The Current Situation and Improvement Strategies of Shanghai's Municipal Wastewater Treatment System
上海市における排水処理システムの現状と改善戦略

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Abstract: About six million m^3 of municipal sewage is discharged every day in Shanghai, with 2.5 million m^3 of it free from any treatment. This has caused serious water pollution in the city, damaging industrial production, public health and urban amenities, directly causing economic loss and constraining Shanghai's development. Improving municipal wastewater treatment system effectively and economically is the key for resolving these problems. Based on a field investigation and available statistical data, this paper attempts to identify the problems with current situation of municipal wastewater treatment in Shanghai, and present some ideas on technological measures and policies to improve the situation through the forecast of the future trends of wastewater discharge and in the light of experiences in other countries. The main problems include: the disposal capacity of Shanghai's Municipal Sewerage Systems lags far behind city's requirement; residential wastewater keeps increasing and becomes the focus to resolve the problems of municipal wastewater; wastewater discharged from hotels and restaurants, Township and Village Enterprises (TVEs) has not been under control yet; and current financing and contraction system can not satisfy the demand of municipal sewerage development. Ideas on technology choice (large-scale wastewater treatment plant, community plant or Johkaso), wastewater reuse system, sewerage charge, Built-Operation-Transfer (BOT) and Private Finance Initiative (PFI) are discussed as improvement strategies in this paper.

Keywords: *municipal wastewater, sewerage, water pollution, wastewater reuse, Shanghai*

1. Introduction

Shanghai, one of the largest metropolises in China, is facing environmental problems caused by rapid economic development, population growth and urbanization. About six million m^3 of municipal sewage is discharged every day, with 2.5 million m^3 of it free from any treatment,[1] causing a predominant problem of water pollution, and making Shanghai plunging into a relative water shortage. The Suzhou Creek and its 14 tributaries have become black and malodorous over years, and the Huangpu River has unacceptable water quality for more than 150 days per year.[2]

In early 1980s, Shanghai Environmental Bureau organized a study project for controlling pollution in Huangpu River, and Shanghai Sewerage Project (SSP) was proposed as an important measure.[3] This sewerage project was pursuant to the guideline that *"The central wastewater disposal is main, and the dispersed wastewater disposal is supplementary"*. During 1994 to 1997, Shanghai Environmental Science Institute organized another study project on the Huangpu River Water Environment Control.[4] SSP, which relies on dilution, dispersion and self-purification capacity of the great water body of the Changjiang Estuary, was still identified to be a suitable method to promote municipal wastewater treatment compatible with Shanghai's economic condition.

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The SSP strategy was formulated based on the situation in early 1980s, and its main objective was to cope with serious surface water pollution. However, the current wastewater is much different from it was before on quantity, quality and distribution, because the rapid expansion of new urban districts and the replacement and innovation of old urban districts during the past twenty years have greatly changed the land use, industrial structure and population distribution. Moreover, because the finished SSP project and other sewage interception and discharge systems just act as the role of transferring pollutants, although the pollution level of the rivers in urban areas may be rapidly and effectively alleviated, water quality of the Changjiang Estuary and the East China Sea is substandard. In addition, due to the limitation of environmental carrying capacity of the receiving water, facilities for primary and advanced treatment need to be improved quickly since the wastewater is increasing and the demand for coastal environmental protection is strengthening. Therefore, whether the current SSP is economically and environmentally appropriate in terms of city's long-term development becomes questionable, long-term, comprehensive, and effective strategies should be explored to improve municipal wastewater treatment.

