# Rehabilitation and water quality monitoring in the Golden Horn

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**Abstract** In this work, the oceanographic aspects of the Golden Horn and some results of the Golden Horn Rehabilitation Project are presented. The hydrographic structure of the Golden Horn responds rapidly to the conditions in the southern Bosphorus, which is especially true for the outer parts of the estuary up to the Valide Sultan Bridge (VS). West of this bridge which was blocked by the pontoons of the bridge, carries the major pollution load and is dependent on the underlying water and surface mixing, for its renewal. The dissolved oxygen concentrations were measured below the detection limit in the region between the VS and Eyüp-Sütlüce (ES) section during the majority of the measurement periods where $H_2S$ has been determined simultaneously until February 2000. Although the microbial contamination of the estuary stations is very high, decreases in the contamination at stations are observed. The highest concentrations are recorded at the ES–VS section and supported by Fecal Coliform data during the rainy months in general despite the operational collector system surrounding the estuary. An obvious decrease of pollution in comparison with the data of the previous years is clearly observed as an encouraging result of the rehabilitation efforts achieved so far.

**Keywords** Bosphorus; environmental rehabilitation; Golden Horn; pollution; water exchange; water quality

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## Introduction

The Golden Horn is an estuary of the Bosphorus, approximately 7 km long with a maximum depth at the entrance of 40 m. The bottom shallows rapidly after the first kilometre from the entrance, the depth decreases from 40 m to about 2 m at a distance of approximately 4 km from the mouth (Figure 1).

The water quality has been highly changed as the pollutant loads have been sent out to this region by the existing discharge points and throughout the creeks functioning as open channels previously. The two small creeks, namely the Alibey and Kagithane Creeks have very low discharges of about $3 \times 10^5$ $m^3$/year (Öztürk *et al.*, 1998). These creeks were previously discharging an average of $3 \times 10^5$ $m^3$/day (Kor, 1963). Therefore, at present, freshwater input to the estuary comes mainly from rainfall and its overland runoff.

The studies in the estuary have shown that, the properties of the water column in the estuary correspond closely to the properties of the water column in the Bosphorus in the vicinity of the entrance. The data measured before the replacement of the historic Galata Bridge shows that, the two-layer flow of the Bosphorus entering the Golden Horn essentially maintains its characteristic temperature, salinity and dissolved oxygen content, with the exception of the top 2–3 m whose properties are greatly changed due to various surface discharges of sewerage from industrial and municipal sources. The freshwater discharge associated with the sewage discharges results in a surface layer of relatively lower density. Due to the discharge of pollutants, the surface layer also contains a very high amount of suspended matter, which results in the absorption of all incident radiation within the first 1–2 m. The consequent increase in the surface temperature further decreases the density of the surface layer (Özsoy *et al.*, 1988). On the other hand, the monthly data

