Centralised versus decentralised treatment and disposal options for Küçükçekmece Basin of Istanbul City

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Abstract Küçükçekmece Lake is a sea lagoon located on the European side of Istanbul city with a drainage area of 4 million inhabitants (year 2040). The original plan to treat all of the wastewater collected from the drainage basin in a single plant located at the Northern end of the lake is compared with the decentralised option involving 4 treatment plants. The initial investment cost of the decentralised option is estimated to be higher than the original plan by an amount of 43 million US $. However, the decentralised option has been chosen finally, considering the low cost and risk of wastewater collection, the possibility of the staging of the services, and the reduced environmental impacts.

Keywords Decentralised treatment; wastewater

Introduction

Istanbul is one of the world's most important cities in terms of history, culture, trade and tourism. Annual population increase is approximately 400,000. One of the main reasons for this rapid increase is intensive internal migration. It could be said that Istanbul's growth is equal to that of a medium sized city province in Anatolia.

Küçükçekmece Lake, located on the European side of Istanbul city, is one of the major drainage basins with a future (2040) population of about 4 million inhabitants.

Originally a single wastewater treatment plant was considered for all of the basin at the Northern end of Küçükçekmece Lake (Figure 1). Foundation reinforcements were started because of the poor soil characteristics at the site. Excessive costs involved in soil reinforcement motivated further studies to evaluate other options in parallel with the master plan studies, which were in progress. Thus, the aim of this paper is to present the results of the reevaluation studies to compare decentralised options instead of a single centralised treatment plant at the Northern end of the lake.

Küçükçekmece Lake

Küçükçekmece Lake is situated on the European side of the Bosphorus approximately 15 km from central Istanbul. The width of the lake varies between 900–4,500 m, with an approximate length of 7,500 m. The lake has a "spoon shape" and has a maximum depth of 19 m. The surface area and volume of the lake vary according to wind direction and tidal fluctuations, with average values of 17 km^2 and 145 million m^3 respectively.

To the south of the lake lies the Florya-Avcılar shoreline of the Marmara Sea. The total catchment area of the lake is 340 km^2, of which the Sazlıdere, Menekşedere, and Ispartakuledere drainage areas are the most important. The approximate size of each of these drainage areas is given below:

Ispartakuledere : 157 km^2;
Sazlıdere : 84 km^2; and
Menekşedere : 43 km^2.

