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Current and Future Strategies for Water and Wastewater Management of Istanbul City

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ABSTRACT / Istanbul has experienced rapid increases in population to more than 12 million people, which has created infrastructure problems of water supply and wastewater treatment and disposal. In this article, the achievements and approaches of the Istanbul Water and Sewerage Administration (ISKI) to solve the water shortage problem and to improve services are summarized. Istanbul had a very severe water shortage problem in 1994 because of ignorance of the implementation of the needed projects. After reviewing the reasons and causes of the problem, new priority criteria adopted after 1994 are given. Following the implementation of the projects determined according to the aforementioned criteria, water supplied has exceeded the water demand. The added capacity is equal to one to three times of the capacity built up to 1994 for water treatment, service reservoirs, pumping stations, transmission lines, and the water distribution network; water quality has been improved the meet local and international potable water standards. Unaccounted for water has been reduced from 60% to 27%. The percentage of treated wastewater has been increased from 10% to 90% in 8 years, resulting in drastic improvements and rehabilitation of the Golden Horn and coastal water quality. Through improved customer services, complaints were reduced from 33% in 1994 to 0.3%. Some of the main criteria and the approaches behind this success are summarized.

Istanbul is the largest city in Turkey uniquely situated on two continents (Europe and Asia). As the major industrial and commercial center of modern Turkey, the city has become a magnet for many migrants from other Turkish cities and villages. Today, one person out of six in the country lives in Istanbul and 40% of all Turkish industry is located within the boundaries of the city. This rapid urban development arising from socio-economic and political policies has created major infrastructural problems such as water supply, wastewater treatment, and disposal (Eroglu and others 2001).

Until recently, Istanbul had experienced chronic water shortages. Interim measures had included importing water by sea tanker and road transport and desalinating seawater—the ultimate affront when ample surface sources were available for development given the will and the finance. However, finance depended on revenue from water sales. Water was frequently not available, and of that put into the network, around 65% became unaccounted for. During the period between 1994 and 2002, new water resources with a total capacity of $3{,}3 \times 10^8$ m^3/year were added to the existing water supply capacity of $5{,}9 \times 10^8$ m^3/year, increasing the available water resources by 56%. Water-treatment-plant capacity tripled in the same 8-year period. Significant improvements were also achieved in water quality by upgrading the existing treatment facilities. Istanbul Water and Sewerage Administration (ISKI) operates approximately 700 km of raw-water and treated-water transmission systems. The distribution network amounted to 11,500 km, of which approximately 93% comprised ductile iron pipe. Under ISKI's ongoing program, the remaining polyvinyl chloride (PVC), asbestos cement, cast iron, and steel distribution pipes will eventually be replaced. In keeping with the increasing capacity of available water resources and water-treatment facilities, the capacities of transmission lines, service reservoirs, and pumping stations were also expanded. During the early years of the period of 1994–2002, great proportions of the ISKI revenues were allocated to water supply projects to solve the severe water shortage problem. However, after meeting the water demands, funds were diverted to wastewater projects, and in 1999, investments in wastewater projects were equal to those of water projects. Increasing the share of wastewater projects continued in the following years and reached the level of 80% in the year of 2002. As a result of the diversion of funds to waste-

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Table 1. Population growth and water demands for Istanbul city from 1990 to 2035

Year	Population[a] (million)	Average raw water demand (m^3/day) Europe	Asia	Total
1995	10.7	1,292,892	819,946	2,111,838
2000	12.4	1,516,325	1,055,110	2,571,435
2010	15.2	1,994,086	1,560,871	3,554,957
2020	17	2,352,845	1,911,305	4,264,150
2030	18.1	2,684,214	2,127,166	4,581,380
2035	18.7	2,848,966	2,209,185	5,058,151

[a]Population growth rate of 2010–2020 and after 2020 are 1.69% and 0.6%, respectively.
Source: IMC (1999)

water projects, the percentage of treated wastewater has increased to the level of 90% by the end of 2003 from the level of 11% in 1994. The target is to treat and to control 95% of the wastewater by the end of year 2004 (ISKI 2001).

The aim of this article is to summarize the achievements of the last 8 years and to present the management approaches which have facilitated significant improvement of the services.

Population and Water Demand

Twelve million people currently live in Istanbul and population growth is almost twice that of Turkey. According to the assessment of the Istanbul Master Plan Study carried out by ISKI, the population of Istanbul will reach 18.1 million people in the year 2030. Istanbul is the most important industrial and commercial center of the country. Migration, together with random development of industry and uncontrolled urbanization, caused the infrastructure to remain insufficient and unsatisfactory. The population of Istanbul increased at a rate of 4.9% from 1955 to 1997. The population, water demands, and treated water of Istanbul from 1990 to 2035 are given in Table 1. Future populations of Istanbul are estimated as 15.2 million in 2010 and 17 million in 2020. A breakdown of the unit water demand and details of the population and demand forecasting are given in the master plan (IMC 1999). The records for 3 years following the completion of the master plan (1999–2002) have demonstrated that the demands were somewhat overestimated in the master plan.

