Planning of wastewater treatment and disposal systems of Istanbul metropolitan area

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Abstract Current and future wastewater treatment and disposal strategies of Istanbul city are presented. Istanbul is the largest city of Turkey and has a population of 10 million that may reach about 20 million in 2032. The city is divided into Asian and European sides by the Bosphorus Strait. The Sea of Marmara is an enclosed sea, connected to the Black Sea and Aegean Sea by the straits of Bosphorus and Dardanelles. Therefore, there is very strong and permanent stratification in the Sea of Marmara throughout the year, lower layers carrying Mediterranean and the upper layers carrying Black Sea water. This unique coastal structure of Istanbul necessitated a detailed study to determine the level of wastewater treatment and the location and depth of marine outfalls.

A comprehensive three-dimensional water quality modelling study concluded that tertiary treatment including nitrogen and phosphorus removal is required for the effluent discharges into the Marmara Sea. However, enhanced primary or even primary treatment has been found satisfactory for discharges into the lower layers of the Bosphorus and into the Black Sea. Provisions for upgrading to secondary treatment were recommended. The status of existing and planned wastewater treatment plants and sea outfalls of Istanbul city are also presented. Although the amount of treated wastewater was only 63 percent in 1998, a target of 95 percent treatment level by the end of 2000 has been adopted in implementation plans. All treatment plants are located at or close to the coast except Pasakoy WWTP which is in the catchment area of Omerli Reservoir, the major source of drinking water for Istanbul city. The Pasakoy WWTP has been designed to treat wastewaters collected from the catchment area of Omerli Reservoir to tertiary level before ultimate disposal. The implementation programme together with the cost estimates are given. Total investment on water, wastewater and stormwater projects up to year 2032 is estimated at about 10 billion US Dollars. The share of the wastewater projects in this total is increasing with time. The financial analysis concluded that investments for a Higher Demand Scenario can be realised by raising the water tariffs to 1.0 $/m^3 for Phase 1 and 0.9 $/m^3 for Phase 2.

Keywords Disposal strategies; financial analysis; water tariffs; marine outfall; water quality modelling; wastewater treatment; Istanbul

Introduction

Istanbul city with its 10 million population is the most populous city of Turkey with its historical, economic and cultural significance. A population census has started during the 1950s when the city was the major industrial and commercial center of modern Turkey. As a result, the city has become attractive for those living in other cities and major migrations have started to take place leading to unprecedented population increase. Today one person out of six in the country lives in Istanbul. Consequently, 40% of the Turkish industry is located in this city and almost half of the taxes are collected from Istanbul. Fast growing population and rapid urban development arising from socio-economic and political policies have created infrastructural problems such as water supply, wastewater treatment and disposal.

Population

Assuming the rate of population increase will decrease in the future, the Master Planning Consortium, IMC has made the population projections given in Table 1. Currently, the

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Table 1 Projected Populations and Wastewater Flows (IMC, 1999)

Year	Population (person)	Wastewater Flow (m3/day)
1997	9,300,000	1,596,000
2010	15,160,000	2,601,000
2032	18,336,000	4,210,000

daily amount of water supplied to the city is about 2 million m^3 including industrial water uses.

The aim of this paper is to present and evaluate current and future wastewater treatment and disposal practice and strategies in the light of the studies conducted by the Istanbul Water Sewerage Administration (ISKI). A brief history of the past strategies will also be presented.

Existing and planned treatment and disposal facilities

The existing wastewater treatment plants and the marine outfalls are illustrated in Figure 1 and are summarized in Table 2 and 3. Yenikapi wastewater treatment plant which has been under operation since 1988 has mechanically cleaned screens and aerated grit chambers. The plant has an odor control system using ozone since the plant is close to the commercial district. The effluents are discharged into the lower layers of the Bosphorus at a depth of 60 m. The tracer studies sponsored by ISKI and conducted by the Institute of Marine Science of METU (Ozsoy *et al.*, 1995) have verified the assumptions made in the design of the wastewater disposal system.