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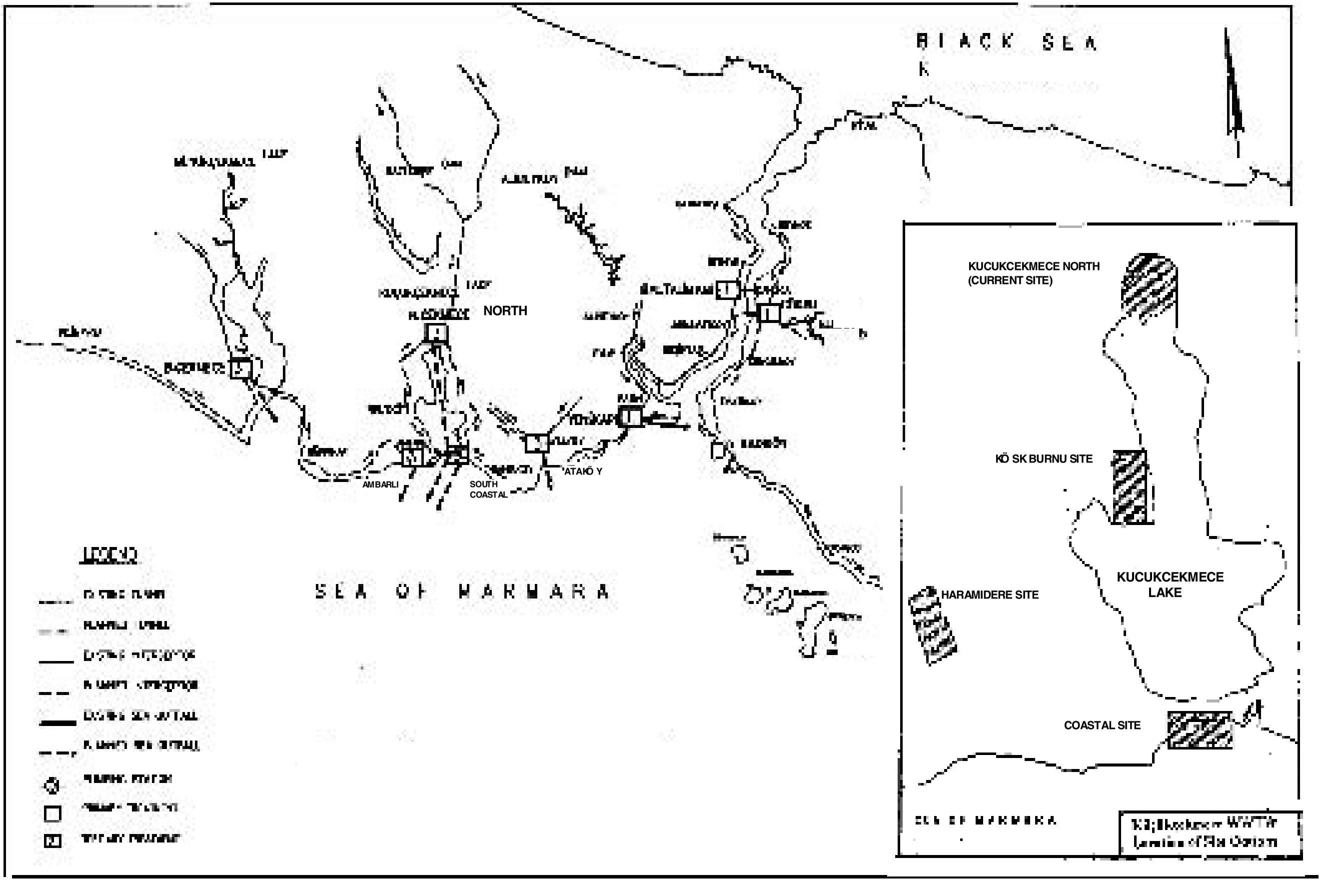

Figure 1 Decentralised treatment and disposal options for Küçükçekmece Basin

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Küçükçekmece Lake is actually a sea lagoon connected to the Marmara Sea via a canal which is approximately 2 km long and 2 m deep. The canal acts as both a source and a sink of water depending on the sea and other influences, notably wind direction. When salt water intrusion occurs into the lake from the Marmara Sea, (as occurs during strong onshore winds), a saltwater wedge develops on the bottom of the lake.

The catchment area of Küçükçekmece Lake is becoming increasingly urbanised. The Hoşdere – Eskinoz – Firuzköy settlement areas dominate the western side of the lake, with the Ikitelli – Halkalı – Sefaköy settlement lying to the east. The lake also lies between the two most important highways of Turkey. The rate of urbanisation within the catchment has been prolific over recent years, which currently supports a population of approximately 250,000 persons. There is also quite a sizeable industrial presence; approximately 100 factories are located within the catchment, comprising metal, textile and plastics manufacturing facilities, in addition to Halkalı open dump and the Institute of Nuclear Research.

Municipal and industrial wastewaters are currently discharged either directly or indirectly into Küçükçekmece Lake. The lake is evidently very heavily polluted. During the 1990s, no recorded precaution was taken to prevent pollution in the lake, in spite of increasing land based pollution sources and it is therefore likely that water quality in the lake has deteriorated.