2 Municipal Wastewater Treatment

2.1 Water Pollution in Shanghai

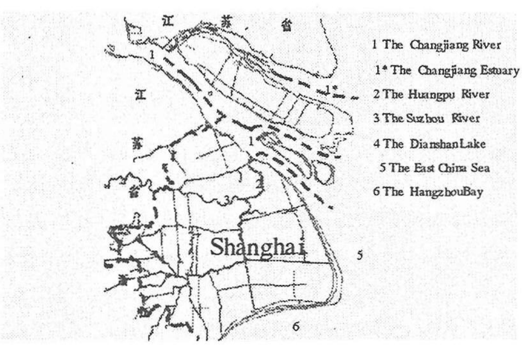

Fig.1 Water System in Shanghai

As a region with intensive networks of rivers and lakes, 11% of Shanghai's land consists of water and the total length of rivers and canals amounts to 32,000 km. It is estimated that about 80% of the drinking water for this area is provided by the Huangpu River, the last branch of the Changjiang River pouring into the Changjiang Estuary (Fig.1), and most of the wastewater is also received by it.[4] It is reported that 2.1×10^9 m^3 of municipal wastewater was discharged in 1997, with the following pollutant loads: 386,000 tons of COD, 3,582 tons of oil, 29 tons of CN^-, 5.0 tons of Cr^{+6}, 0.004 tons of Hg, 0.02 tons of Cd, 4.4 tons of As and 1.7 tons of Pb.[5] The water quality of all the main water bodies in Shanghai area except the Changjiang Estuary were lower than the required water standards according to the monitoring data for rivers in 1997 and seas in 1995.

2.2 Municipal Wastewater Treatment in Shanghai

(1) Overview

In Shanghai, the city's Municipal Sewerage Systems mainly receive residential wastewater, some part of industrial wastewater, and urban runoff. It received about 4.9×10^6 m^3 municipal sewage at an average daily level in 1995, including 2.2×10^6 m^3 or 82% of the total domestic wastewater, 1.4×10^6 m^3 or 8.3% of the total industrial wastewater, and 1.2×10^6 m^3 urban runoff.[4] Industrial wastewater is generally treated, then directly discharged into the ambient water system, although a small fraction enters into the Municipal Sewerage Systems. In 1997, 93.8% of the city's industrial wastewater was treated before discharge,[5] but only 77% of the effluent could meet the required discharge standards in 1995.[4] Through city's municipal Sewerage Systems, 41% of the collected wastewater entered into the branch of the Huangpu River, 22% directly into the Huangpu River and 37% into the Changjiang Estuary.

Before 1949, only the concession areas were served by sewerage and there were only three sewage treatment plants with a total disposal capacity of 20×10^3 m^3/d.[4] By the end of 1995, the area served by sewerage had been expanded to 342 km^2 including 7.47 million residents and 3 million transient population, and the number of sewerage treatment plants had increased to 23 with a total design capacity of 0.74×10^6 m^3/d. In addition, about 2.50 million m^3 of wastewater can be collected and conveyed to the Changjiang Estuary by three sewage interception and conveyance systems every day. However, it is true that the total capacity of Shanghai's Municipal Sewerage System is still far from city's needs. Now, all of the urban population in Shanghai is provided with water supply,[6] but only 58% of them are provided with sewerage service. And the total design flow of 23 wastewater treatment plants only accounts for about one quarter of the domestic wastewater. Fig.2 shows the composition and capacity of Shanghai's Sewerage Systems. Here, Nan Sewer Main will be linked to SSPII that is to be completed in October 1999.

Municipal Sewer System

Built Area Served by Sewer: 342.35 km^2
Population Served by Sewer: 7.47 million resident population and 3 million transient population

Municipal Sewage Treatment Plants

23 Units

Total Design Capacity : 0.74×10^6 ton/d
Aerobic Biodegradation Process

Sewage Interception and Discharge Systems
(1)Nan Sewer Main
Service Area: 40 km^2
Design Flow: 0.55×10^6 m^3/d
(2)Xi Sewer Main
Service Population: 1.50 million
Design Flow: 0.64×10^6 m^3/d
(3)Shanghai Sewerage Project
SSPI
Service Area: 70.57 km^2
Service Population: 2.55 million
Average Dry Weather Flow: $1.40 \times 10^6 m^3/d$
SSPII
Service Area: 271.7 km^2
Service Population: 3.56 million
Average Dry Weather Flow: 1.70×10^6 m^3/d

Fig.2 Shanghai's Municipal Sewerage Systems

(2) Sewer System

A combined sewer system and a separate sewer system are both adopted. The combined sewer system is mainly used in the old urban areas due to the compatibility with the existing old system. In the new urban areas built after 1978, however, the separate sewer system was adopted. In the 1960s, the sewer system in old urban areas was renovated, but complicated distribution, aging and limited capacity are still urgent problems.

(3) Sewage Treatment Plants

The construction history of municipal sewage treatment plants in Shanghai can date back to the 1920s. The earliest three plants were built in 1920s, all of them were characterized by small capacity and a primitive air blow aeration process.[4] The current 23 plants have adopted biological aerobic degradation as a main treatment process. The design flow of the biggest Nonghua plant is only 105×10^3 m^3/d. In comparison with the plants in main cities of industrialized countries, however, the capacity of each plant in Shanghai is relatively small. In Tokyo, there are 7 sewage treatment plants with disposal capacity over 400×10^3 m^3/d, and the largest, Morigazaki plant amounts to $1{,}115 \times 10^3$ m^3/d. As for distribution of Shanghai's sewage treatment plants, 20 plants are located in urban districts while only 3 plants are in counties.