Measurements have indicated that the major flux of dissolved organic material through the Bosphorus – and into the Marmara Sea – was the flow of Black Sea water. The soluble organic material from Yenikapi discharge was never observed to exceed 10% of the total concentration in the lower layer of Mediterranean water. The increase in the concentration of dissolved organic matter in the Bosphorus and flowing into the Sea of Marmara during the periods of blockage was of the order of about 10%.

Fecal coliforms were the most direct assessment of the pollution problems which could

Table 2 Existing Treatment Plants

Location	Capacity (m^3/day)	Level of treatment	Current status
Yenikapi	873,000	Preliminary(1)	Under operation since 1988
Uskudar	108,000	Preliminary	Under operation since 1992
Atakoy	35,000	Secondary(2)	Restored and put into service in 1996
Baltalimanı	625,000	Preliminary	Under operation since 1997
Tuzla	1,051,000	Secondary	Completed in October 1998. The operation of the first phase started in October 31, 1998. The plant will be upgraded to the tertiary level

(1) Screening + Aerated grit chamber (2) Trickling filter plant

Table 3 Existing Marine Outfalls

	Length (m)		Diameter (mm)		Depth of	Type of
Location	Land	Marine	Land	Marine	Discharge (m)	Flow
Yenikapi	1200	1180	1600	2000	60	Pressure
Uskudar	122	300	1170	1170	40	Gravity
Tuzla	1012	2203	2200	2200	47	Gravity
Baltalimani	570	300	1600	1600	70	Gravity