Existing and Future Water Resources

In 1995, Istanbul still suffered from insufficient water supply. In order to provide additional water, the following alternatives were identified (Eroglu and Sarikaya 1998);

1 Construction of new dams
2 Exploitation of the available groundwater reservoirs
3 Desalination of seawater
4 Reuse of reclaimed wastewater
5 Transfer of water from water-rich parts of Turkey by ocean tankers or balloons
6 Reduction in water losses from the following:
a Evaporation from surface-water reservoirs
b Water distribution systems, reservoirs, and transmission pipes between the dams and distribution centers
7 Water conservation using water-saving devices
8 Construction of dual water distribution systems and rainfall harvesting

For effective administration of such a vast water supply and distribution system, it is necessary to implement "Management Optimization." Optimization of the system can provide the release of the same amount of water from the dams at convenient times, with both a more uniform balance and more effective use. Such scientific studies were conducted for the optimum water operation and management for Istanbul surface-water reservoirs.

Substantial investment will be required to harness new water resources in addition to ongoing projects. Currently, ISKI distributes around 2.0×10^6 m^3/day of water from existing resources, and future demand of around 5.0×10^6 m^3/day is projected for the year 2035 (Table 1). All customer connections are installed with water meters of several sizes, according to consumption. As mentioned earlier, recent measurements of water flows do not justify the future demand of 5×10^6 m^3/day. Adjustments are needed for the future water demands based on the actual observations. Details of the existing and planned raw-water sources are given in Table 2, together with their safe yields. Over the 8-year period of 1994–2002, new sources were added and annual yield rose from 5.9×10^8 to 9.2×10^8 m^3 in 2002. Several storage facilities have serious water-quality problems. The lake at Kucukcekmece does not meet the Water Pollution Control Regulation (WPCR) standards for a potable water source. Wastewater projects are under construction to improve the water quality in Kucukcekmece Lake. The reservoirs at Alibeyköy and Elmali are also of poor quality and in danger of exceeding WPCR limits. The water quality of the Buyukcekmece and Omerli reservoirs is also deteriorating. In all cases, the cause is land-based sources of pollution from

Table 2. Existing and planned raw water sources

Source	Average inflow ($\times 10^6 m^3$/year)	Reservoir storage ($\times 10^6 m^3$)	Safe yield ($\times 10^6 m^3$/year)
European side			
Terkos Lake	162.7	145	142
Alibeykoy reservoir	67.4	35	36
Buyukcekmece reservoir	108.8	162	70
Sazlidere reservoir	49.2	61	55
Istranca stages 1 and 2	199.1	146	159.8
Istranca stages 3[a] and 4[a]	155.1	128	129.8
Kucukcekmece Lake[a]	37.3	—	30
European side totals	**779.6**	> 677	**622.6**
Asian side			
Elmali reservoir	14.1	10	15
Omerli reservoir	242.3	235	220
Darlik reservoir	96.4	107	97
Kirazdere reservoir[a]	151.8	55	20
Yesilcay regulators	168.4	0	145
Subtotals	673.0	407	477
Buyuk Melen[a]	1373.5	639	1190
Asian side totals	**2046.5**	**1046**	**1687**
Existing minor sources abandoned on commissioning of Melen stage 1			
European side—various	—	—	6.5
Asian side			
Yesilvadi dam	—	—	10
Sile wells	—	—	30
Total of minor sources	—	—	**46.5**

[a]Planned raw-water sources.
Source: IMC (1999).

the residential and industrial developments in the reservoir catchments. ISKI is currently vigorously pursuing infrastructure construction to intercept wastewater flows in the catchment basin of the surface-water reservoirs.

Current and Future Water-Treatment Technologies

The location of the existing and planned major water treatment facilities in Istanbul city and their respective water sources are shown in Figure 1. There are five water-treatment plants with a total capacity of 2,935,000 m^3/day. Construction of a further extension of the Ikitelli Fatih Sultan Mehmet Han (FSMH) treatment plant is planned with corresponding development from Istranca stream sources. Concurrently, improvements have been made to expand raw-water supplies such as construction of a third pipeline for the Terkos–Kagithane raw-water transmission system. The Buyuk Melen scheme, however, will provide the major raw-water source through a 170 km transmission system to a new treatment plant at Cumhuriyet. This source will be developed in three stages and will ultimately supply 1.19×10^9 m^3/year to the project area. Prior to the beginning of construction of the large transmission system, the Yesilcay scheme, which is already under operation, has a capacity of 1.45×10^8 m^3 of water annually to a new plant at the Omerli treatment works.