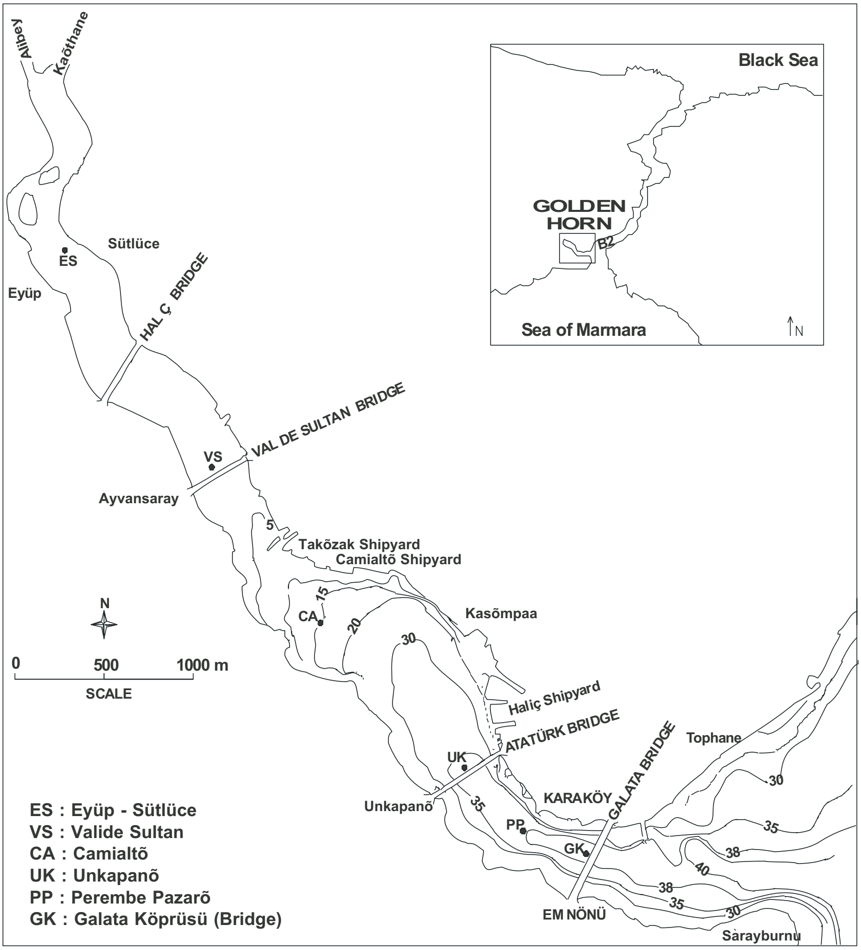


**Figure 1** Location map and bathymetry of the Golden Horn (depth in metres). The region specifying letter coding used in oceanographic station naming is also shown inside the frame

presented here obtained during the period 1998–2000 shows a two-layer system in the Golden Horn; an upper layer extending the depths of about 25 m; and a bottom layer, lying below approximately 25 m. After the replacement of the historic Galata Bridge, a two-layer system is established in the estuary.

The hydrographic characteristics of the Golden Horn are presented in the following in terms of annual marches of temperature, salinity and dissolved oxygen together with profiles and transects of temperature and salinity.

#### Hydrographic characteristics

During the earlier years, the surface layer (i.e. the top 2–3 m) in the Golden Horn differed greatly in its properties from the underlying water, although the origin of both the surface layer and the upper layer is the same. The most important difference was the very low dissolved oxygen content of the surface layer. The salinity of the surface layer was also lower by about 2 psu on average, as compared to the upper layer. The temperature at the surface is generally higher than the underlying water, showing that the effect of solar radiation at the surface is not passed on to the lower, adjacent depths (Özsoy *et al.*, 1988).

The monthly data presented here were obtained during the period from January 1998 to

December 2000. Profiles of temperature, salinity, dissolved oxygen (DO) and biochemical parameters were measured at different stations in the estuary.



#### Annual evolution of temperature and sa1inity

The annual march of temperature and salinity for the surface layer is shown in Figure 2 for the period January 1998–December 2000, at two stations (GK, UK) in the Golden Horn and at station B2 in the Bosphorus close to the entrance to the estuary. The lowest temperatures occur in the winter during February and March, while the highest temperatures at the surface are observed in July and August. The range of temperatures during the three year period was from 6°C to 26°C. The surface salinity ranged from 7 psu in February 1999 to 19 psu, in November 2000. The lowest salinity in February 1999 was due to high rainfall and increased overland runoff.

The temperature and salinity at a depth of l0 m are considered representative of the upper layer values and are shown in Figure 3. It is seen that the values for all locations are in good agreement in general, showing that the upper layer of the estuary has an efficient exchange with the Bosphorus. The same is not true always for the surface layer, as can be seen clearly by a comparison of the salinity plots in Figures 2 and 3. The high salinity values observed in February and December 1999, and in January 2000 at stations in the Golden Horn at 10 m are not seen in the surface layer. The high salinities at the 10 m depth in the Golden Horn were observed after strong southwesterly winds, which increased the salinity of the surface layer in the Bosphorus to the highest value (23 psu) in December 1999 (Figure 2).

