SEWAGE OUTFALL PLUME IN THE TWO-LAYER CHANNEL: AN EXAMPLE OF İSTANBUL OUTFALL

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ABSTRACT

Municipal wastewater from the city of İstanbul is discharged into the Bosphorus Strait through the outfall built on the southern end of the Strait. The behaviour of the wastewater plume in the Bosphorus environment is quite complicated as a result of the two-layer stratification, the rapid currents flowing in opposite directions in each layer, their transverse variations, and the turbulence and entrainment processes in the ambient waters. The wastewater is injected from 22 diffuser ports on each of the two pipelines located in a depth range of 40 - 60 m. The numerous plumes from the multiple ports combine to yield a line source of plume-like behaviour in the far-field. The plume typically rises due to its buoyancy in the lower layer, and becomes arrested at the interface between the upper and lower layers of the Bosphorus, but the swift undercurrents bend the plume to align it with the interface along the Bosphorus.

KEYWORDS

Wastewater outfall; buoyant plume; acoustical backscatter, two-layer flow.

INTRODUCTION

Municipal wastewater from İstanbul City is discharged into the Bosphorus Strait through the outfall built on the southern end of the Strait at Ahırkapı. The wastewater discharged from the diffusers forms a buoyant plume in an environment of two-layer Bosphorus stratification and currents.

The wastewater is essentially land-derived wastes in freshwater. Therefore it is warmer and less saline than the ambient waters of the Bosphorus. The Mediterranean water in the Bosphorus lower layer near the discharge outfall has constant temperature and salinity of ~14.5°C and ~38.5 ppt respectively, while the upper layer Black Sea waters have salinity of ~ 20 ppt and temperature which varies with depth and the time of the year.

In this study we present field measurements using echo sounder, ADCP and CTD data under different oceanographic conditions in the Bosphorus for understanding of the buoyant plume dispersal in a two layer stratified flow. The plume was routinely detected with the 30 KHz transducer of the echosounder on board the R/V BİLİM during the surveys in the vicinity of the diffusers. The ADCP measurements allow calculation of the absolute backscatter in the water column. The temperature, salinity and turbidity measurements at fixed oceanographic stations are used to detect the plume properties.

METHODOLOGY

The İSKİ Ahırkapı sewage outflow plume in the vicinity of the diffusers was detected with the 30 KHz transducer of the JMC echosounder and the 150 KHz ADCP transducer on board the R/V BİLİM. Acoustic signal emitted from the transducers are scattered by suspended matter in the water column. Because the wastewater contains particulate material and has a different density from the environment, acoustical backscatter from the plume can be detected with relatively high signal strength.

The ADCP measures the intensity of the scattered signal (echo intensity) from suspended particulates relative to the emitted signal, and thus allows the calculation of the absolute backscatter in the water column. Obtaining the backscatter from the echo intensity data requires careful calibration, to eliminate thermal noise arising from different sources. The calibration procedure was applied to remove the noise due to the temperature variations in the electronics and the transducer. Furthermore, sound velocity data obtained from CTD profiling are used to account for the range-dependent attenuation and geometric spreading of the acoustic beams. The procedure used in this work to calculate the absolute bacscatter from the ADCP data follows the procedure given in Flagg and Smith (1989).

OBSERVATIONS

Acoustic backscatter in the diffuser region was measured during a number of different surveys corresponding to the different dynamical regimes of the Bosphorus. The best measurements with clear separation from background noise were obtained during 18 May 1992 and 4 March 1993. During these dates the İSKİ pretreatment plant was instructed to pump wastewater at maximum rate possible for the current operating conditions, and therefore three pumps were operating during the time of measurements, with a total discharge of $Q = 7.5m^3s^{-1}$.

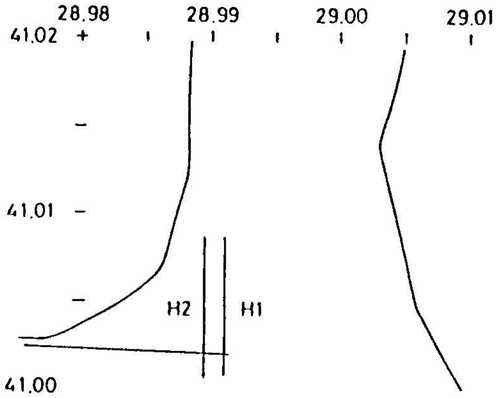

Fig. 1. The geographic location of the Ahırkapı seawage pipeline. The ship tracks for the measurements mentioned in the text are overlapped.