The total design flow of these 23 plants is far lower than the wastewater need to be treated. Moreover, in some plants, sewage treatment facilities stand idle due to inadequate flows, and in some other plants, the sewage treatment water can not meet the required discharge standards due to over loading.[7] This state is mainly the consequence of the policy of "*surface first, underground later*". [7] When new dwelling area was formed, residential buildings were usually constructed earlier than relevant sewage treatment plants and septic tanks are chosen as a transitional method to deal with the discharged domestic sewage. As a result, when the sewage treatment plant starts operation, the underground sewer interface often can not be found or the storm sewer was linked to the plant by mistake due to imperfect management and faulty construction.

(4) Sewage Interception and Conveyance Systems

Early in the 1960s, in order to alleviate surface water deterioration and seek way-out for amounts of sewage, Shanghai government adopted the measure of discharging sewage directly into the Changjiang River. For this, Nan and Xi Sewer Main were completed in early 1970s. In the mid-1980s, a series of sewage interception and conveyance engineering projects were launched with the following slogan: "*Pay close attention to the Suzhou Creek and the Huangpu River, and resolve the problems of the black and malodorous water*".[2] They are SSPI completed in December 1993, SSPII planed to be completed in October 1999 and SSPIII in plan.

SSPI intercepts and coveys wastewater flows originally discharged into the Suzhou Creek to the coast at Zhuyuan, where the wastewater is pretreated, then discharged into the deep water in the Changjiang River for dilution and dispersion. 1.6 billion RMB Yuans (about U.S.$200 million) was invested in this project, of which U.S.$145 million was financed by the World Bank Loan. **SSPII** aims to effectively improve the water quality of the middle and upper reaches of the Huangpu River. The investment of SSPII is estimated at about 5 billion RMB Yuans (about U.S.$625 million), including a loan of U.S.$250 million from the World Bank. The wastewater will be discharged and diffused offshore into the waters of the Changjiang Estuary at Bailonggang after pretreatment.[8]

2.3 Sewage Discharge and Disposal

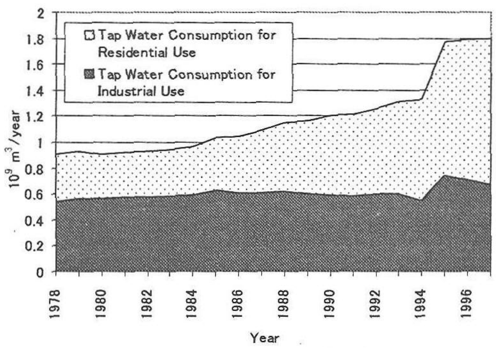

Fig.3 Tap Water Consumption in Shanghai

Data Source: '98 Statistical Yearbook of Shanghai[6]

Fig.3 indicates the tap water consumption, reflecting the change of sewage discharge. The water consumption for residential use kept increasing during the past years, and began to exceed that for industrial use in 1990. During 1994 to 1995, the tap water consummations for industrial and residential uses both increased drastically. The remarkable economic development, rapid population growth in urban area during that period might account for the increases. While the urban population increased with the expansion of delimitated urban area, number of agricultural population immigrated into the city due to the rapid economic development. The total volume of tap water consumption in 1997 reached 2.0×10^9 m^3/year, lower than the total municipal sewage volume of 2.1×10^9 m^3/year published by Shanghai Environmental Bureau. The ignored urban runoff and the water extracted by enterprises themselves may be responsible for this difference.

