /household)
Court treatment system	1~2 (2~10 persons)	≤1	Courtyard constructed wetlands	Class II of Integrated Wastewater Discharge Standard ^a	When large open area available	500~1,000	0.01~0.025
Small-sized dispersed treatment systems	2~30 (10~100 persons)	1~10	Natural stabilization ponds	Class II of Integrated Wastewater Discharge Standard	When large open area available	/	0.005~0.015
			Embedded sewage filtration process	Class I of Nation Discharge Standard of Pollutants for Municipal Wastewater ^b	When large open area available	2,500	0.02~0.2
			Dispersed treatment facilities	Class II of Nation Discharge Standard of Pollutants for Municipal Wastewater	When large open area not available	1,500~2,500	0.05~0.25
Dispersed treatment systems	30~600 (100~2,000 persons)	10~200	Compound anaerobic ponds/ constructed wetlands	Class II of Nation Discharge Standard of Pollutants for Municipal Wastewater	When large open area available	500~1,000	0.025~0.1

			Compound aerated bio filter ponds/ constructed wetlands	Class II of Nation Discharge Standard of Pollutants for Municipal Wastewater	When large open area available	600~1,000	0. 025~0. 075
			Sewage purification bio-gas pools/ constructed wetland	Class I of Integrated Wastewater Discharge Standard	Higher treatment required, when large open area available	1,000~2,000	0. 025~0. 05
Centralized treatment systems	600~10,000 (2,000~30,000 persons)	300~3,000	Chemical enhanced flocculation process/ constructed wetlands	Class I of Nation Discharge Standard of Pollutants for Municipal Wastewater	Higher treatment required, when large open area available	300~500	0. 1~0. 3
			Combined biological process/ ecological process	Class I of Nation Discharge Standard of Pollutants for Municipal Wastewater	Higher treatment required, when large open area available	1,500~2,000	0. 1~0. 2
			Compound anaerobic process/ contact oxidation process	Class II of Nation Discharge Standard of Pollutants for Municipal Wastewater	When large open area not available	800~1,500	0. 1~0. 3
^a Integrated Wastewater Discharge Standard (DB 31 /199—1997) .							
^b Nation Discharge Standard of Pollutants for Municipal Wastewater (GB 18918-2002).							

Although the “Guide” has provided detailed policies or guidelines of sewage treatment in suburban areas, there are still no guidelines for the sludge issue of sewage treatment. Untreated final sludge could greatly increase the probability of secondary pollution. In addition, due to inadequate and low coverage of drainage system in suburban areas, sewage could not get a systematic and comprehensive treatment. The supervision and management of sewage treatment in suburban areas also need to be strengthened. I believe that in the near future the Shanghai government will gradually improve all aspects of sewage treatment in the suburban areas to make the sewage treatment of entire city better.

5 Conclusion

A basic and general understanding has been obtained through my study on the Shanghai sewerage system. Through indefatigable effort made in the past 20 to 30 years, Shanghai's sewerage treatment system has made remarkable progress. The sewage treatment rate reached 78.9% in 2009, which can be considered a leap compared with the 62.8% figure in 2003, while the rate in 1988 was only 24.6%. Moreover, in 2008, Shanghai has realized the entire coverage of pipeline network in urban areas.

However, those achievements are far from enough if compared with that in developed countries. Many aspects should be improved through my study on Shanghai sewerage system.

Firstly, in Shanghai's drainage system, the problem of combined mixing with separated drainage system is severe. According to statistics in 2005, combined mixing with separated drainage system accounted for about 20.09% in the entire pipe network. Sewage collection in those parts was still in confusion. Further improvements should be done, for example, energetically developing separated drainage system in those areas.

Secondly, in Shanghai's sewage treatment system, standards for effluent discharging should be improved step by step. In order to better improve water quality in Shanghai, the item of total nitrogen (TN) should be added in the standards. Moreover, with the improvement of regulations and standards, tertiary treatment processes are becoming an irresistible general trend in sewage treatment system. Treatment process of sewage treatment plant should be upgraded under the rising limitations and standards which including both the capacity and the capability.

