A REVIEW OF THE ISKI DYE STUDY OF THE BOSPHORUS 1991-1993

Emin ÖZSOY

Institute of Marine Sciences, Middle East Technical University, Mersin, Turkey
Eurasia Institute of Earth Sciences, İstanbul Technical University, İstanbul, Turkey
ozsoyem@itu.edu.tr

In this short review, the dye study in the Bosphorus performed as part of the İSKİ wastewater studies in the 1990's, originally reported by Özsoy *et al.* (1994, 1995a) and Beşiktepe *et al.* (1995), are briefly re-described for the present context.

Starting with the 1960's till the present time, what to do with the wastes of the growing megapolis of İstanbul has been a major problem for the millions of people living in and around the city and on the coasts of the whole Turkish Straits System (TSS) and adjacent seas. The design and development of a waste collection and disposal system has been an urgent objective of the city administrations, so far partly achieved through veritable efforts on the part of the İstanbul Water and Waste Administration (İSKİ), possibly in need of further updating against the uncontrolled growth of population and industrial pressures. The initial design of the marine waste disposal system, at least for the greater part of İstanbul has relied on the existing physical mechanisms of the TSS. In the two-layer current system of the TSS, it has been proposed that the wastes discharged into the Bosphorus would be carried to the Black Sea by the lower layer flow, with only a small amount possibly making its way to the surface by mixing, which in any case would be low because of the strong stratification. It was also hoped that the wastes remaining in the TSS system would be reprocessed by the marine biogeochemical processes, although bio-treatment of the wastes would also be needed.

However, the TSS with its very small domain and inertia, as well as the adjoining Black Sea are almost closed water bodies receiving huge amounts of nutrients via rivers and the atmosphere as well as wastes from the encircling hinterland. Because the Black Sea ecosystem is already threatened by eutrophication, concerns have been expressed whether the export of wastes to the Black Sea would add to the problems there. Similar concerns existed for the possibility of the pollution of surface waters in the Bosphorus and the Sea of Marmara. The effective role of the TSS in the transport to and from the adjacent Black and Mediterranean Seas have been studied by Polat and Tuğrul (1995) from the above viewpoint. At the same period of time the existing studies Ünlüata *et al.* (1990), Özsoy *et al.* (1995a, 1996, 1998, 2001), Gregg *et al.* (1999), Gregg and Özsoy (2002) provided the background information necessary to understand the basic dynamical setting and transport aspects of the Bosphorus currents. The above concerns have actually proved to be right by the present state of the environment which has deteriorated ever since, especially in the Marmara Sea and the TSS despite the efforts to resist the rising tide of pollution effects by the waste discharge system at the forefront of its defenses.

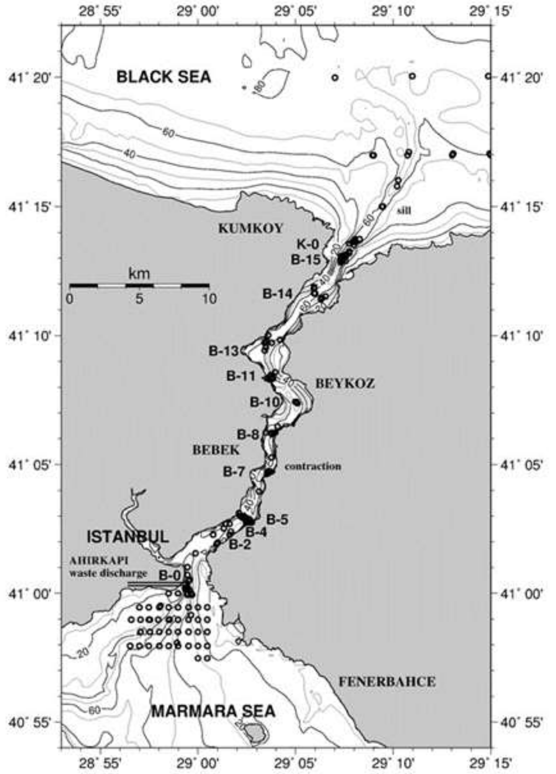

Figure 1. Location map for the İSKİ project of the IMS-METU showing the Bosphorus topography, regular measurement stations and the network of stations used in the dye dispersion study making use of the two ships, R/V BİLİM of Middle East Technical University and R/V ARAR of İstanbul University.