The backscatter measurements were done across this diffuser starting from the southern end and continued till the plume disappeared on the echo sounder. The ship tracks along three separate measurements during May 1992 and the position of the pipeline are presented in Fig. 1. The ship track during the March 1993 case was similar.

Plume Acoustic Backscatter during 18 May 1992

Prior to the plume measurements, the currents regime and hydrography of the Bosphorus were investigated by ADCP and CTD measurements along the strait. Vertical profiles of the velocity vector at stations along the Bosphorus are presented in Fig. 3. High velocities reaching 100 cm/s are indicated in the upper layer, while the currents in the lower layer were smaller, with an average of 20 cm/s.

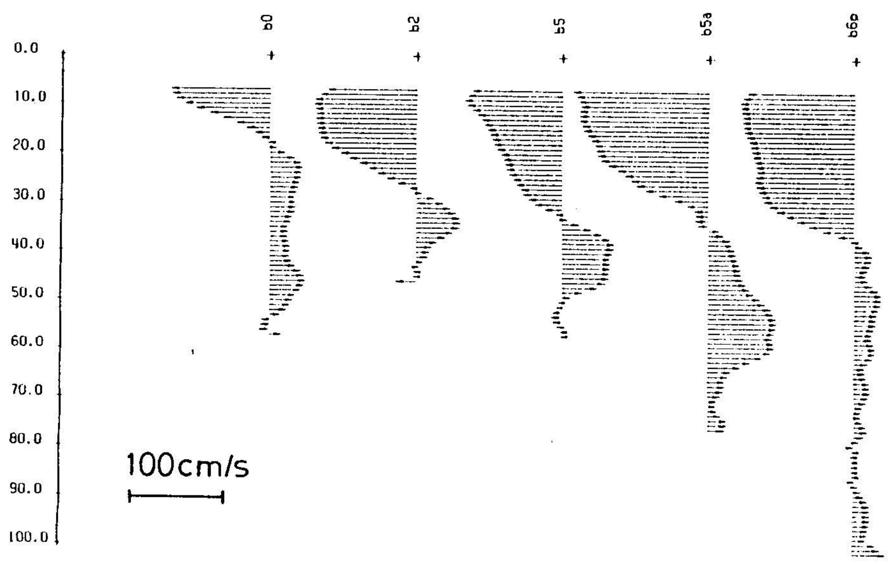

Fig. 2. The ADCP derived current vectors along the Bosphorus, 18 May 1992.

In order to present the acoustical backscatter strength of the Ahirkapi sewage outflow plume, two separate transects (H1 and H2, Fig. 1) were made across the diffuser pipeline starting from the south of the diffuser, repeated each time at different distances from the shore. Contour plots of absolute acoustic backscatter, and the corresponding echo sounder records along the same transects are presented in Figs. 3 – 4 respectively for each case. Acoustical backscatter signal strength is plotted in dB units.

Along the deepest section (Fig. 3), roughly along the tip of the diffuser pipeline (located in a bottom trough), the plume rise was limited to about 20 m above the bottom and it did not reach the pycnocline. The lower layer currents bent the plume northward, forcing it to move parallel to the bottom. Rapid decrease is seen in the plume backscatter in a distance of ~500 m. The echosounder record (Fig. 3a) indicated the main part of the plume body to be bent parallel to the ground, though there were some particles rising steadily towards the interface.

In contrast to the observations in the deepest part of the discharge, the transect along the shallow region (Figs. 4a,b) showed that the plume rose continuously and became arrested at the pycnocline level by forming a mushroom like structure. The plume occurs in the form of a concentrated patch of turbid water roughly 150 m wide, 30 m long and slightly inclined to the north. This three dimensional structure of the plume was probably associated with the locations of diffuser ports and the weaker lower layer currents closer to the shore in this part. The entrainment of the lower layer waters into the upper layer is a well-known process, and the largest relative contribution to entrainment occurs in the waters of the southern Bosphorus, due to dissipative hydraulics in the same region (Beşiktepe *et al.*, 1994).