The range of variation of the lower layer properties is quite narrow; therefore, annual variations for this layer are not described here (see Figure 4).

#### Profiles of temperature and salinity

The profiles of temperature and salinity at a station GK in the Golden Horn are presented to show the characteristics of the water column for the period between January and December 2000 (Figure 4).

The 2-layer structure in the estuary is evident in the figures. The upper layer has a well mixed structure in the autumn and the winter months, due to convective mixing by winds

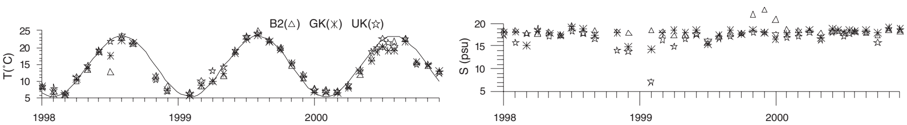


**Figure 2** Surface temperature and salinity at stations B2, GK and UK during the months of 1998–2000

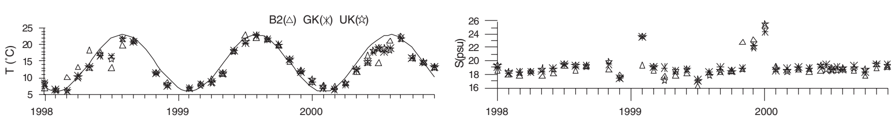


**Figure 3** Temperature and salinity at 10 m depth at stations B2, GK and UK during the months of 1998 – 2000

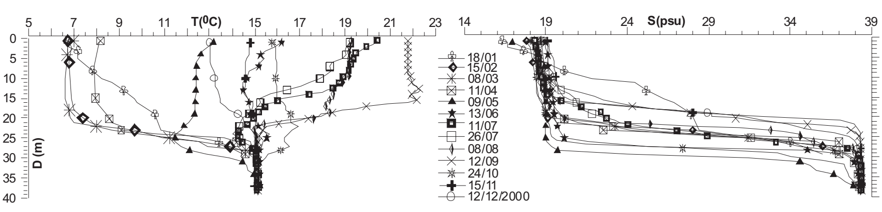


**Figure 4** Temperature and salinity profiles at station GK during the months of 2000

and surface cooling. But it is not true under heavy rainfall and strong wind, which can be observed by a comparison of the salinity plots in Figure 4. The low salinity values observed in January and February 2000 at stations in the surface layer correspond to high rainfall (Sur *et al.*, 2001). The unusually high salinity seen in the upper layer in the January profile results from the strong southwesterly prevailing during the cruise day, which exposes the higher salinity Marmara seawater by blocking the upper layer in the Bosphorus. The high salinity water is then advected into the Golden Horn. On the other hand, during the dry week of the month, the surface layer identified by its low salinity in March–May and July 2000 corresponds to increased runoff through Alibey Creek originating from the Alibey Dam. The upper layer has its maximum extent in May, reaching to a depth of about 28 m at GK (Figure 4). The minimum depth of the upper layer is 16 m, in September. The bottom layer at GK has quite uniform properties with a temperature of about 15°C, and salinity of about 38 psu. The interface between the two layers lies between the depths of 16 m and 28 m.

#### Temperature and salinity transects

The transects of temperature and salinity show the variations of these parameters along the longitudinal axis of the estuary. Since the water column properties depend largely on seasonal changes in the wind regime, the rainfall, the air temperature, and the sea-level difference between the Black Sea and the Sea of Marmara, the transects are discussed here on a seasonal basis.