Rapid increase of residential wastewater is mainly due to the population increase, life standard improvement, and tertiary industry development. Furthermore, wastewater from hotels and restaurants needs more attention because of its high pollution load. There are about 40 hotels and restaurants with a wastewater discharge over 1,000 tons/month, the total wastewater discharged by these 40 hotels and restaurants is about 850,000 tons/month, while only 400,000 tons of it is treated by biochemical disposal facilities.[9] As for 7,000 small and medium sized hotels and restaurants discharging wastewater of between 200 to 1,000 tons /month, only 40% of them are equipped with grease trap, whereas the others have no treatment facilities.[9]

Besides the tertiary industry's pollution, the urgency of controlling TVEs' pollution needs to be underscored. In China, industrial water pollution control is mainly regulated and enforced on state-owned enterprises but effectively exempt from TVEs. With the rapid development of TVEs, they are becoming an increasingly large source of pollution.[28] Effluents from TVEs which generally scattering in rural area now heavily pollute the small tributaries of main rivers, have spread what used to be a relatively concentrated urban problem to a much wider area.[28]

2.4 Financing of Municipal Sewerage Construction

Municipal sewerage construction can not catch up with the economic development and improved life standard in cities. This is mainly due to inadequate funds and an imperfect construction contracting system, accruing from the construction mechanism for municipal sewerage.[22] Prior to 1984, China's municipal sewerage projects were only funded by central and local governments.[22] The users of the completed facilities were not required to pay for the benefits of improved water quality. After "reforming and opening policy" put into effect in 1979, an internal and international bank loan system was established for the municipal construction and maintenance together with direct government funding.[21]

A construction contraction system mainly transferred from the West worked well before 1957, but it was condemned as a capitalist practice and abolished in subsequent years.[22] Municipal sewerage projects similar to other construction jobs were allocated to construction enterprises by the government on the basis of the state annual capital construction plans without any contract between the development organization and the construction enterprise.[22] The major drawback of this practice is the lack of adequate incentives for construction enterprises to control time, cost, and quality. A series of recommendations and laws were issued over the following years to resume the contract negotiations. As a result, *The Tendering Procedures for Works of Building and Civil Engineering Construction* was published in December 1992, which improved government-business relations.

With the reformation of financing system, the investment in capital construction of municipal sewerage increased rapidly year by year during the past 20 years. The average annual investment was 0.24 billion RMB Yuans during 1981 to 1985, 0.45 billion RMB Yuans during 1986 to 1990, and the investment in 1991 grew to 1.02 billion RMB Yuans and 1.41 billion RMB Yuans in 1992.[21] The World Bank and the Asian Development Bank have been funding 100 million British Pounds for Shanghai's urban development and environment. However, only 15% of China's wastewater are currently treated.[22] In the near future, improving the financing system and reforming construction administration is the base to ensures successful implementation of municipal sewerage development plans.

3. Forecasting of the Future Trends

3.1 Economic Development and Industrial Structure Change

According to the development plan of the city, Shanghai will be an international center of economy, finance and trade by the end of 2010.[9] Shanghai's municipal wastewater treatment is facing new challenges with the changes in industrial structure, land use patterns, population density and distribution, and so on. Some main social and economic indicators of today's Shanghai are presented in Tab.1.

During the period of 1981 to 1996, the index of GDP in Shanghai increased at an average rate of 10.1%.[29] By assuming GDP growth rate consistent with the planned national growth rate (8% till 2000, 7% in the period of 2000 to 2010), the index of GDP will reach 6,217 in year 2000, 8,719 in year 2005 and 12,229 in year 2010 respectively (1952=100).

Tab.1 Main Social and Economic Indicators of Shanghai (1997)

Land Area (km^2)	**6,340**	**Life Expectancy (year)**	**77.2**
Urban Area	2,643	Male	75.2
County	3,697	Female	79.2
Population (10^6)	**13.1**	**Natural Growth Rate (%)**	**-**
Urban Area	10.2	Urban Area	-3.0
County	2.9	County	-0.12
Population Density (persons / km^2)	**2,059**	**Building over 8 Storeys (floor space, 10^6 m^2)**	**37.2**
Urban Area	3,854	Urban Area	36.9
County	776	County	0.3
Household (10^6)	**4.6**	**GDP (10^9 RMB Yuan)**	**33.60 (100%)**
Urban Area	3.6	The Primary Industry	0.76 (3%)
County	1.0	The Second Industry	17.54 (53%)
Average Persons per Household	**2.8**	The Tertiary Industry	15.30 (44%)
Urban Area	2.8	**Infrastructure Investment (10^9 RMB Yuan)**	**4.13**
County	2.8	II/GDP (%)	12

Data Source: '98 Statistical Yearbook of Shanghai[6]

3.2 Population Change

Shanghai's total population kept increasing during the past years. It exceeded 10 million in 1959 and reached 13 million in 1997. Urban population has tended to spread from the populated downtown area to the suburbs with the rapid expansion of urban area form 1992. In 1997, there were 10.2 million inhabitants or 78% of city's population in the urban area.