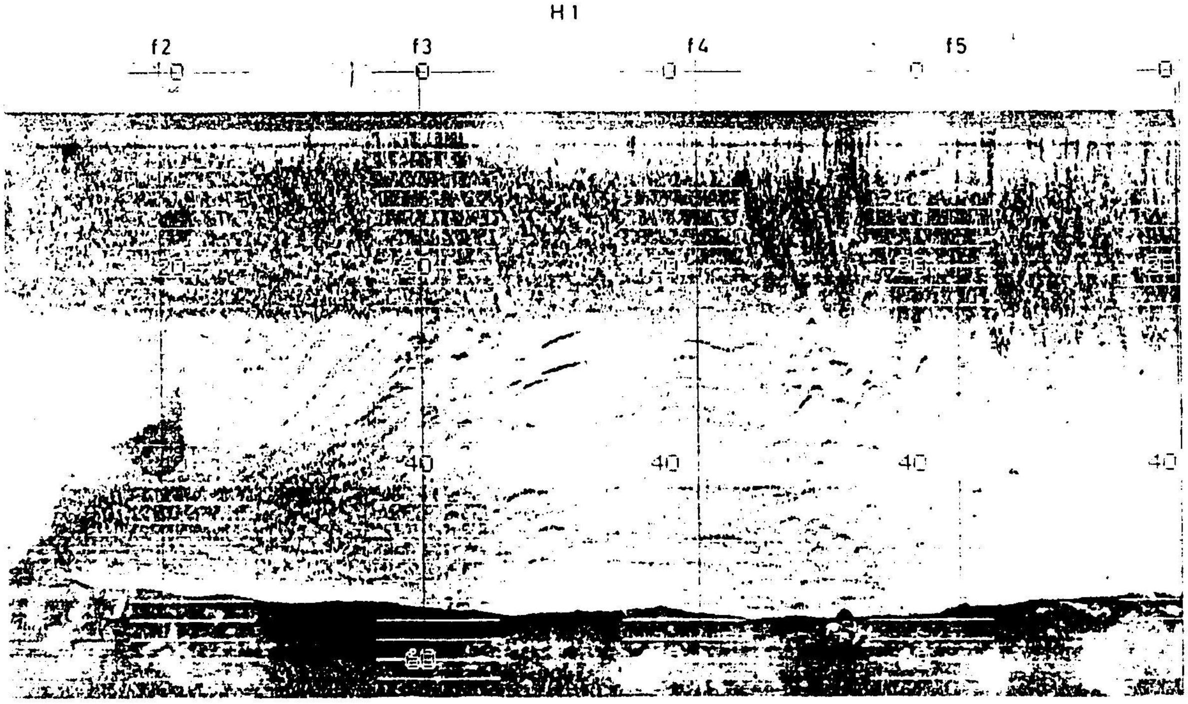

Fig. 3.a. Echo sounder record along section 1 across Ahirkapi diffuser pipeline, 18 May 1992.