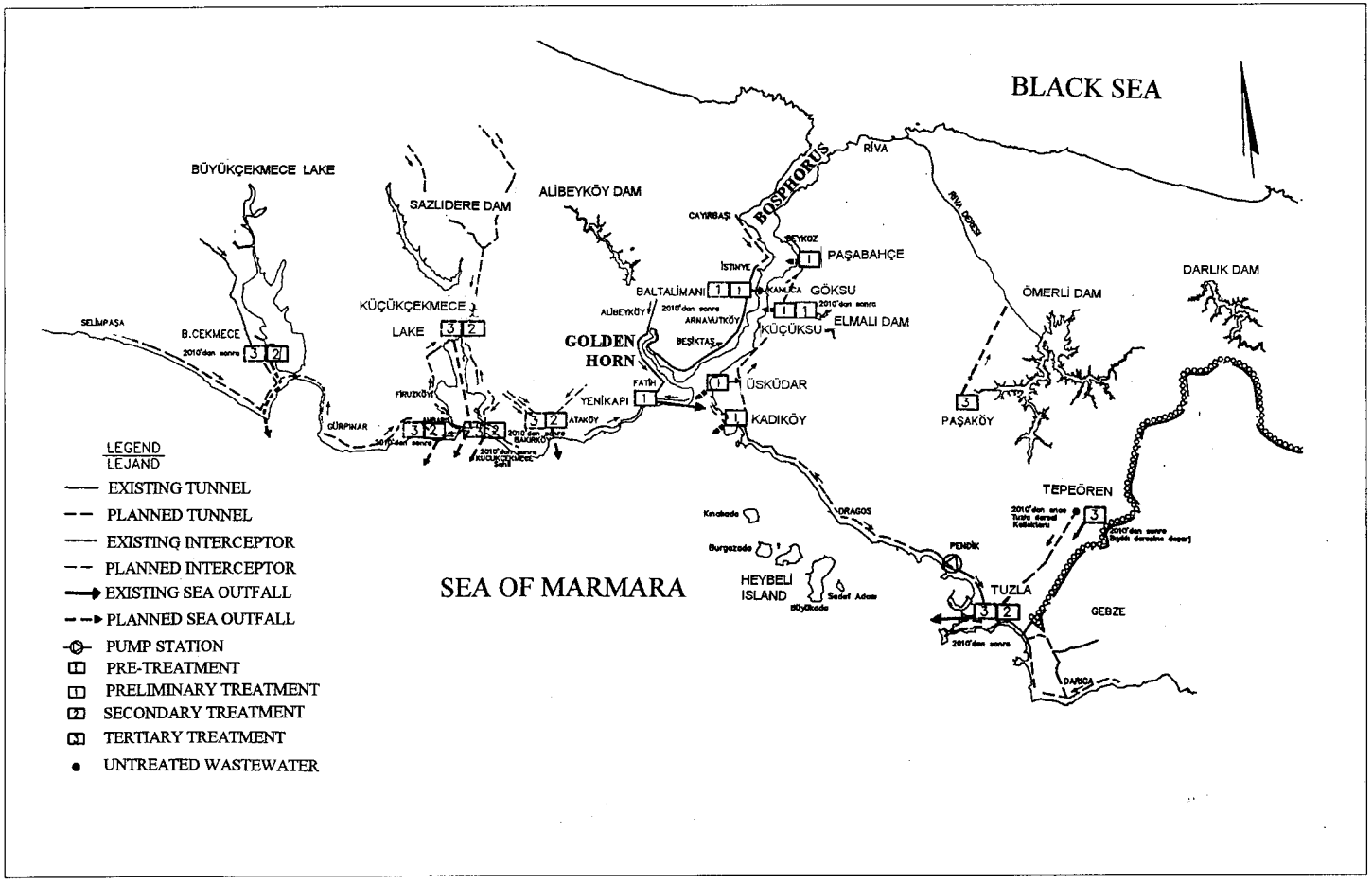

Figure 1 Adopted treatment and disposal strategy

be attributed to the Yenikapi discharge. It has been observed that the fecal coliforms originating from Yenikapi could survive up to to the Black Sea end of the Bosphorus through the lower layer of Bosphorus flow, most probably due to the inability of solar radiation to penetrate into the lower layers.

Atakoy wastewater treatment plant constructed in 1960 was renovated and placed in operation in 1996. Currently, the effluents from this small capacity trickling filter plant are discharged into an open channel which also carries storm water. The performance of the plant after the renovation met the local discharge standards. The average effluent BOD, COD and TSS concentrations were 35 mg/l, 119 mg/l and 43 mg/l respectively for the last 5 months (October 1996–February 1997). The average BOD and TSS removal ratios were about 80%. The plant will be upgraded by adding effluent filtration and disinfection to irrigate the green belts and the parks along the coast.

Comparison of Table 2 and 4 indicates that a significant fraction of the wastewater is treated before discharge. Due to an incomplete wastewater collection system about 25% of the built capacity of the Yenikapi Wastewater Treatment Plant is utilized. Figure 2 gives the distribution of the percentage of treated wastewater with years. As is evident from this diagram there was little increase in percentage of treated wastewater, 9% in 1989 to 16% in 1996. The start of the operation of the Baltalimani, B.Cekmece and Tuzla WWTPs in 1998 increased the percentage of the treated wastewater to 63%. It has been planned that the percentage of the treated wastewater in accordance with the recommendations of the master plan will rise to 95% by the end of 2000.

The results of discharge from Kadıkoy will be monitored. If the results of the monitoring studies prove that a higher degree of treatment is required or national and regional standards require secondary or tertiary treatment, the options of treatment of wastewaters at Goksu or at Riva will be considered in the future. Then, conveyance of the wastewaters from Kadıkoy to Goksu or to Riva using a tunnel will be needed.

Four of the deep-sea outfalls have already been built. Two major outfalls, namely Kadıkoy and B.Cekmece are under construction. Tender documents are ready for the outfall from Kucuksu and the bids will be called soon. K.Cekmece sewerage and outfall are among the priority projects of ISKI.