Different conventional water-treatment technologies are used, varying from the old Degremont type to recent British and French technologies (pulsator, microsand, upflow sludge blanket, clarifiers). Following a feasibility study funded by the USA Trade Development Agency and carried out by EET Inc. and MIMKO AS., ISKI is upgrading its existing water-treatment plants.

The distributed water quality has been improved significantly as a result of the upgrading work and by training operators to improve operations. About 350 water samples are taken daily from the network to check the compliance of the supplied water (Eroglu and others 2002a). ISKI has upgraded laboratory facilities in order to measure the presence of pesticides, *trihalomethanes* (THMs,) taste, and odor (MIB and Geosmin concentrations), bromide, and bromate. ISKI is applying preozonation in water-treatment works to reduce THMs. Application of preozonation in place of prechlorination has reduced the total THM levels sig-

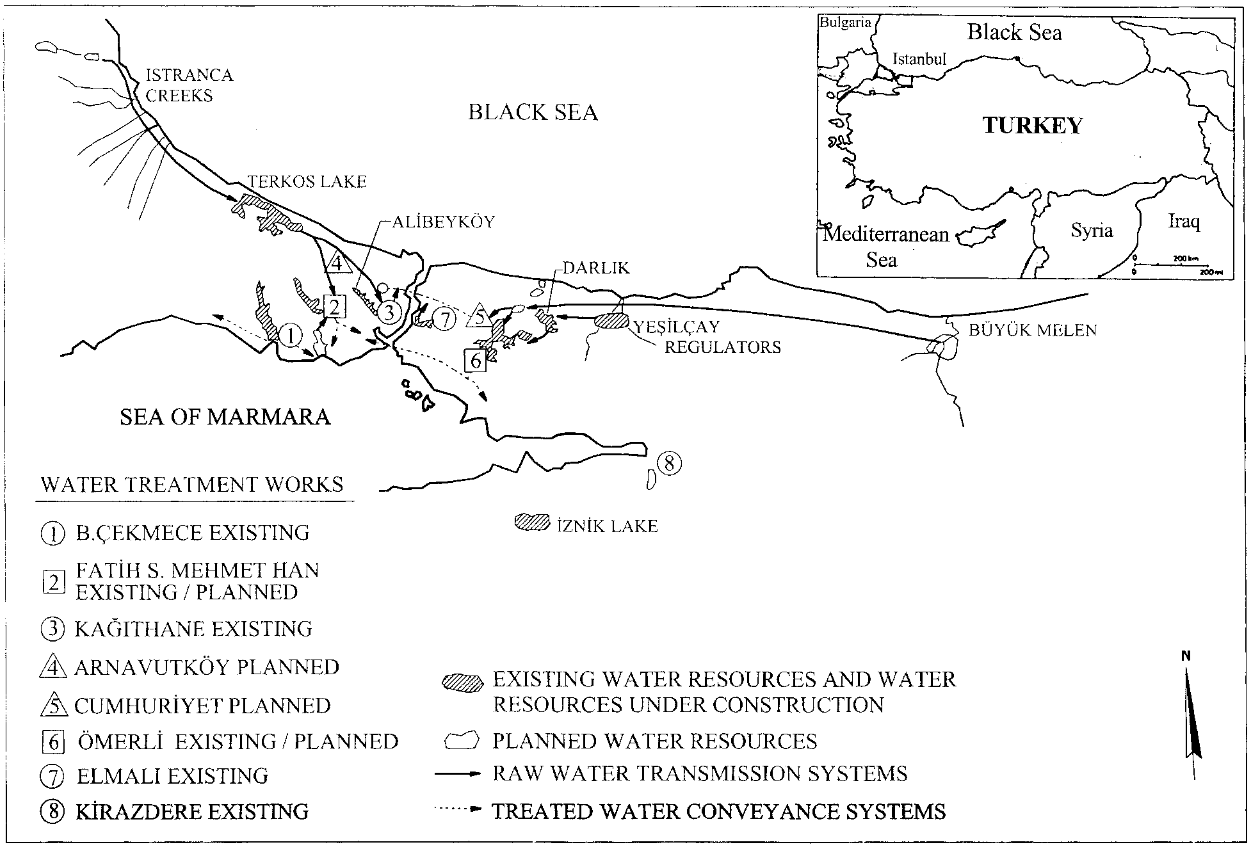

Figure 1. Existing and planned water resources and treatment plants (IMC 1999).