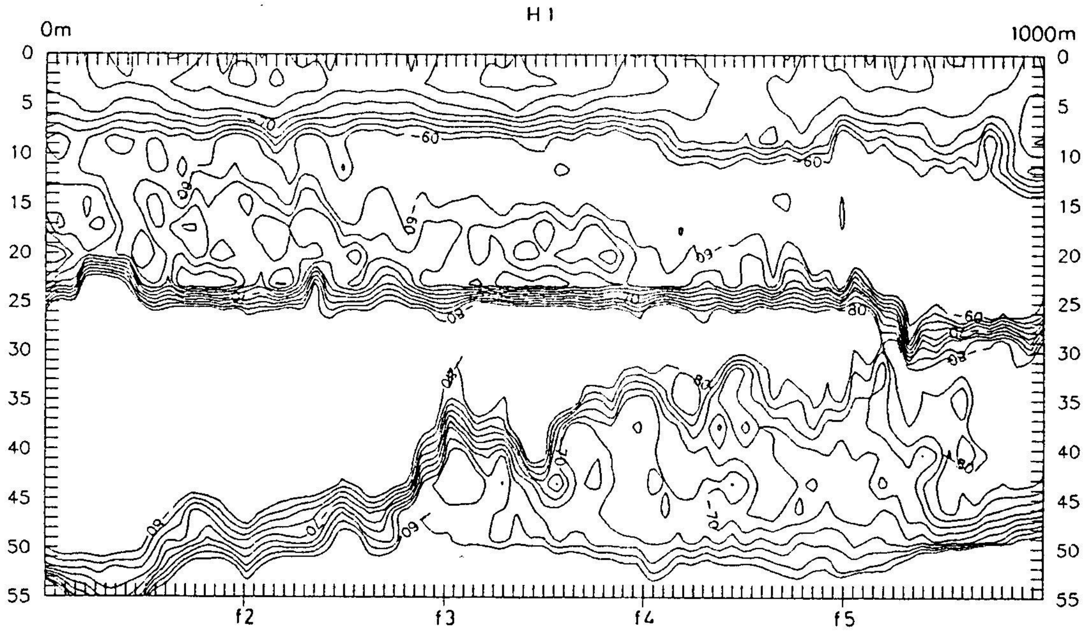

Fig. 3.b. Absolute acoustic backscatter(db) recorded along section 1 across Ahirkapi diffuser pipeline, 18 May 1992.

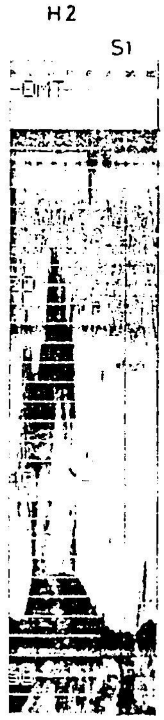

Fig. 4.a. Echo sounder record along section 2 across Ahirkapi diffuser pipeline, 18 May 1992.

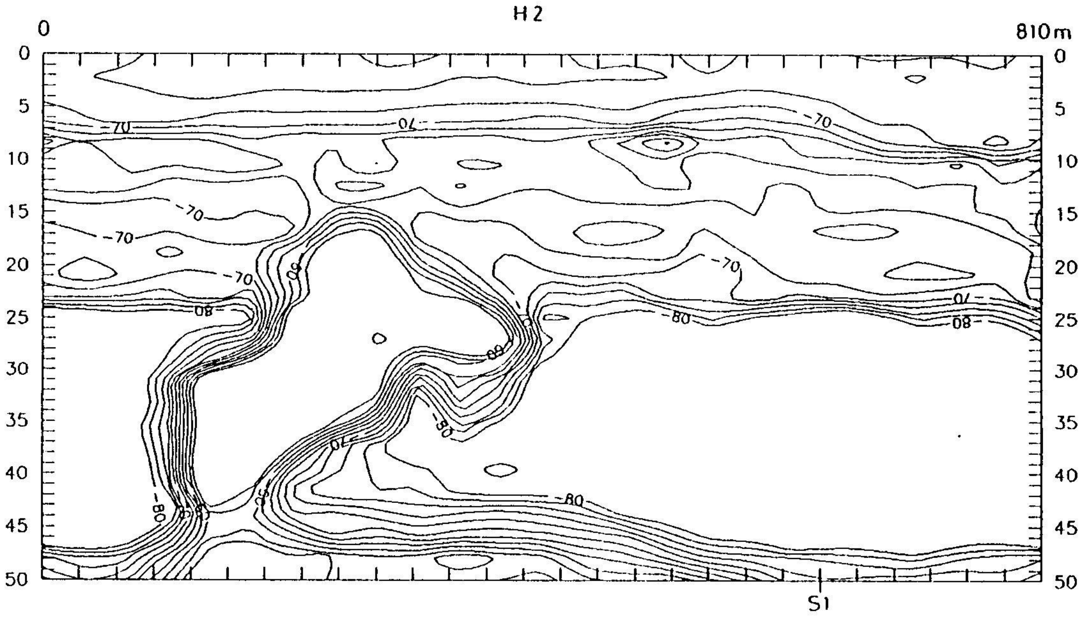

Fig. 4.b Absolute acoustic backscatter(db) recorded along section 2 across Ahirkapi diffuser pipeline, 18 May 1992.