The population of Shanghai in the future can be extrapolated by the following formula:

$$P_y = P_0 \times (1 + r_p)^y$$

Where P_o is the population in 1997, r_p is the average annual population growth rate during 1978 to 1997. It is expected that Shanghai will have a population of 14.7 million in 2010.

3.3 Change in Municipal Wastewater Discharge

It is difficult to extrapolate the change trend of industrial water because the technology improvement in the future can reduce water consumption per unit of output while increasing total output means more water consumption.

Residential wastewater amount can be calculated by following formula:

$$W_y = \alpha \times V_y \times P_y$$

where W_y is average daily generation volume of residential wastewater in year y, V_y is per capita water consumption volume for residential use in year y, P_y is population in the year y, and α is water-wastewater conversion coefficient.

Factors such as living standards, climate condition and life styles determines V_y,[11] in this paper, using the data of index of GDP per capita from 1978 and 1997, Vy is estimated by the following formula:

$$V_y = 12.85972 \times \left(G_y\right)^{0.3535}$$

Based on the above extrapolation, the volumes of residential sewage in the future can be calculated. If the future discharge volume of industrial wastewater keeps at the level of 1997, the discharge amount of total municipal wastewater can be estimated. All the calculated results are shown in Tab.2. The calculated data for residential wastewater amount in 1997 is slightly lower than the published data; it can be considered as the result of that the urban runoff is not taken into account in this prediction.

Tab.2 GDP, Population, Water Consumption and Sewage Generation in 2000, 2005 and 2010

Year	Index of GDP (1952=100)	I*	II*	III*	Total Population 10^6	Water Consumption for Residential Use (l/day/person)	Residential Sewage (10^6 m^3/day)	Municipal Sewage (10^6 m^3/day)
1978	889 (100%)	4%	76%	20%	10.98	137	1.4	-
1997	4,935 (100%)	3%	53%	44%	13.05	237	2.8	5.5
2000	6,217	-	-	-	13.42	254	3.1	5.8
2005	8,719	-	-	-	14.04	282	3.6	6.3
2010	12,229 (100%)	1%	39%	60%	14.69	313	4.1	6.9

Notes: I stands for the primary industry; II* stands for the second industry; III* stands for the tertiary industry. Data in Source of Data in Shadow: 98' Statistical Yearbook of Shanghai*[6]

4. Strategies for Improving Shanghai's Municipal Waste Water Treatment System

4.1 Technology Choice

(1) Large-scale Wastewater Treatment Plants

In view of economic efficiency and environmental effectiveness, the most suitable combination of different types

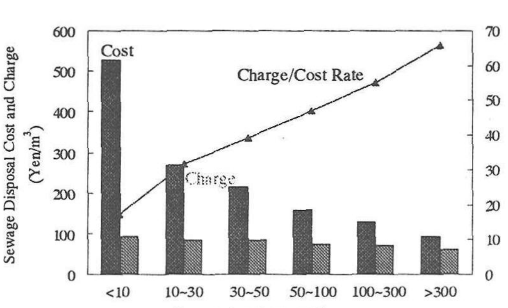

Fig.4 Sewage Treatment Cost and Charge in Japan

Data Source: Sewerage[12]

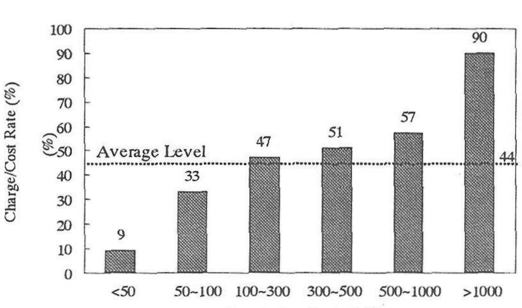

Fig.5 Sewerage Diffusion Rate and Population Scale in Japan

Data Source: Sewerage[12]

of technologies (large-scale centralized plant and small-scale community plants) should be worked out. In such a densely populated metropolis as Shanghai, the role of a central treatment system is absolutely essential. The fact in Japan shows that the greater the population scale, the cheaper the disposal cost of per unit of sewage is (Fig.4), and the sewerage diffusion rate (the percentage of population served by sewerage in an area to its whole administrative population) therefore appears an increasing tendency with the increase of population scale (Fig.5). In addition to population, population distribution and density are also important factors that directly influence the construction cost of sewer system. Here, consideration of the situation in Japan may be useful: About two thirds of the investment in sewerage in Japan is devoted to sewer system and only one third for sewage treatment plants.[12]