Table 3. Median TTHMs and TOC data for the period of one year 2001 (Eroglu et al., 2002b)

Reservoir	Finished water TOC (mg/L)	Median values of TTHMs (μg/L)
Buyuk Cekmece	2.5–5.0	77
Ikitelli	2.2–4.0	42
Kagithane	1.6–5.0	83
Elmali	1.6–3.0	49
Omerli	1.2–3.0	43

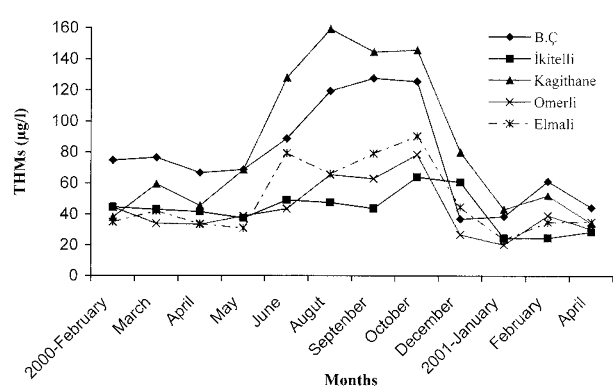

Figure 2. Seasonal TTHMs variations in Istanbul finished drinking waters (Eroglu and others 2002b).

nificantly (89% at Ikitelli FSMH and 65% at Elmali Water Treatment Works). Following the application of preozonation, median levels of total THM were reduced below 83 μg/L for the year 2000 (Table 3). High seasonal variations of total THMs have been observed (Figure 2) (Eroglu and others 2002b).

Maximum total THM levels measured at the Ikitelli, Omerli, Kağithane, and Büyükçekmece water-treatment works were 44.3, 58.8, 86.2, and 86.4 μg/L, respectively, in the period 1996–2002. Although currently there is no limit for total THMs in Turkish Drinking Water Standards, the water supplied to Istanbul meets the European Union (EU) standard (100 μg/L). A sudden increase in the brominated species in the summer months should be given special emphasis because this carries higher risks than chloroform. The maximum total THM values in all of the facilities have been observed in the summer months.

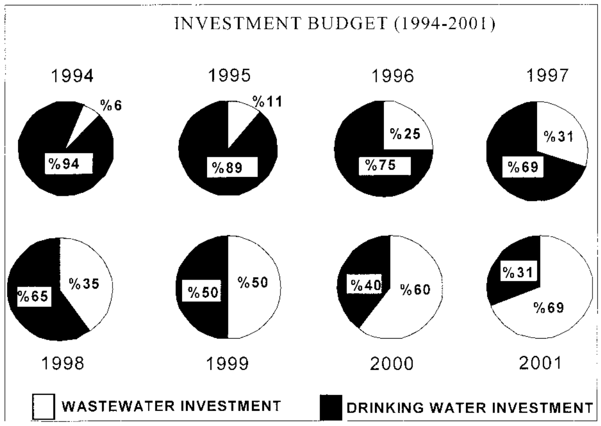

Figure 3. Allocation of the investment budget between the water and wastewater projects (IMC 1999).

Allocation of Funds and Priorities

The administration of ISKI holds a strong belief that the water and wastewater problems of a metropolitan municipality cannot be successfully solved without having a reliable master plan which includes financial analysis and an implementation plan. Therefore, master plan studies were restarted in 1995.

Determination of the priorities in macroscale as well as in microscale (project scale) was given greatest priority to cope with the huge accumulated problems, but with limited financial resources. The projects which provided the highest benefit for a given cost were given the highest priority. The projects were implemented, starting from downstream elements and progressing to the upstream to get the benefit of every meter of pipe laid as early as possible (Eroglu and others 2002a).

To avoid severe water shortages and to increase the revenues generated through water sales, priority was given to the water projects until the water demand was fully satisfied. This was very clearly reflected in the allocation of the budget to water and wastewater projects from 1994 to 2001 (Figure 3).

Although ISKI is also responsible for wastewater, the succeeding years saw a massive early imbalance on the potable water side in the investment budget, with a gradual swing to wastewater as the crucial water supply problems were overcome. ISKI records show that for the years 1994–1996, water supply absorbed respectively 94%, 89% and 75% of total spending, and in more recent years, this fell to 50%, 40% and, in 2001, 31% as the emphasis turned to wastewater. (Sarikaya and others 2002). Over the 8-year period 1994–2002 a programmed upgrading of treatment works and a comprehensive replacement of old cast iron and asbestos cement distribution pipes with ductile iron has raised quality to the levels of WHO guidelines and cut unaccounted for water to 27% of input. Customer complaints have dropped from 33% to 0.3% over the period, and customer service efficiency has been boosted by setting up regional directorates and contracting out the water meter reading and printing and distribution of water bills. Overall management is via a new computer center that makes use of GIS, SCADA, and Internet/intranet systems (Sarikaya and others 2002).

All of these changes, allied to the setting of sustainable and rational water tariffs, have contributed to a much improved revenue flow, and overall operational efficiency of the organization is further strengthened with across-the-board staff training programs and an emphasis on research and development.