Plume Acoustic Backscatter during 4 March 1993

During the survey on 4 March 1993, it was observed that the flow of Black Sea water was blocked during a short period (Özsoy *et. al*, 1994). Therefore the sewage outflow during backscatter measurements took place under a rare condition of the Bosphorus flow system. This extreme regime was observed only on 4 March 1993 and in the following days the system recovered to normal conditions.

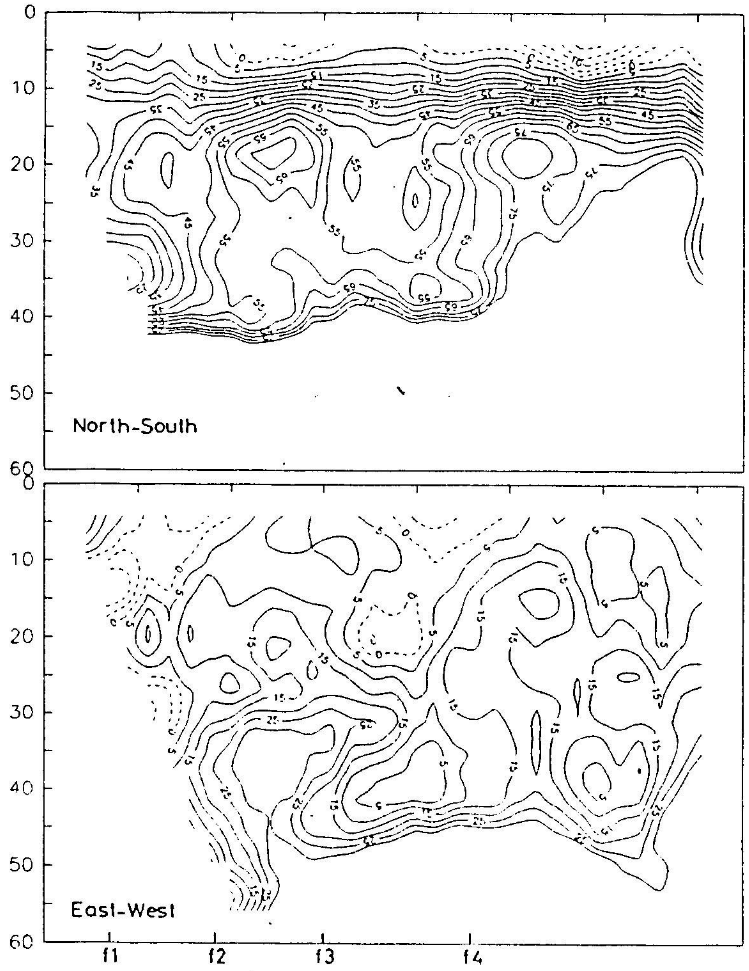

Fig. 5. The ADCP derived velocities along section 1 across the Ahırkapı diffuser pipeline, 4 March 1993. Upper panel shows north-south component of the velocity and positive indicate north (solid line). Lower panel shows east-west component of the velocity and positive indicate east (solid line).

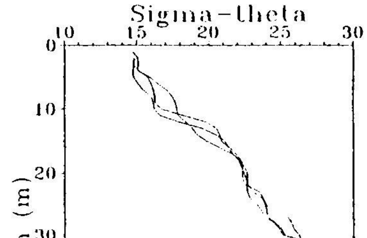

Fig. 6. The vertical profiles of density (sigma-theta) measured at station B0 before and after carrying out the section 1, 4 March 1993.

The north-south and east-west components of the velocity along the transect starting from the south of the diffuser pipeline and continuing north are plotted in Fig. 5. This transect approximately follows the same route as H1 in Fig. 1. The southerly flowing part of the upper layer was confined to the upper 5 m of the water column and rest of the water column was flowing towards north. The northerly velocities were increasing with depth to reach a maximum of 70-80 cm/s near the bottom. The high degree of vertical mixing during conditions of near-blocking of the upper layer flow are evident in the vertical profiles of density at station B0 (Fig. 6).