An improvement in the sea water quality, especially in the Golden Horn is observed after 1998 since discharge of the raw wastewater diminished after completion of the

Table 4 Planned Treatment Works

Location	Capacity (m^3/day)	Level of treatment	Current status (1999)
Pasakoy	322,000	Tertiary	Construction has started, completion time is 18 months.
Kadıkoy	833,000	Preliminary	Under construction, the operation will start by the end of 1999.
Buyuk Cekmece(1)	334,000	Tertiary	Provisional treatment plant is under operation.
Kucuk Cekmece	1,017,000	Tertiary	Under planning stage.

(1) The construction of the provisional preliminary treatment has been completed

Table 5 Planned Marine Outfalls

Location	Length (m) Land	Marine	Diameter (mm) Land	Marine	Depth of Discharge (m)	Type of flow
K.Cekmece	–	1500	–	2200	35	pressure
B.Cekmece	8000	1200	1400	1600	30	gravity
Kadıkoy	–	2280	2150	2150	50	pressure
Kucuksu	1400	488	2150	2150	71	gravity

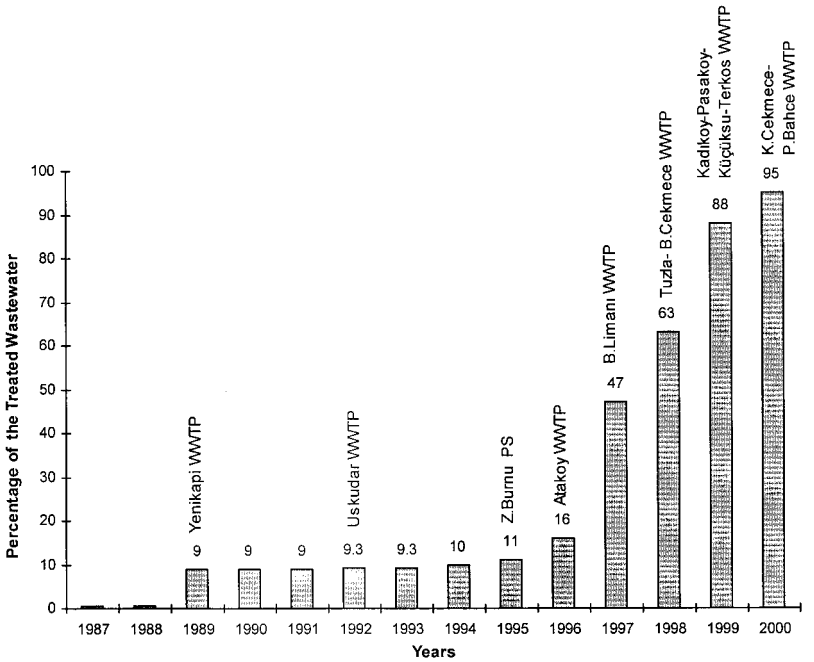

Figure 2 The increase of the percentage of treated wastewater with time

intercepting sewers along the creeks discharging into Golden Horn Estuary, by the end of 1997.

Pasakoy WWTP has been designed to treat the wastewater collected from the catchment area of Omerli reservoir and to treat them to the tertiary level before the ultimate disposal.

Proposed treatment and collection infrastructure

The preferred option, costing just over $4255 million, represents a reduction in capital cost of about $500 million compared to the option proposed by ISKI in 1993. However, it would still require a massive investment of $2128 million in the early years of the program before 2010 in order to commission the identified treatment facilities. These costs cover not only the treatment facilities, but also the associated collection and interception infrastructure, and the marine outfalls.

Provision has also been made for sludge treatment and disposal facilities, which have been based on guidelines proposed by IMC for further investigation by ISKI when it updates its existing sludge management strategy as part of some separate future study. Principal investments in this respect will be regional sludge incineration facilities at Büyükçekmece on the European side and at Tuzla on the Asian side.

The preferred option will also result in a long-term reduction in operation and maintenance costs, amounting to savings over the Master Plan period of about $1200 million (at 1999 prices). The capital cost and the implementation period for the proposed projects are given in Table 6.