Wastewater Treatment and Disposal Strategies

Marine disposal has been adopted as the discharge strategy for effluents in Istanbul. The environmental implications of this for the marine environment will be fundamental in shaping the long-term wastewater-treatment strategy for Istanbul. In developing an appropriate effluent disposal strategy, ISKI has conducted an assessment using previous technical publications and ongoing marine monitoring programs of the oceanography, trophic state, and the water quality of the junction zone bounded by the Sea of Marmara, the Bosphorus, and the Western Black Sea. The Danish Hydraulic Institute modeled marine pollution for ISKI (DHI 1994).

The most important oceanographic characteristic of the seas bordering Istanbul is the existence of a two-layer flow separated by a pycnocline, a phenomenon which occurs throughout the Turkish Straits. The depth of the pycnocline varies from 10 m along the Dardanelles to 20 m in the Sea of Marmara, to 50 m at the entrance to the Bosphorus from the Black Sea. The less saline Black Sea upper layer waters flow through the Turkish Straits system into the Aegean Sea, and the more saline Aegean Sea lower layer waters flow in the opposite direction into the Black Sea. The upper and lower layer flows in the Bosphorus average approximately 20,000 and 10,000 m^3/s, respectively. Hydrodynamic conditions within the Bosphorus cause some intrusion and mixing between the layers, resulting in the return of a proportion of the lower-layer waters to the Sea of Marmara.

The Master Plan (IMC 1999) disposal strategy currently being considered for Istanbul based on the water-quality modeling study conducted by the Danish Hydraulic Institute (DHI 1994) are as follows:

Table 4. Existing and planned wastewater-treatment plants and marine outfall pipes

Location	Capacity (m^3/day)	Level of treatment	Outfall pipe: Diameter (mm)	Outfall pipe: Depth of discharge (m)
Existing plants				
Yenikapi[a]	873,000	Preliminary	2000	60
Uskudar[a]	108,000	Preliminary	1170	40
Baltalimani[a]	625,000	Preliminary	1600	70
B. Cekmece	334,000	Preliminary	1600	30
Kucukcekmece	1,017,000	Preliminary	2200	35
Atakoy[b]	35,000	Secondary	—	—
Tuzla	1,051,000	Secondary	2200	47
Pasakoy	322,000	Tertiary	—	—
Terkos	5000	Tertiary	—	—
Plants under construction or planned				
Kadikoy[a]	833,000	Preliminary	2150	50
Kucuksu[a]	654,000	Preliminary	2150	71
Pasabahce[a]	20,000	Preliminary	1000	70

[a]Screening + aerated grit chamber.
[b]Trickling filter plant.
Source: IMC (1999).

1 *Sea of Marmara:* The wastewater plants at Buyukcekmece, Kucukcekmece, Western Marmara, Tuzla, and the Princes Islands should discharge to the lower layer of the Sea of Marmara through deep outfalls after tertiary treatment.
2 *Bosphorus:* Primary effluents from Yenikapi, Baltalimani, and Uskudar can continue to discharge into the lower layer currents of the Bosphorus and into the lower layer in the Black Sea. Similarly, the other proposed plants at Kadikoy, Kucuksu, and Pasabahce could also discharge into the lower layer currents.
3 *Black Sea:* Wastewater from the Pasakoy drainage area can be discharged into the Riva Stream after tertiary treatment. Effluents from the Terkos wastewater-treatment plants can also be discharged to the Terkos Stream after secondary treatment. Wastewater from the Sile and Kilyos areas could be discharged into the Black Sea after secondary treatment.

At present, the main operational facilities in Istanbul are the pretreatment plants at Baltalimani, Yenikapi, Uskudar, Büyükçekmece, and Küçükçekmece, the biological plants at Atakoy and Tuzla, and the advanced treatment plant at Pasakoy and Terkos. These treatment plants are summarized in Table 4. Pretreatment plants planned at Kadikoy, Kucuksu, and Pasabahce are under construction. In addition, the existing and planned marine outfalls are given in Table 4. The location of the existing and planned major wastewater-treatment plants in Istanbul is shown in Figure 4. Up to 2010, the level of treatment is preliminary for discharges into the Bosphorus and into the Black Sea, and secondary for discharges into the Sea of Marmara. After 2010 (second stage), treatment levels will be upgraded to the primary level for discharges into the Bosphorus and Black Sea and to the tertiary level for direct discharges into the Sea of Marmara (Figure 4). This type of staging is required especially for developing countries where financial resources are limited. Staging of investments is also needed to keep the water and wastewater tariffs at an affordable level (Paraskevas and others 2002).

Originally one large wastewater-treatment plant was considered for the Kucukcekmece basin. Further studies have demonstrated that splitting the capacity of a single plant to four plants is more attractive from an economic as well as a technical point of view (Eroglu and others 2002c). Small settlements, especially in the water catchment basins, will be served with small-scale decentralized treatment units to reduce the cost of wastewater collection (Paraskevas and others 2002; Lim and others 2002).