The echosounder and absolute backscatter measurements corresponding to Fig. 5 are given in Figures 7a and 7b, respectively. In contrast to the May 1992 observations, a strong pycnocline was not detected by the acoustic backscatter measurements, also confirmed by the CTD data (Fig. 6). The plume rise was continuous, with slight bending due to the lower layer currents, but the echosounder records did not indicate whether the rise in fact reached the surface. It seems that the upper 10 m layer of low density water prevented the plume rise reaching to the surface, since a maximum in backscatter is observed at 10 m depth, slightly north of the diffuser, where the material from the diffuser may have reached.

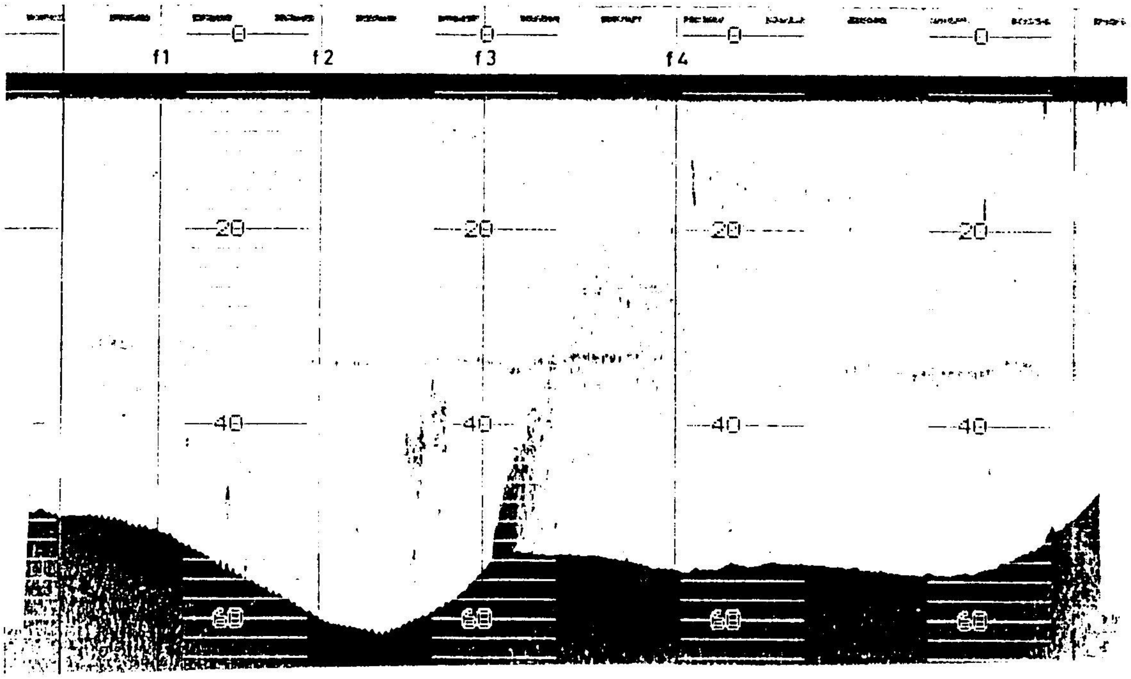

Fig. 7.a. Echo sounder record along section 1 across Ahirkapi diffuser pipeline, 4 March 1993.