In the longer term, Istanbul Water and Sewerage Administration (ISKI) plans to pump up to 30 million m^3/year from the lake into Sazlıdere reservoir for treatment at Ikitelli Water Treatment Works (WTW). Before this is done, the likeley impacts of the lake water on Sazlıdere reservoir should be studied. It is anticipated that water quality in the lake will ultimaltely increase as a result of commissioning interceptors surrounding the lake and the North and South Küçükçekmece advanced wastewater treatment plant. In the long term, all wastewater in the catchment area will be collected and discharges to the lake will be prohibited. However, release of nutrients and heavy metals from the very thick sediment layer will continue for many years. In addition, decreasing freshwater inflow and increasing salt water intrusion into the lake will occur due to the operation of the Sazlıdere reservoir. Thus, ISKI's plan may only be applicable for a short term drought period if water is urgently required by the city. Although the water of Küçükçekmece Lake has been polluted by domestic and industrial wastewater discharges, it is clear that water quality will be improved by the implementation of the wastewater collection and disposal systems proposed in the Master Plan. A monitoring programme should be implemented to examine the rate and magnitude of this remediation. The use of this source as a potable water resource should be decided according to the assessment of the monitoring results.

Küçükçekmece System

The existing Küçükçekmece system consists of the existing Küçükçekmece Eastern Shore Interceptor and the Florya-Küçükçekmece Interceptor. Küçükçekmece Eastern Shore Interceptor is 1.85 m in diameter and 2.7 km long. Florya-Küçükçekmece Interceptor runs along the Marmara Coast and is 1.5 km long with a diameter varying from 0.8 to 1 m. There are pump stations at Florya and Menekşe, and a 200 m long force main downstream of Florya.

According to earlier studies of the Master Plan, a major wastewater treatment works on the northern coast of Küçükçekmece Lake is proposed. According to these plans, design and tender documents have been completed for the following collector systems: the Ataköy transfer tunnel (2.9 km of 2.8 m diameter); the Küçükçekmece transmission tunnel (9.2 km of 3.8–4.8 m diameter); the Firuzköy tunnel (3.3 km of 2 m diameter); the Küçükçekmece discharge tunnel (9.3 km of 4.8 diameter); and the Gürpınar – Ambarlı tunnels (11.5 km of 2.0–3.0 m diameter) and the Ambarlı pumping station. In addition to these main tunnels, the following interceptors are proposed: the Firuzköy interceptors (4.2 km of 1.2 m diameter); the Ambarlı

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– Küçükçekmece interceptors (6.2 km of 3.2 m diameter); the Avcılar – Küçükçekmece interceptor (1.2 km of 1.0 m diameter); and the Ataköy interceptor (5 km of 1.8–2.2 m diameter). Also, planning has been completed for the 2.1 km long, 1.2 m diameter, Florya interceptor.

Sewerage arrangements at Küçükçekmece have been based on ISKI's preferred plans for wastewater treatment for this region which adopts the decentralised local treatment strategy using four separate wastewater treatment plants: one at the north lake site, one at the south lake site, one on the coast near Ambarlı, and one at Ataköy. The north lake plant serves Firuzköy and Esenyurt with local collectors discharging through the Firuzköy interceptor tunnel to the west of the plant. A second interceptor and tunnel system collects wastewater from Küçükçekmece to the east.

The proposed plant south of Küçükçekmece Lake serves the Küçükçekmece eastern coastal interceptor, the Florya interceptor and the Avcılar interceptor. The wastewater from the residential areas in Florya, Ambarlı and the south-east coast of the lake will be treated at that plant.

The proposed coastal plant at Ambarlı serves the Gürpınar coastal interceptor. This interceptor along the west side of Küçükçekmece Lake will transfer wastewater to the treatment plant. The networks serving the coastal plant are entirely gravity systems.

The tertiary plant at Ataköy will collect wastewater from the industrial and residential areas of Bakırköy and Ataköy. Two separate collector sewers serve the plant from the north-west and the north-east. Decentralised system plans of Küçükçekmece drainage area are given in Figure 1.