The percentage of wastewater treated and disposed off has increased sharply in recent years. In 1995, only about 11% of the wastewater could be treated, but by the end of 2002; the percentage of the wastewater treated had reached 90%. The target is to treat 95% of the wastewater by the end of 2003 (Figure 5) (ISKI 2001).

Following the implementation of the wastewater collection, treatment, and disposal projects, significant im-

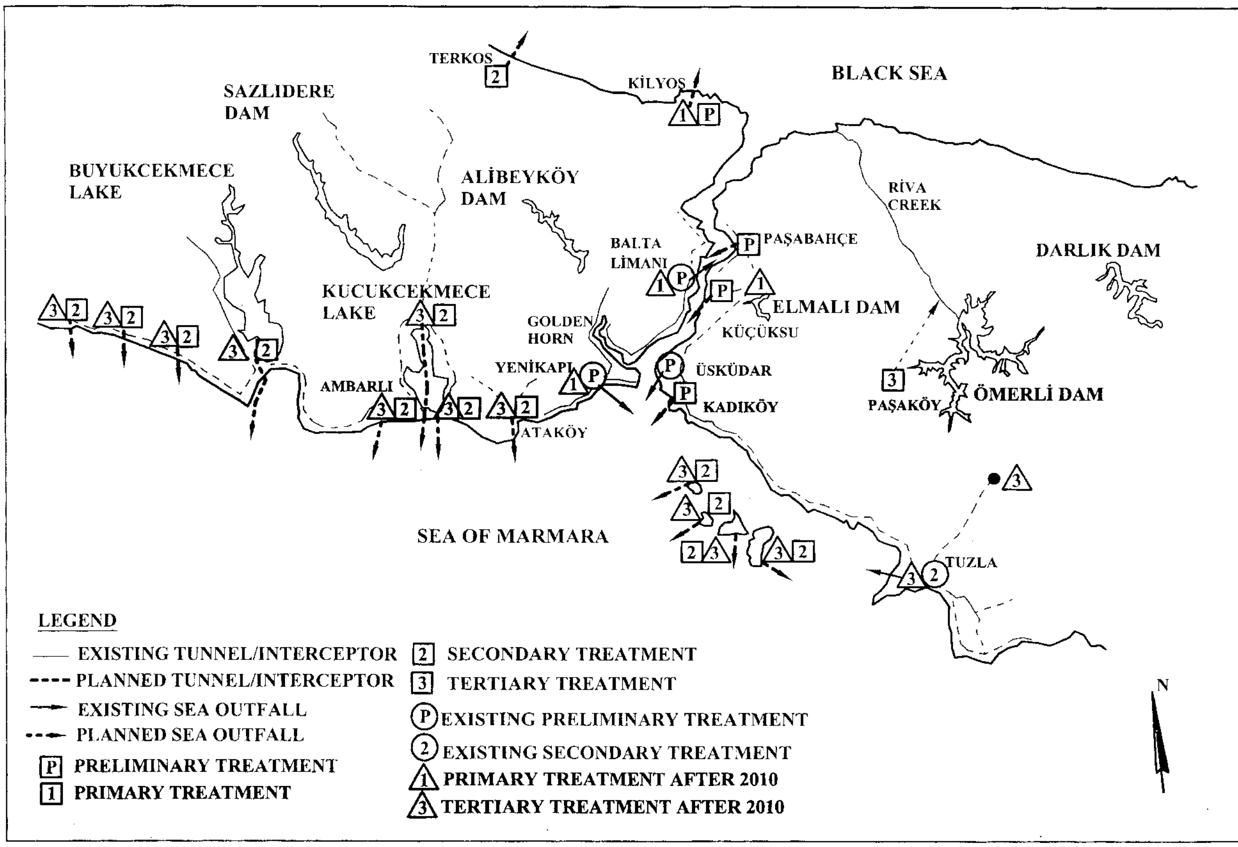

Figure 4. The location of the existing and planned major wastewater-treatment plants in Istanbul City (IMC 1999).

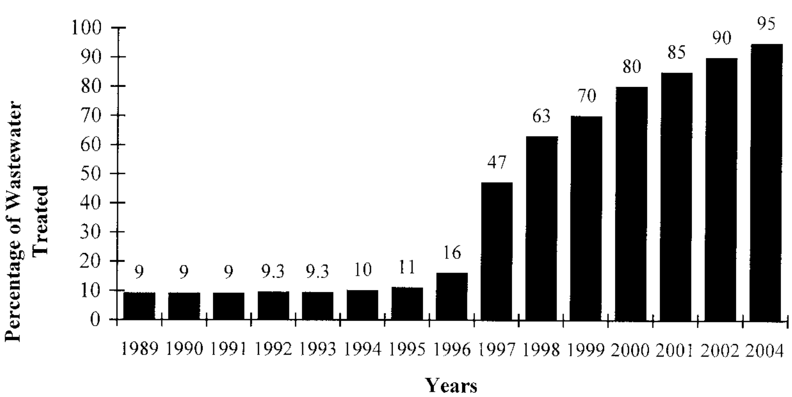

Figure 5. Percentage of wastewater treated versus years (ISKI 2001).