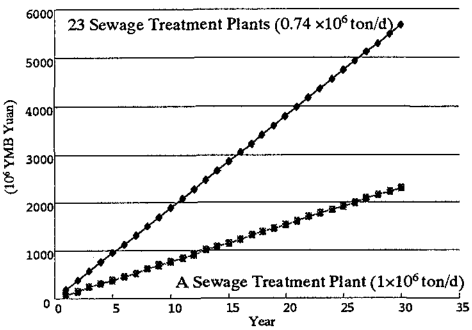

Fig.6 Accumulated Operation Charges of Different Scale Sewage Treatment Plants

It is desirable to establish large-scale centralized sewage treatment plants as substitutes for the many, dispersed, low-efficient, high-cost, and small-capacity plants in Shanghai's old urban areas, where there are 6.32 million population and the population density is as large as 33,678 persons/km^2. As suggested by the experiences in large cities of Japan, it took a long time and large costs to improve the sewer and wastewater treatment systems.[12] That is the very reason why small-scale treatment facilities have been preferred in hotels and other large buildings in Shanghai. However, the cost for a larger plant is smaller than the total sum of the many smaller plants. Fig.6 shows the operation expenditure for a assumed 1 × 10^6 m^3/d plant is far lower than that of Shanghai's current 23 plants (0.74 × 10^6 m^3/d). The accumulated operation expenditure of 23 plants for ten years can build and maintain a 1 × 10^6m^3/d plant for the same time.

(2) Community Plants and Johkaso

In combination with the centralized system, the role of smaller plants is also important. For example, community plants may be a good choice for the community with small population but high density and distant from the central treatment plant, because it is not economically feasible for it to convey sewage over a long distance.

Wastewater generated from rural households rarely receives treatment in China. However, with the rapid improvement of living standards in Shanghai, it will become necessary and possible to install private wastewater treatment facilities in rural households. Now in Japan, the use of combined type Johkaso (combined type of private sewage treatment system) is promoted because of its advantage of remarkably reducing pollution load compared with single type Johkaso (single type private sewage treatment system). The use of similar technology will be a practical method for improving domestic wastewater treatment in rural areas in China. Based on this idea, Japan's technology is being experimented in Wuxi City area in order to improve the contaminated water of the Taihu Lake. The similar technology option can be adopted in the suburban areas of Shanghai.

4.2 Wastewater Reuse System

The wastewater reuse combining wastewater treatment with water supply not only alleviates shortage in water supply, but also decreases the wastewater discharge. In Japan, water provided by wastewater reuse system is used in toilet flushing, cooling water, landscape irrigation, car washing, washing and cleaning, and flow augmentation.[15] In China, wastewater reuse system is not developed because of the high cost of dual-sewer system.[16]

However, in Shanghai, it is becoming necessary to assess the feasibility of wastewater reuse system. One reason is that the increased cost for water supply caused by the movement of water intake point from the heavily polluted downstream to the far upstream of the Huangpu River may make wastewater reuse more economical. Another reason is that the pressures for water supply and wastewater treatment strengthened by increasing water consumption creates a requirement to reusing wastewater as possible. In addition, the dramatic increase of high buildings in populated urban area also creates a benefit condition for using wastewater reuse system. By the end of 1997, there were 2,437 high buildings over 8 storeys and the total floor space of them are 35 million m^2.[6] According to Shanghai's environmental regulation, each commercial building whose space floor exceeds 10, 000 m^2 is required to be equipped with a wastewater treatment facility.[9] The treatment cost per unit of wastewater is very high due to small treatment scale. By using wastewater reuse system in these intensive high buildings, the saving for water supply and wastewater treatment may offset the cost for additional pipe.