The current site, at the northern end of the lake, necessitates a long influent and effluent tunnel. Other than land reclamation and piling works, very little construction has been completed at the site. The purpose of investigating relocation is to possibly eliminate all, or part of, these tunnels, which are major cost elements of the Küçükçekmece scheme and provide a more economic investment.

Three alternative sites were chosen for analysis:

- Coastal site at southern end of the lake on a strip of land which separates the lake from the sea
- West of the lake between Yakuplu and Avcılar in the valley formed by the Haramidere stream
- West side of the lake at Köşkburnu.

South/coastal site

The coastal site is bounded to the north by the D100 (old E-5) highway, to the east and west by housing developments, and to the south by the Marmara Sea. The residential development comprises high-rise housing with views of the sea and overlooking the possible site for the treatment works. Land available (21 ha) at the site had a very low utilisation at the time of the study. A significant part of the cost of this option is an estimated $60 million that would be needed for site improvement and land-filling, in order to reclaim land from the sea and provide sufficient area to allow for the construction of a tertiary treatment facility.

Haramidere site

The Haramidere site is located in the valley formed by the Haramidere stream. There is an industrial area at this location, with a large electric transformer station, and an Aygaz plant, among several industries there. All land near the sea is occupied, but there is sufficient available area inland. The land proposed for the treatment works is fairly level terrain. The sides of the valley, however, are steep and covered with existing homes or with homes under construction, and these homes would look directly onto the treatment plant. Despite this, there would not seem to be as many environmental problems as at the coastal site,

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since this is an industrial area already. There would be a large number of high voltage overhead lines to remove and relocate around the site.

One advantage of this site is that the Danish Hydraulics Institute (DHI, 1994) marine modeling report recommended transferring some of the effluent, or raw wastewater, from Küçükçekmece to Büyükçekmece, since the coastal waters in the area around Küçükçekmece are very sensitive and also have very poor flushing characteristics. Relocating to the Haramidere site could facilitate this transfer in the future. A disadvantage of this site is that it is approximately 15 m higher than the current site, and additional operating costs for pumping would be incurred.

Köşkburnu site

Located on the western side of the lake in an area that is not developed, the Köşkburnu site had no obvious major environmental impact problems. The site is more remote than the other sites, but is in a geologically unstable area subject to landslides. Additionally, this site is approximately 10 m higher than the current site and will incur additional pumping costs.

Decentralised option

In view of the concerns about locating a major treatment plant on the coast, a decentralised option was examined, which makes provision for much smaller plants at the original coastal site and at Ambarlı just to the west of the original site. This option also retains a smaller, but still substantial plant at the North Lake site, and provides for a separate treatment plant at Ataköy. In the form conceived, the decentralised scheme overcomes a number of other concerns, namely:

- The coastal plants (Küçükçekmece South and Ambarlı) will treat wastewater from Küçükçekmece, Avcılar and Florya, and avoid the need for pumping to a central plant at the North Lake site; additionally, an influent tunnel, or influent pipeline on the lake bed, is avoided together with the attendant risk of lake pollution;
- Collector systems will be able to avoid geologically unstable (landslide) areas to the east and west of the lake;
- Wastewater flows from the industrial zone at Ataköy are treated at a dedicated local treatment plant, thereby avoiding any risk to the process at the much larger, central municipal plant at the North Lake site if industrial pre-treatment facilities prove to be either ineffective, or not properly controlled.