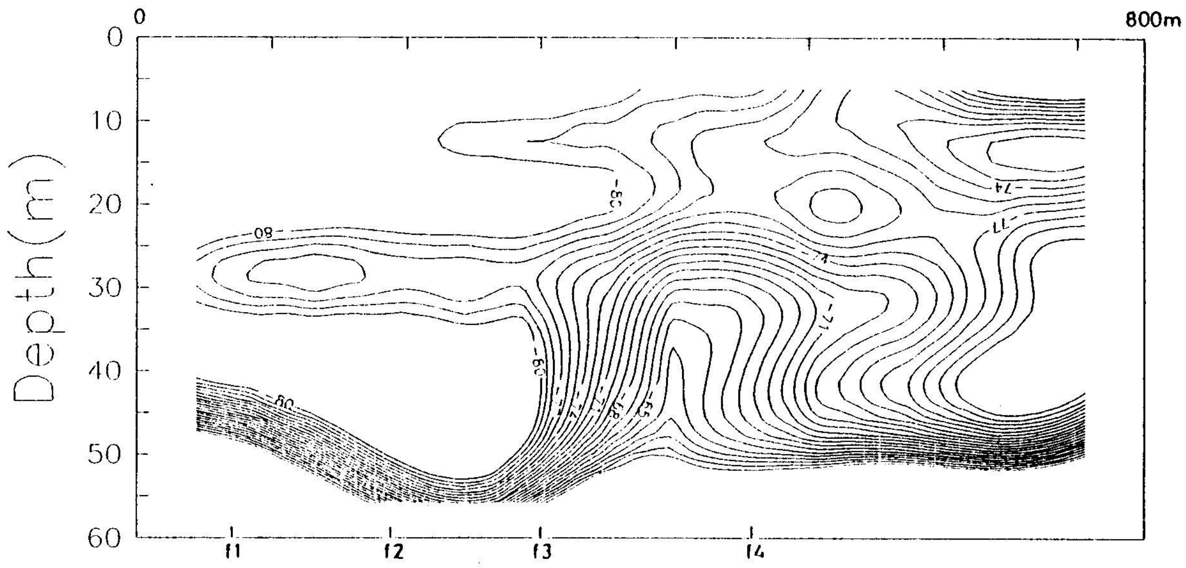

Fig. 7.b Absolute acoustic backscatter(db) recorded along section 1 across Ahirkapi diffuser pipeline, 4 March 1993.

CONCLUSIONS

The observations indicate that the wastewater plume has different structure and dilution along various sections across the diffusers, implying the effects of bottom topography and horizontal variability on the Bosphorus current system and mixing processes. It is also noted that the variability observed in only a limited number of measurements is too high for assessments of wastewater mixing and dispersion based on acoustic imprints.

The above two experiments demonstrate that the dynamics of the Bosphorus current regime has significant influence on the mixing and dispersion of the Ahırkapı sewage outflow. In most cases, the plume rise is arrested by the existing stratification. Although the stratification in the southern Bosphorus is weakened by the dissipative vertical mixing mechanisms, it seems to be sufficiently strong to trap the effluents at depths below the upper layer.

Most rigorous mixing in the salinity structure and the highest plume rise was observed during conditions of blocking of the upper layer flow, in which case the sewage outflow plume can rise to reach depths very close to the surface. However, since the typical upper layer blocking cases last for a short time period (of order one day), the effects of the effluent entrainment are limited on a long term basis.

It should be noted that all of the above measurements were carried out while the three pumps of the Yenikapı discharge station were operating. This was requested from İSKİ, to be able to test the most critical conditions. During the normal operating conditions using only one or two pumps, the plume rise was more limited, and often did not reach the interface, as often shown by echosounder observations during our various cruises in the area.

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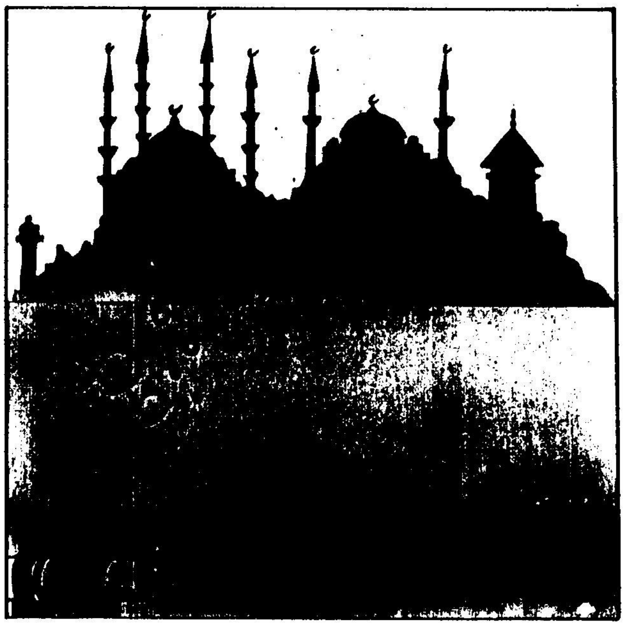

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