provements were obtained in coastal water quality. Since 1995, coastal water quality has been continuously monitored at about 50 stations. Improvement in bacteriological water quality is obvious from Figures 6 and 7. Figure 6 shows the surface water coliform variation at Besiktas, in the Bosphorus, over a period of time and Figure 7 is for the Golden Horn Estuary, which was totally anaerobic some 5 years ago. Following the interception of the wastewaters from the banks of the Golden Horn and after dredging of 5×10^6 m^3 of sludge from the bottom, the water quality has improved significantly and 27 species of fish have returned to their former habitat. The Golden Horn during the Ottoman period was one of the best recreation areas of Istanbul. As a result of the implementation of the environmental protection and rehabilitation projects, the Golden Horn is now regaining its historical recreational value (Eroglu and others 2002a).

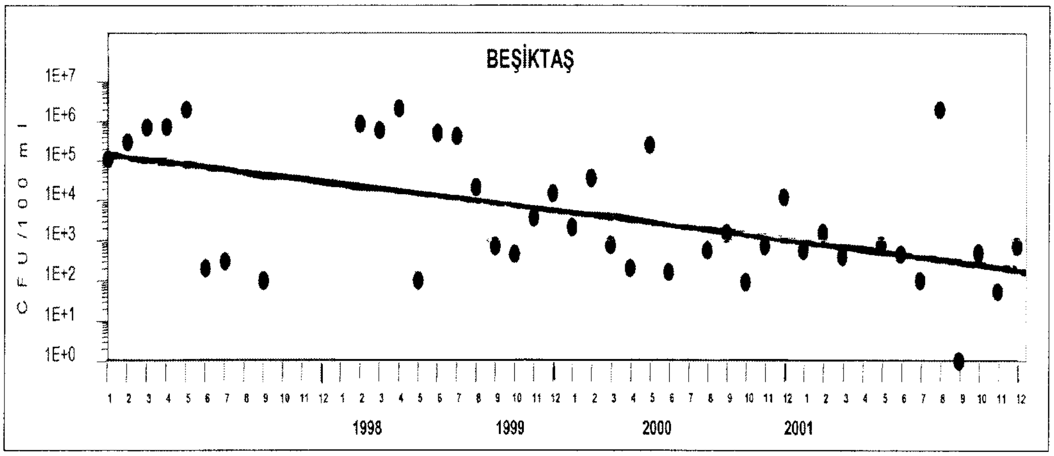

Figure 6. Surface-water coliform variation in Besiktas (in Bosphorus) (Eroglu and others 2002a).

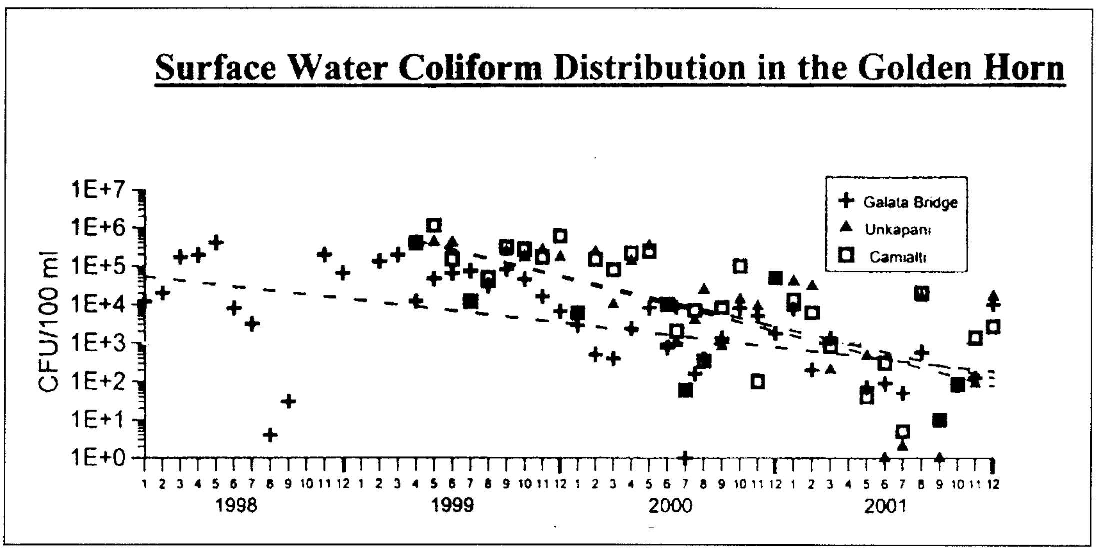

Figure 7. Surface-water coliform variation in the Golden Horn (Eroglu and others 2002a).