*Winter transects*. The data for January can be considered representative of the winter conditions in the estuary. The effects of rainfall and southerly winds during the winter are the main features of the winter transects, given in Figure 5. The influence of the vertical mixing due to the southerly winds is seen to prevail throughout the estuary in the transects. The wind, measured at the meteorological station at Istanbul, was from south and southwest for ½ day preceding the January 18 cruise and also during the cruise day, with hourly average speeds between 4–6 m/s (Sur *et al.*, 2001). Under these conditions, the upper layer in the Bosphorus in the southern reaches was pushed back, while the exposed high salinity Marmara water moved in and became submerged below the surface wedge. Strong vertical mixing occurs in this region. The water column entering the Golden Horn thus has high salinity. The interface between the upper and the bottom layer is almost non-existent and the whole water column is continuously stratified.

*Spring transects*. The transects for May, Figure 6; show the transition of the temperature structure from the winter to the summer conditions. The temperature of the upper layer has increased to 12°C.

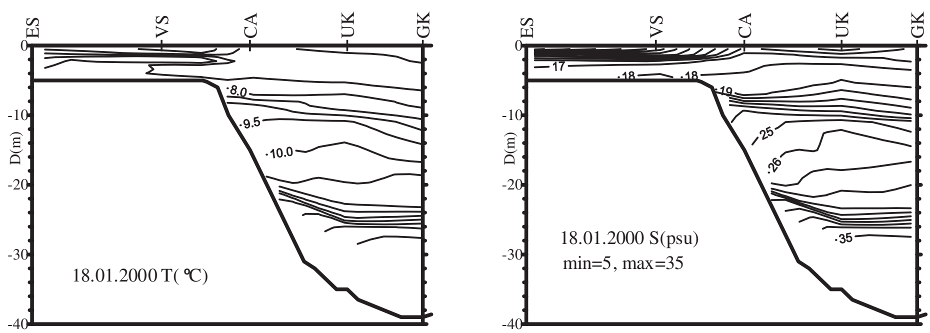


**Figure 5** Transects of temperature and salinity along the Golden Horn (T = 0.5°C, S = 1 psu)

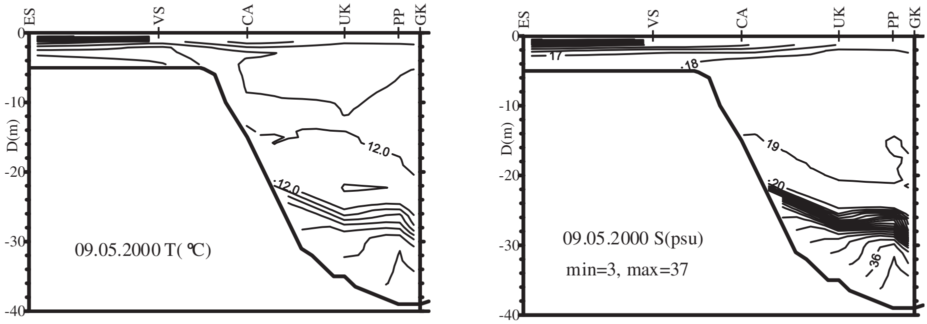


**Figure 6** Transects of temperature and salinity along the Golden Horn (T = 0.5°C, S = 1 psu)

The rise in the temperature of the surface layer due to local solar heating is seen to have begun, and the surface is warmer than the deeper water. A continuing warming of the surface layer takes place. The surface layer is seen clearly in both the temperature and salinity transects. The layers are separated by well defined interfaces, in contrast to the January structure.

*Summer transects*. During the summer months, the Black Sea discharge increases and the prevailing winds are from the northern directions. Both these factors tend to increase the upper layer flow in the Golden Horn, yielding to the entrainment of the lower layer water upwards. The transects for the summer season, Figure 7, show this feature in the salinity sections. The salinity interface is quite thick as a result of the vertical mixing due to the higher velocities of the upper layer in the Golden Horn. The temperature transect for 11 July 2000 (Figure 7) shows a core of cooler water located in the 20–28 m depths. The salinity at these depths is about 30 psu, indicating that the cooler water originates in the Sea of Marmara below the thermocline, that is, it is not affected by the surface heating at this time. The cold core is not seen in the fall transect of November, which is due to the continuation of the solar heating during the late summer and vertical mixing which together erode the cold water core.