4.3 Sewerage Charge

In Shanghai, the use of economic instruments such as sewerage charges is being considered for improving the municipal wastewater treatment system. Although factories have to pay pollution charges (Paiufei), households generally do not pay for sewerage charges. Recently, however, Shanghai began to collect sewerage charges. If sewerage charges were universally introduced and gradually raised to full cost recovery levels, effective economic incentives would be provided for households to decrease wastewater discharge and public investments in wastewater systems would be more financially viable. The comparison on sewerage charges and costs between Japan and Shanghai (Tab.3) shows: the current standard for sewerage charge adopted in Shanghai is only symbolical because it is far lower than cost; and it is potential to limit wastewater discharge and withdraw capital by improving sewerage charge standard further. If a middle-level standard is adopted in Shanghai's sewerage charges, the average sewerage charge per capita and the sum will be 16.92 Yuans and 161 million Yuans a year respectively.[26]

Tab. 3 Comparison of Sewerage Charges between Japan and Shanghai

	Water Charge	Sewerage Charge	Sewage Disposal Cost	Water and Sewerage Charges / Living Expenditure
Japan (Yen/m^3)	158 (100)	109 (69)	206 (130)	1.33%
Shanghai (Yuan/m^3)	0.90 (100)	0.24 (27)	0.70 (78)	0.60%

Data Source: '98 Japan Statistical Yearbook,[19] Sewerage *Statistics-administration volume,*[20] *Water Service Almanac*[14] *and '98 Statistical Yearbook of Shanghai*[6]

To control municipal sewage, adjusting pricing system of water supply is another effective instrument that not only alleviates water shortage but also decrease pollution at same time. Water prices in China traditionally have not reflected resource value and cost recover, subsidized water supply, even for commercial users, is still common in Chinese cities, which has led to widespread inefficiency in water utilization, encouraged industries to adopt water-intensive technologies, and generated inadequate funds for water investment.[28] Therefore, reforms to raise water prices and self-extraction fees, reduce the reliance on quotas should be introduced further.

4.4 Financing of Municipal Sewerage Construction

China's municipal sewerage construction can not get along well during a relatively long time. It is mainly due to financing shortage and inefficient administrative capability originated from institutional problems. It is not financially sustainable to use a large sum of government money to subsidize the water supply and wastewater disposal and better regulations and policy coordination could replace direct investment controls.[28] Furthermore, China's increasing market orientation requires a strategy for future environmental protection that goes beyond the command and control measures of the past. This means accelerating economic reforms-reorienting state enterprises so that they respond to environmental penalties, adjusting the pricing system to ensure that it reflects environmental costs, liberalizing international trade to give Chinese industry access to the latest environmental technology, and developing capital markets to provide financing to firms and municipalities supplying environmental infrastructure.

The model known as Built-Operation-Transfer (BOT) and the policy entitled Private Finance Initiative (PFI) can be effective instruments to improve municipal sewage treatment system. The use of BOT mechanism is a way to secure the infrastructure project.[23] BOT entails a concession company providing the design, construction, operation and maintenance of an infrastructure facility for a specified concession period, at the end of which the facility is transferred to the host government free of charge.[23] The PFI is a UK government policy aimed at encouraging private sector investment in public sector projects in order to leverage private sector skills and initiative into the public sector.[24] The aim of the PFI is to increase capital and service provision in an economic environment that is dominated by tight spending controls and, at the same time, to achieve value-for-money savings.[24] In PFI system, the private sector takes the risk of financing, designing, construction and operating the project, and in return the private sector receives payment linked to deliverance and effectiveness of the end product.[25] The PFI has become one of the UK government's main instruments for delivering higher quality and more cost effective public services. Since its launch in 1992, the capital expenditure under the UK government's PFI has reached almost 10 billion English Pounds and is set to continue to rise.[24]

Economic condition in China is very different from UK and other industrialized countries. China is just in the process of transition from planned economy to market based economy, and many state owned enterprises are being privatized. There are not many private companies that have high technological and financial capacities to work for the environment. However, China can learn from the successful experiences of BOT and PFI, and establish its own project financing systems.

5. Conclusion

The construction of Shanghai's Municipal Sewerage System lags far behind city's development. The surface water has been polluted heavily. Although most of industrial wastewater is subject to primary treatment, its purification rate needs to be improved further, especially in suburban areas where a number of Township and Village Enterprises (TVEs) are scattered. The residential wastewater amount increased rapidly during the past several years and exceeded the industrial wastewater amount. But its treatment rate is very low due to limited treatment capacity and management level.

How to deal with the residential wastewater becomes the central point to resolve the problems of municipal wastewater. Among others, the wastewater from hotels and restaurants needs to be given priority in view of its high pollution load. It is economically appropriated to substitute big-scale wastewater treatment plants for current low efficient, small-capacity plants in populated urban area. Wastewater reuse system might have a potential to be used in Shanghai because of the high water price and large water demand in commercial buildings. Economic instruments may play a role to limit wastewater discharge and withdrawing capital for sewerage use by revising the sewerage charge rate. The use of new financing mechanism such as BOT and PFI should be studied taking into account of China's economic and other conditions.