Financial Analysis of Investment Program

Capital expenditure for the program can be divided into four major categories:

1 Water supply projects funded by ISKI
2 Wastewater projects funded by ISKI
3 Water supply projects funded by others (e.g., State Hydraulic Works—DSI)
4 Stormwater systems

The first three of these categories are treated as direct expenditures incurred by the utility and must be paid for out of revenues generated by the sale of water, wastewater treatment, as well as associated services. Stormwater systems are funded by the municipality and therefore not charged to the water services. The water supply projects funded by others are the Yesilçay and Buyuk Melen projects, which are currently being built by DSI (State Hydraulic Works).

A summary of the capital expenditure in each phase of the Master Plan is given in Table 5. Foreign costs represent those that would be incurred offshore on imported items, such as electromechanical equipment, ductile iron pipes, and specialist services. Local costs would mainly cover civil engineering works, locally manufactured goods and services, and labor. Over the remaining Master Plan period to 2032, foreign costs are estimated to amount to 2.08 billion US$, which is some 20% of the total investment (Eroglu and others 2001; IMC 1999).

Table 5. Phased investment costs (US$ million)

Projects	Phase 1 (up to 2010)	Phase 2 (2010–2020)	Phase 3 (2020–2032)	Total
Water supply projects funded by ISKI	1,542	527	385	2,454
Wastewater projects funded by ISKI	2350	1,390	1,000	4,740
Water supply projects funded by others	1,443	160	508	2,111
Subtotal	5,335	2,529	1,441	9,305
Stormwater drainage	575	608	555	1,738
Total	5,910	2,685	2,448	11,043

Source: IMC (1999)

Table 6. Financial criteria for the investment program

	Phase 1 (up to 2010)	Phase 2 (2010–2020)
Contribution to investment	38.14%	100%
Amount of borrowing (US$ million)	3300	Nil
Debt at end of phase (US$ million)	2957	0
Required tariff (US$/m^3)	Increasing to 1.0	Declining to 0.9

Source: IMC (1999).

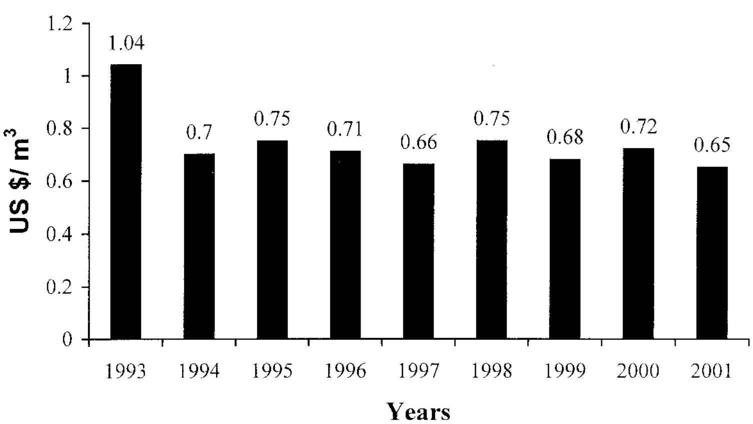

Figure 8. Weighted average water tariffs according to years (ISKI 2001).

Details of the financial analysis for the investment program are presented in Table 6. Financial analysis conducted within the scope of the Master Plan indicate that the weighted average water and wastewater tariffs should be increased to 1.0 US$/m^3 by the end of 2010 from the current level of 0.70 US$/m^3 in order to implement the projects as recommended in the Master Plan (IMC 1999). The changes in weighted average water and wastewater tariffs are illustrated in Figure 8 (ISKI 2001). The program results in sharply different financial situations in the two phases. Phase 1 is a period of high borrowing, creating substantial debt, with a relatively small contribution to investment. Phase 2, on the other hand, is a period during which no borrowing is required and there is a pay down of online debt.

Conclusions

Istanbul is the largest city in Turkey, which is a developing country that has experienced the transition from the status of poor water supply service to the level of continuous water supply with quality meeting national and international standards. This successful transition was mainly the result of the following:

1 Preparation of a comprehensive master plan
2 Prioritization of projects (on macroscale and microscale)
3 Correct allocation of the financial resources among the water and wastewater projects
4 Good management practices
5 Setting rational water tariffs as determined by the

financial analysis to be able to implement planned projects
6 Adoption, implementation of modern tools in operation such as GIS and SCADA
7 Privatization of some services (maintenance of networks, water meter reading, billing, etc.)
8 Training of personnel
9 Upgrading of facilities and the balance maintained in the capacities of the facility elements from source to the customer's tap
10 Improvement of customer services by setting up district branches of ISKI all over the city

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