*Fall transects*. The fall season is characterized by relatively high surface salinity in the Black Sea due to the end of the runoff from the major rivers. Due to the cooling at the surface and wind mixing, the upper layer in the Black Sea becomes well mixed with uniform temperature and salinity. These characteristics are also reflected in the transects for November in the Golden Horn, Figure 8. The upper layer has a temperature of about 15°C in November. The temperature interface is diffuse because the temperatures of the two layers differ by only about 1°C during this period. The salinity interface is sharp and relatively

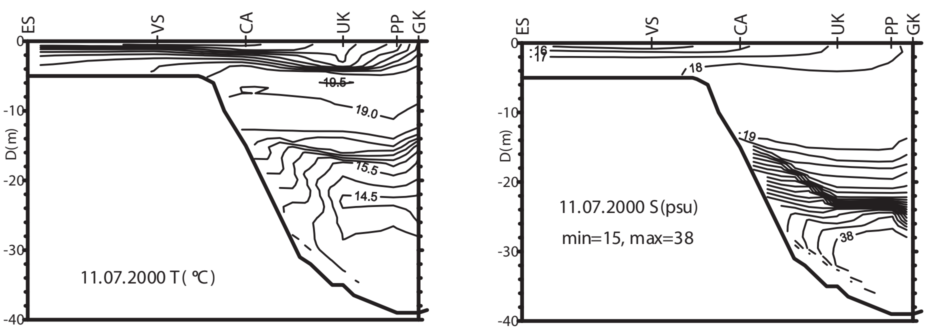


**Figure 7** Transects of temperature and salinity along the Golden Horn (T = 0.5°C, S = 1 psu)

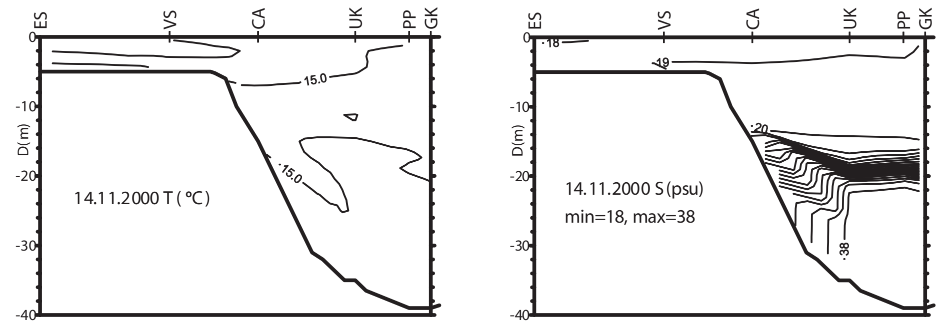


**Figure 8** Transects of temperature and salinity along the Golden Horn (T = 0.5°C, S = 1 psu)

thin, indicating a strong stratification in the Golden Horn due to the relatively calm wind conditions at the time of this cruise (Sur *et al.*, 2001).

A spreading of low salinity water is observed to enter the estuary in several of the transects (Figures 5–7), and extends to the entrance (see also Figure 4).

#### Annual evolution of dissolved oxygen (DO)

The annual march of the dissolved oxygen distribution for different levels in the estuary are seen in Figure 9–11 for the period January 1998–December 2000, at station GK in the Golden Horn and at station B2 in the Bosphorus close to the entrance to the estuary. The surface is seen to have lower oxygen content, generally about 5 mg/L at station GK. The values in the estuary and Bosphorus are not consistent until March 2000, meaning that the surface layer of the Golden Horn has no efficient exchange with the Bosphorus. The range of dissolved oxygen during the three year period was from 2 mg/L to 11 mg/L. The overall linear trend for station GK is uphill for the surface oxygen content in the Golden Horn.