Last but not least, sewage treatment in suburban areas should be paid more and more attentions because of the low sewage treatment rate (61.1% in 2009). Due to the scattered pollution sources in suburban area, small-sized or medium-sized treatment facilities needed to be developed like constructed wetlands of stabilization ponds and etc. The issue of final sludge also needed be treated. To do this, a comprehensive and systematical sewage treatment system should be established in suburban areas.

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Appendix 1

Appendix 1. Six centralized sewage treatment systems in Shanghai in 2003 (Zhu and Tang 2003)

Sequence Number	Name of the sewage treatment system	Date of being put into operation	Design capacity (unit: thousand m ³ /day)	Actual capacity (unit: thousand m ³ /day)
1	Shi Dongkou sewage treatment system	1971	800	306.3
2	Zhu Yuan sewage treatment system	1993	1,700	1,690
3	Bai Longgang sewage treatment system	2000	1,700	926.3
4	Xing Huo sewage efflux system	1993	100	26.4
5	Feng Xian sewage efflux system	1998	100	23.6
6	Nan Hui sewage efflux system	1998	150	19.7
	Total		4,550	2,992.3

Appendix 2

Appendix 2. 34 sewage treatment plants in Shanghai in 2003 (Zhu and Tang 2003)

Sequence Number	Name of the sewage treatment plant	Date of being put into operation	Service area (unit: km ²)	Service population (unit: thousand)	Design capacity (unit: thousand m ³ /day)	Actual capacity (unit: thousand m ³ /day)
Total			423.81	3,788.5	1,446.2	1,168.3
Urban Total			96.56	2,839	937	775.9
1	Long Hua water purification plant	1986-10	14	200	105	84.2
2	Qu Yang water purification plant	1984-7	4.5	200	75	54.9
3	Tian Shan water purification plant	1985-12	6.7	330	75	74
4	Tao Pu water purification plant	1997-12	5	55	60	49
5	Min Hang water purification plant	1961-8	28	150	50	55.8
6	Wu Song water purification plant	1992-10	7.8	390	40	33
7	Eastern water purification plant	1926-3	13	800	35	29
8	Cao Yang water purification plant	1954-11	4.5	210	30	24
9	Chang Qiao water purification plant	1992-11	4.94	157	22	21

A General Investigation of Shanghai Sewerage Treatment system

10	Bei Jiao water purification plant	1968-5	2.82	200	20	18
11	Si Tang water purification plant	1992-11	4.9	130	20	22
12	Cheng Qiao water purification plant	1996-10	0.4	17	5	4
13	Shi Dongkou sewage treatment plant	2003	/	/	400	306.3
Suburban Total			98.95	770	272.5	230.6
14	Song Jiang sewage treatment plant	1985-8	36	250	68	47.6
15	Min Hang sewage treatment plant	1985-6	15	120	45	26.6
16	Jia Ding water purification plant	1979-6	19.35	130	30	40.2
17	An Ting water purification plant	1996-10	7.2	30	25	17.4
18	Jin Shan water purification plant	1988-12	3.2	40	17	14.1
19	Zhou Pu water purification plant	1988	4.5	50	12.5	16.7
20	Nan Qiao sewage treatment plant	1990	3.7	70	10	10.6
21	Qing Pu sewage treatment plant	1986	10	80	15	14.2

A General Investigation of Shanghai Sewerage Treatment system

Township and village Total	22	Qing Pu Second sewage treatment plant	2002	/	/	15	11.8
	23	Song Jiang sewage treatment plant	2003	33	/	350	314
				228.3	179.5	236.7	161.8
	24	She Shan sewage treatment plant	1997	0.1	/	6	/
	25	Lian Tang sewage treatment plant	2002-4	205	10	6	/
	26	Zhong Fang sewage treatment plant	1996-12	/	20	5	/
	27	Dong Jing sewage treatment plant	1990	/	15	3	/
	28	Zhao Tun sewage treatment plant	2001-8	/	1.5	5	/
	29	Ying Gang sewage treatment plant	`1996	2	20	1.7	/
	30	Da Guanyuan sewage treatment plant	1988-5	/	10	1.2	/
	31	Si Jing sewage treatment plant	1998	/	/	10	/
	32	Shang Ta sewage treatment plant	1996-6	1.2	3	1	/
	33	San Lin sewage treatment plant	1994	/	/	9	/
	34	Shi Hua sewage treatment plant	1976	20	100	188.8	140