Central site with advanced treatment and discharge to lake

The current site at the northern end of the Küçükçekmece Lake necessitates long tunnels and interceptors as well as a long discharge tunnel, pumping station and marine outfall. Also the location of the marine outfall is not suitable, because of poor surface and lower layer currents, and because of the very low dissolved oxygen concentrations at this location. Consequently, wastewater absorption may be poor and, to protect the coastline, effluents may have to be subject to disinfection. For these reasons, an alternative that includes discharge to the Küçükçekmece Lake after advanced treatment (nutrient removal and filtration) was analysed. Although the main discharge will be to the lake, a by-pass pipeline would also be necessary at the coastal pumping station for discharging untreated wastewater into the sea under emergency conditions. This alternative would achieve a reduction in present worth of $26.3 million compared to the current programme. However, a stringent programme would be required to control industrial effluents discharged into the sewers from preliminary industrial treatment plants, otherwise there could be adverse impacts on the biological treatment processes at the main municipal plant, with the

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attendant risk of discharging untreated industrial pollutants to the lake. Heavy metals, phosphate in detergents, and flows from the Nuclear Research Institute may cause particular problems.

Analysis of options

The major influence on cost difference between the alternative sites and the current (north lake) site relates to individual scheme requirements for interceptors and tunnels, energy for pumping, and ground treatment. The existing north lake site will require an estimated additional $10 million to complete the land rehabilitation work currently suspended there.

Conceptual wastewater collection, treatment and disposal schemes were prepared for each of the sites, and capital and operating costs for each scheme estimated. These costs were then discounted over a 50-year operating period to provide a basis to compare the cost-effectiveness of each option. The discounted present-worth values are expressed in Table 1 below as the differential between the existing and alternative sites.

The Köşkburnu site is more expensive than the existing North Lake site and is, therefore, given no further consideration. In addition to the cost differential shown, provision would have to be made for remedial works to prevent further landslides.

The coastal site shows a cost advantage over the Haramidere site, although this is eroded in present-worth terms due to the effect of discounting annual energy costs. However, the capital cost advantage must decrease if unforeseen difficulties are encountered in reclaiming land at the coastal site. Environmental impacts should also be considered, particularly as reclamation works for such a large area (in excess of 70 ha) may give rise to ecological problems in the Marmara Sea. It is possible that the impact of reclamation works could be mitigated by adopting a less conventional ("small footprint") process technology at the coastal site in order to greatly minimise the area of reclaimed land required. This in turn may also reduce the capital cost of the scheme. However, for the present purpose of preliminary optimisation, conventional processes have been used at all sites so that the competing schemes can be compared on equal terms. It should, however be borne in mind that the use of a non-conventional process could go some way to overcoming the visual impact of a large site, and the ecological impacts of marine reclamation works. A further point to be considered is that construction of a major facility at this location would appear to violate the Municipality's policy of maintaining the coastal areas for recreation. Considerable objections to a treatment works located on the coast could also be anticipated from local residents.

The Haramidere site is located in an area likely to give rise to less environmental and public concern, although objections from neighbouring residents would be inevitable. The site is, however, not in an area of high amenity value and the local area has already been partly dedicated to industry.

Neither the coastal or Haramidere sites should be adopted without first undertaking extensive geotechnical investigations to verify ground conditions and the feasibility of

Table 1 Küçükçekmece Alternative Sites (IMC, 1999a,b)

Site:	North Lake	Coastal Site	Haramidere	Köşkburnu	North of Lake	Decentralised
Treatment:	Tertiary	Tertiary	Tertiary	Tertiary	Advanced	Tertiary
Disposal:	Sea	Sea	Sea	Sea	Lake	Sea
Difference, $ in present worth	0	–43,400,000	–25,300,000	45,200,000	–26,300,000	43,000,000

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construction. The availability of land for acquisition is also an important factor in scheme selection.

Based on preliminary cost estimates, the coastal site would appear to offer possible savings over the existing North Lake site. However, the financial benefits indicated in Table 1 should be viewed with caution due to the lack of site data needed to prepare more accurate construction estimates, particularly with respect to ground works, which could differ greatly from those estimated. Additionally, the significant environmental and local municipal concerns about the coastal site need to be carefully evaluated.

In addition, the area required for the treatment plant site, which would most likely be assigned through sea reclamation, may not be available to ISKI.

The option of discharging advanced treated effluent to the lake from a single, central treatment plant is not as cost-effective as the coastal site and should, therefore, only be adopted as a possible means of rehabilitating the lake itself.