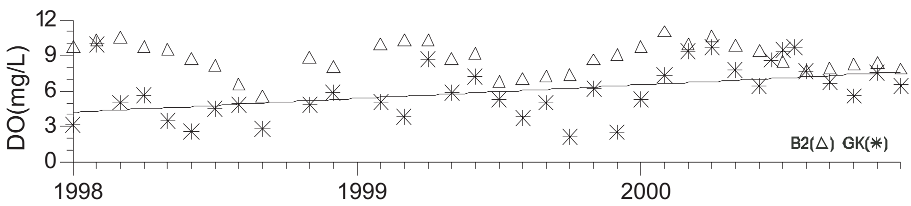


**Figure 9** Surface dissolved oxygen at stations B2 and GK during the months of 1998–2000

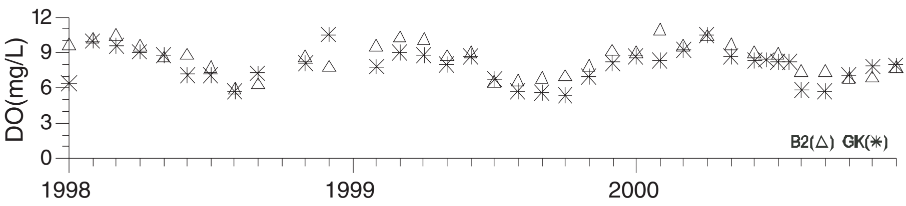


**Figure 10** Dissolved oxygen at 10 m depth at stations B2 and GK during the months of 1998–2000

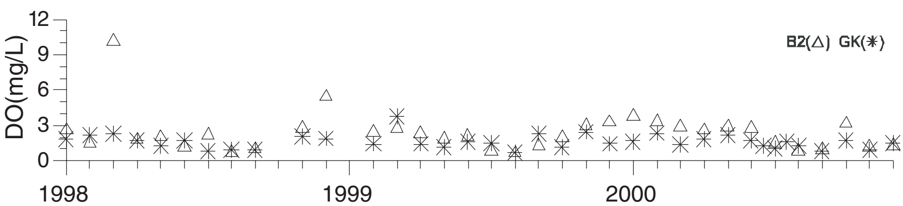


**Figure 11** Dissolved oxygen at the bottom of stations B2 and GK during the months of 1998–2000

The upper layer, represented by the values at 10 m, has high oxygen content of about 8 mg/L (Figure 10). It is also seen that the values in the estuary and Bosphorus are in good agreement in general, showing that the upper layer of the Golden Horn has an efficient exchange with the Bosphorus. The oxygen content decreases at the bottom, the value below 30 m being about 2 mg/L or lower in general (Figure 11).

The range of variation of the lower layer properties is quite narrow annually, but the cruise in March 1999, carried out after southerly winds, shows high oxygen content both in the bottom layer and in the upper layer at station GK. At 10 m, the dissolved oxygen is 9 mg/L, and at the bottom, the value is seen to be about 4 mg/L (Figures 10, 11). The high value in the lower layer results from mixing of the higher oxygen upper layer with the lower layer in the Bosphorus, the mixed water column being subsequently transported into the Golden Horn.



The relatively stable level of oxygen in the bottom layer, about 2 mg/L, shows that the anoxic condition is not present close to the bottom, implying a continuing supply of oxygen through the inflow from the Bosphorus.

### Transparency

Light penetration in the Golden Horn is very limited, as expected, due to the suspended sediment load at the surface. The line fitted to the total suspended sediment (TSS) values at station GK shows the decreasing trend for the surface TSS content in the Golden Horn (Figure 12). As shown by salinity and DO content of the surface layer, the surface TSS values in the estuary and Bosphorus are inconsistent in general, again pointing out that the surface layer of the Golden Horn has no efficient exchange with the Bosphorus.

The Secchi disc (SD) data for several months are also given in Figure 12. The SD depth is low mainly before August 1999. Observations show very clear water from the Bosphorus being pushed into the estuary mainly under stronger northeasterly winds (Sur *et al.*, 2001), however, these cleaner conditions are transient. As is shown in the discussion of TSS data, there has been a gradual decrease in the TSS load at the surface since 1988, and a corresponding increase in the SD depths is evident, despite the algal blooms observed in the estuary during last year. The present value of the TSS is not high as compared to the Bosphorus (Figure 12).