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References:

1 Chen, H.: *Study on Shanghai's Municipal Wastewater Treatment Strategies* (in Chinese), East China Normal University, 1998

2 First Shanghai Combined Sewerage Project Construction Headquarters: *First Shanghai Sewerage Project* (in Chinese & English), Shanghai, China, 1988

3 Ge, H.Z.: *Surface Water Pollution and Control in Shanghai* (in Chinese), Shanghai Environmental Protection Bureau, China, 1999

4 Institute of Shanghai Environmental Science: *The Study on the Huangpu River Water Environment Control* (in Chinese),

1997
5 Shanghai Environmental Bureau: *'98 Shanghai Environmental Bulletin* (in Chinese), 1998
6 Shanghai Municipal Statistics Bureau: *'98 Statistical Yearbook of Shanghai* (in Chinese & English), China Statistical Publishing House, 1998
7 Chen, Z.C.: Strategies for Cleaning the Suzhou River (in Chinese), *Abstracts of Papers Presented in 8th Shanghai's Environmental Science Meeting*, Shanghai Environmental Science Association, 1997
8 Second Shanghai Sewerage Project Construction Headquarters: *Second Shanghai Sewerage Project* (in Chinese & English), Shanghai, China, 1997
9 Gu, P.: *Study on Environment Control and Management Resulting from Rapid Tertiary Industry Development in Shanghai* (in Chinese), East China Normal University, 1998
10 Chen, J.J.: *Research on the Coordination Development of Regional Environment and Economy* (in Chinese), East China Normal University, 1998
11 Kaneko, S.: Water Demand and Urbanization in China (in Japanese), *Viewpoint to East Asia 1999' Spring Volume*, Center of International East Asia, pp.126-139, 1999
12 Katou, E.: *Sewerage* (in Japanese), Hokuto Press, 1997
13 Japan Sewerage Association: *'95 Sewerage Statistics Abstract* (in Japanese), 1997
14 Water Service Edit Room: *Water Service Almanac* (in Japanese), Water Service Industry Press, 1999
15 Okun, D.A.: Water Use in Developing Countries , Water & Wastewater International, 5 (1), pp.13-20, 1990
16 Ma, Z.Y.: Current Situation on Municipal Wastewater Reuse (in Chinese), *Water and Wastewater*, 23 (12), pp.61-63, 1997
17 Ishii, I. and K. Yamada : *Johkaso Revolution* (in Japanese), Goudou Publishing House, 1996
18 Ishii, I. and K. Yamada : *Sewerage Revolution* (in Japanese), Fujihara Publishing House, 1990
19 Statistics Bureau, Management and Coordination Agency: *'98 Japan Statistical Yearbook* (in Japanese), Japan, 1997
20 Japan Sewerage Association: *Sewerage Statistics-administration volume* (in Japanese), 1995
21 Wu, S.: The Current Situation and Development of China's Municipal Sewerage (in Japanese), *Journal of Japan-China Economy Cooperation*, April, 1994
22 Vickridge, I. and Y.Lu : Civil Engineering in China, *Proceedings of The Institution of Civil Engineers: Civil Engineering*, 132, pp.14-23, 1999
23 Keong, C.H. et al: Conditions for Successful Privately Initiated Infrastructure Projects, *Proceedings of The Institution of Civil Engineers: Civil Engineering*, 120, pp.59-65, 1997
24 Grubb, S.R.T.: The Private Finance Initiative-Public Private Partnerships, *Proceedings of The Institution of Civil Engineers: Civil* Engineering, 126, pp.133-140, 1998
25 Tiffin, M. et al: PFI-the Last Chance Saloon?, *Proceedings of The Institution of Civil Engineers: Civil Engineering*, 126, pp.12-18, 1998
26 Zhang, T.Z.: Study on Standard of Municipal Residential Wastewater Discharge Charge (in Chinese), *Water and Wastewater*, 23 (1), pp.5-9, 1997
27 National Statistic Bureau: *A Statistical Survey of China* (in Chinese), China Statistical Publishing House, 1997
28 The World Bank: *World Bank China Library on CD-ROM: CHINA 2020 and other Sector Reports*, Asia 2000 Ltd., 1998