This is also a possibility at the North Lake site in the decentralised option, where discharge to the lake might also be possible in conjunction with advanced water treatment or perhaps, alternatively, by using the adjacent reed beds for final effluent polishing. A sea outfall would be needed as a precaution against a malfunctioning, or closedown, of the North Lake plant. This would enable untreated effluent to be temporarily discharged to the Marmara Sea, rather than to the lake itself, which would be environmentally more harmful. The outfall pipeline would be laid in the lakebed, rather than tunelling the land based sector. Although this has the potential risk of polluting the lake, use of the outfall would be for limited periods only, and this alignment is considered preferable to tunnelling through the geologically unstable areas at the side of the lake.

The present worth of the decentralised scheme for wastewater treatment and disposal at Küçükçekmece is $43 million greater than a single plant located at the north of the lake. This is to be expected in the case of multiple facilities. However, it is considered that the decentralised option is supportable on the environmental and technical grounds outlined above. A summary of the advantages and disadvantages of this option are given in Table 2.

Istanbul Water and Sewerage Administration (ISKI) has further modified proposals for the decentralised scheme at Küçükçekmece by dividing the duties of the Ambarlı plant between a smaller plant at Ambarlı and a fourth plant, which would be located at the original Coastal Site. This plant would serve coastal areas in East Küçükçekmece, while the

Table 2 Küçükçekmece decentralised option (IMC, 1999a,b)

Advantages	Disadvantages
• existing North Lake site, in which investment has already been made, is retained; • need for influent tunnel and pumping from coastal collectors is avoided; • possibility of future use of reed beds for final polishing and discharge to lake, once tertiary treatment installed at North Lake plant; • majority of industrial flows diverted to Ataköy plant, thereby avoiding risk of process disruption at other plants if factory pre-treatments are ineffective; • two small plants at the Ambarlı and South Küçükçekmece coastal sites minimising environmental impacts; • ISKI already own the land at Ataköy; • construction of interceptors and collectors in areas of geological unstable ground is avoided.	• although interceptor and collector costs are lower, overall capital cost is considerably higher; • despite saving on influent pumping (North Lake), overall operating costs are higher with four separate plants; • plant (Ambarlı) at seaside location on coast; • environmental impacts at four locations, rather than one central location; • if discharging direct to the lake, the need for advanced wastewater treatment prior to discharge, and impact on lake ecology, should be investigated.

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Ambarlı plant would serve coastal areas to the west. The effect of introducing this extra plant will be to further increase the initial capital investment required and further reduce the cost-effectiveness of the decentralised option compared to the single, central plant at the Coastal Site.

As can be expected a single plant located at the coastal site is the most cost effective solution. Unfortunately, land available at this site is not enough to build a plant with a capacity to serve all the drainage area.

Therefore, maximum capacity of the coastal plant was determined based on the land available. The rest of the flow was divided among North, Ambarlı and Ataköy sites (Figure 1). Although the cost of the decentralised system is greater then the original scheme of a single plant at the North (Table 1) the former has been chosen for the following reasons:

- Large diameter collectors and tunnels are avoided, reducing the cost as well as the time of construction of the wastewater collection system,
- Staging of the services is easier, starting with the most needed site e.g. coastal risk treatment works and its collection system,
- Reduced environmental impact in case problems arise at the treatment plant.

The four treatment facilities for Küçükçekmece in this modified decentralised option, shown in Figure 1 are currently the basis of ISKI's future planning for wastewater treatment in the Küçükçekmece region, and has therefore been included in the Master Plan investment programming and financial analyses.

Conclusion

The decentralised wastewater collection, treatment and disposal scheme, which involves 4 treatment works, has been chosen instead of one large plant, in spite of relatively higher initial investment cost, considering the reduced risk and cost of wastewater collection, staging of facilities, reduced environmental impacts and the large area requirement of a single plant.

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