### Fecal coliform

The impact of the rehabilitation processes on bacterial contamination of the Golden Horn appears to be significant. During the previous years, fecal coliforms were very high in the surface waters, and in the inner region reached a maximum at station VS with maximum observed values of $114 \times 10^5$ CFU/100 ml in May 1998 (Figure 13). This figure indicates that the on-going

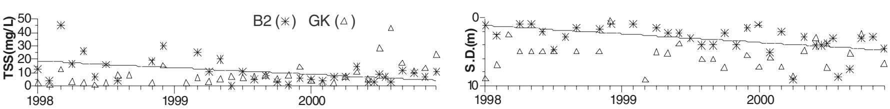


**Figure 12** Surface TSS and Secchi disc (SD) depth at stations B2 and GK during the months of 1998–2000

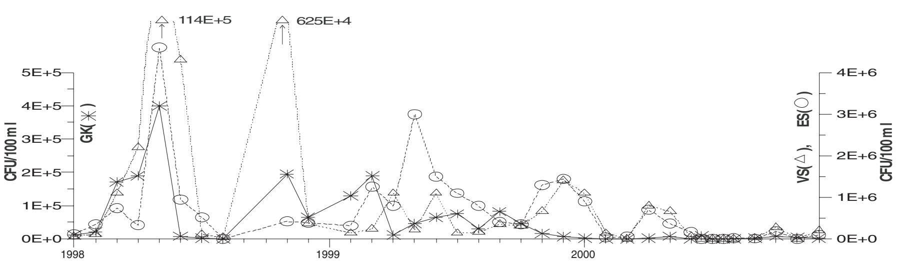


**Figure 13** Surface fecal coliform at stations GK, VS and ES during the months of 1998–2000

restoration efforts resulted in an unusually lower lateral and temporal distribution of fecal coliforms, with relatively high concentrations in the innermost region, decreasing to its east.

## Conclusions

A noticeable decrease of pollution in comparison with the data of the previous years is evidently observed as a promising result of the rehabilitation efforts accomplished up to the present time. Until the replacement of the historic Galata Bridge, the blocking effect of the pontoons of the bridge, and the lack of freshwater discharge needed for flushing the surface, greatly inhibited a horizontal exchange of the surface water with the Bosphorus, while the lower density prevents vertical mixing and subsequent flushing, with the underlying waters. The properties of the surface layer, consisting of the upper 2–3 m of the water column, are greatly modified due to the reduced discharges of pollutants in recent years. The dissolved oxygen at the surface, which was almost zero in the 1980s due to the high load of pollutants, has increased.

The properties of the rest of the water column (excluding surface layer) in the estuary are comparable with the properties of the water column in the Bosphorus at the entrance to the estuary. The close response of the properties extends to about 3.5 km from the entrance where the depth is less than 10 m. Beyond this location, the surface layer, with its higher suspended load and low oxygen content becomes dominant. The anaerobic conditions in the innermost region are a result of the insufficient exchange between the Golden Horn and the Bosphorus due to the blocking effect of the floating type Valide Sultan Bridge, and lack of preventing domestic and industrial wastewater discharges totally.

Persistent and strong southerly winds, which occur during winter in general, cause marked increases in the salinity of the upper layer and the dissolved oxygen of the lower layer in the Bosphorus, then the water column, having significantly different properties than under usual conditions, is advected into the Golden Horn. On the other hand, the relatively low saline water spreading in the surface layer of the whole estuary during the periods of increased rainfall and runoff demonstrate the fact that the surface layer water can be revitalized by reducing the load of pollutants into the drainage basins.

The natural existing mechanism for the supply of the clean and oxygen rich water from the Bosphorus into the upper layer of the Golden Horn yields that the present polluted state of the estuary can be brought to an end by stopping the discharges of pollutants into the estuary and by removing the barriers imposed by the pontoons of the bridges.

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