Phasing of capital costs

A summary of the capital expenditure in each phase of the Master Plan is given in Table 7. Foreign costs represent those that would be incurred offshore on imported items such as electro-mechanical plant, ductile iron pipes, and specialist services not otherwise available in Turkey. Local costs would mainly relate civil engineering works, locally manufactured

Table 6 Major Wastewater Projects in the Master Plan

Project	Period	Cost (US$ million)
Göksu System		
Preliminary treatment	2000–2004	27.6
Primary treatment	2007–2009/2017–2021	148.5
Conveyance and Disposal	2000–2004/2007–2009	107.8
Tuzla-Tepeoren system		
Tuzla		
Tertiary treatment	2019–2021/2010–2012	186.8
Tepeoren		
Tertiary treatment	2010–2012	41.9
Tuzla-Tepeoren Conveyance	2000–2001	48.3
Pasakoy-Tertiary treatment	2000–2001/2007–2009	32
Conveyance	2000–2001	7.5
Princes Islands System	2004–2009	25
Conveyance and Disposal	2004–2006	3.5
Baltalimani – Primary Treatment	2007–2009/2019–2021	85.5
Yenikapi – Primary Treatment	2007–2009/2015–2017	108.2
Kucuk Cekmece Decentralised System		
Secondary treatment	2000–2005	319.5
Tertiary treatment	2010–2012/2015–2017	254.6
Conveyance and Disposal	2000–2005	165.7
Buyuk Cekmece Secondary Treatment	2000–2001	26
Tertiary Treatment (Stage 1)	2007–2009	44.4
Tertiary Treatment (Stage 2)	2019–2021	79
Conveyance	2000–2001	19
West Marmara System	2004–2006	25.3
	2007–2009	27.7
Conveyance and Disposal	2004–2006	46.2
Terkos and Kilyos		
Terkos (Secondary)	2000	3.5
Kilyos (Preliminary)	2000–2002	6.3
Kilyos (Primary)	2006–2008	20
Conveyance and Disposal Sewerage	2000–2002	16.5
Sewerage		
Sewers	2000–2032	1005
Collectors	2000–2009	217
Rehabilitation	2003–2010	104
Equipment	2000–2001	14
Pumping stations	2000–2005	34.5

goods and services, and labour. Over the remaining Master Plan period to 2032, foreign costs are estimated to amount to US$2.08 billion, which is some 20% of the total investment.

For the purpose of the financial analysis the capital expenditure is divided into four categories:

- water supply projects funded by ISKI
- wastewater projects funded by ISKI
- water supply projects funded by others (e.g. DSI)
- stormwater system

The first three of these categories are treated as expenditures that are incurred by the utility, and must be paid for out of revenues for the sale of water and associated services. Capital expenditure on the stormwater system is regarded as funded by the Municipality and therefore not a charge on the water services.

The water supply projects funded by others are the Yesilçay and Buyuk Melen projects, which are currently being implemented by DSI.

The major difference between the capital expenditure between the Higher and Lower

Table 7 Phased Investment Costs – Higher Demand Scenario (US$ million)

Projects		Phase 1 (up to 2010)		Phase 2 (2010–2020)
Phase 3 (2020–2032)	Total			
Water supply projects funded by ISKI	1542	527	385	2454
Wastewater projects funded by ISKI	2128	1260	867	4255
Water supply projects funded by others	1443	612	56	2111
Sub-total	5113	2400	1308	8820
Stormwater Drainage	513	535	491	1539
Total	5626	2935	1799	10360

demand scenarios is that in the latter case it would be possible to defer the timing of implementation of Buyuk Melen Stage 2 by 12 years, with a starting date towards the end of (financial) Phase 2. In practice it may be possible to defer the timing of other expenditure, but the effect of this would be small when compared with the deferment of Buyuk Melen Stage 2. Furthermore, it should be borne in mind that the primary purpose of this aspect of the analysis is to demonstrate that the Master Plan investment programme remains financially viable even if projected demands, and therefore revenues, are lower than forecast. It is not the intention, at this stage, to completely re-phase the entire Master Plan programme, this being something that should be done in later years if the present apparent trend towards a lower water demand is sustained.

In the case of the lower demand scenario the total investment cost for water and wastewater projects in Phase 1 would be reduced from US$ 5113 million to US$ 4426 million, with an increase in Phase 2 from US$ 2400 million to US$ 2235 million. The investment profiles for the Higher Demand scenario are shown in Figure 3.

The financial analysis for the Higher Demand scenario is presented in Table 8.

In the case of the Higher Demand, the financial situation in the two phases is sharply contrasted. Phase 1 is a period of high borrowing, building up a substantial debt, with a relatively small contribution to investment. Phase 2 is a period where no borrowing is required and it is possible to pay off the whole outstanding debt.

Conclusions

Short and long term strategies for the treatment and disposal of wastewaters based on the water quality modelling studies conducted as part of the master plan are presented. The future population of Istanbul city is estimated at about 20 million in 2032 considering the

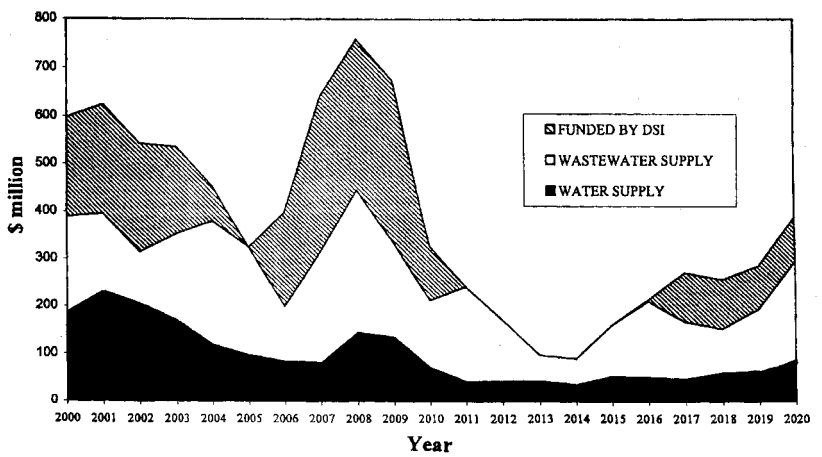

Figure 3 Investment profile for Higher Demand

Table 8 "Higher Demand" Financial Criteria (IMC, 1999)

	Phase 1	Phase 2
Contribution to investment	42.89%	100%
Amount of borrowing (US$ million)	2920	2920
Debt at end of phase (US$ million)	2646	2646
Minimum debt service coverage ratio	1.85	1.85
Revenue at end of phase (US$ million)	1059	1059
Operating ratio at end of phase	55.43%	55.43%
Working ratio at end of phase	37.55%	37.55%
Required tariff (US$/$m^3$)	rising to 1.0	declining to 0.9

population increase rate during the last 35 years. The required levels of treatment were given as primary treatment for discharges into the Bosphorus and Black Sea and as tertiary treatment achieving nutrient removal for discharges into the Sea of Marmara. In either case discharge of the effluents into the lower layers was required.

The percentage of the treated wastewater in accordance with the recommendations of the master plan has reached 63 percent. The implementation plans have been made in order to reach a 95 percent treatment level by the end of 2000. ISKI is also in charge of the control of the industrial wastewaters.

The implementation programme together with the cost estimates were given. Total amount of the investment on water, wastewater and stormwater projects up to the year 2032 is estimated at about 10 billion US Dollars. The share of the wastewater projects in this total is increasing with time. The financial analysis concluded that investments for the Higher Demand Scenario can be realised by raising the water tariffs to 1.0 $/$m^3$ for Phase 1 and 0.9 $/$m^3$ for Phase 2.

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