The measurement campaign was carried out for İSKİ during the early 1990's to determine the environmental fate of the marine waste discharges of the city of İstanbul. The location of the study and stations are shown in Figure1. In addition to an in-depth investigation of the TSS through an intense campaign of in-situ oceanographic measurements, the IMS-METU had also taken the incentive to perform a large-scale dye dispersion experiment based on ship-based measurement of dyes introduced to the İSKİ wastewater discharged into the marine environment. The dispersion patterns of the dye patches were monitored by two ships the R/V BİLİM and R/V ARAR using CTD, ADCP echosounding, water sampling and fluoroemeter concentration measurements, assisted by a small boat equipped with a separate fluorometer to locate the dye patch in the Bosphorus Strait and its exit regions in the Marmara and Black Seas.

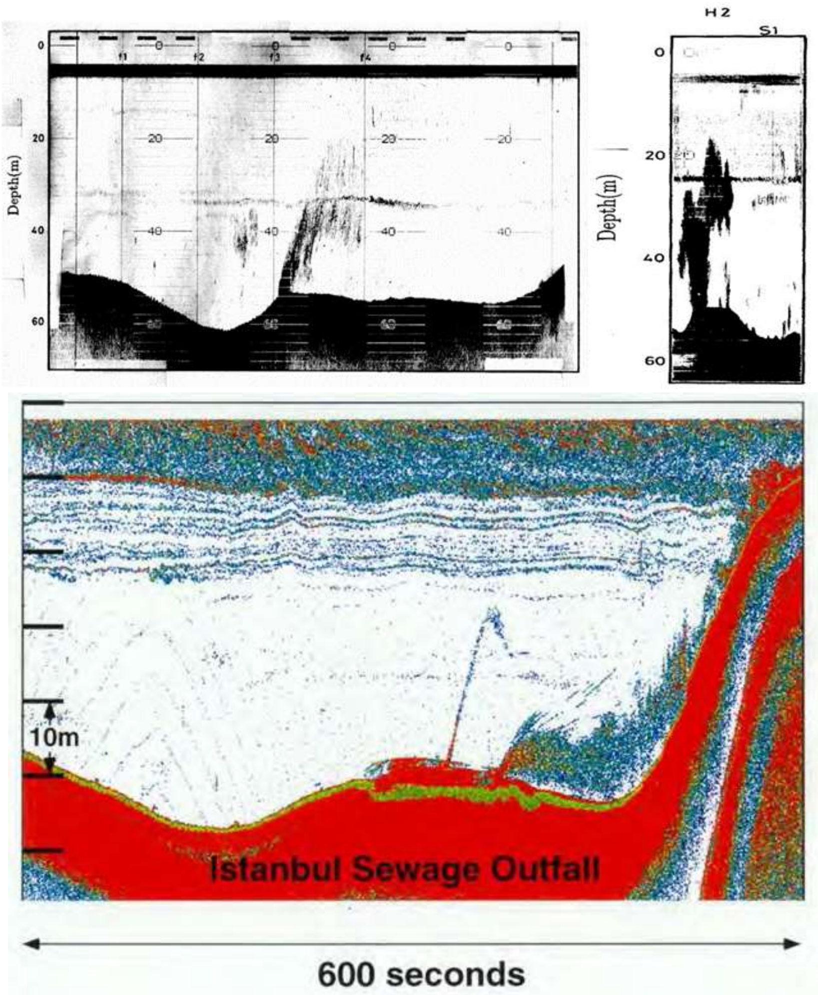

Figure 2. Images of the waste plume issuing from the Ahırkapı diffuser obtained by the echosounder on board the R/V BİLİM during the dye study in the Bosphorus.

Shortly before the IMS-METU study, with the operation of the waste water disposal system in 1987, the city of İstanbul had already started discharging a significant proportion of its waste through diffusers on the seabed of the Bosphorus at Ahırkapı (Figure 1). At the time of the study, the Baltalimanı diffusers and others built later were not yet operative. The experiments were to describe the behaviour of the discharge both during the normal two-layer flow of the Bosphorus and also under extreme conditions when either the upper or the lower layers could become blocked.

The ship-based experiments used echo-sounding and acoustic backscattering measurements to visualize the plume of wastewater (Beşiktepe *et al.* 1995). Examples of the echosounding records are shown in Figure 2. In all similar images, almost at all times the buoyant plume of wastewater discharging from the diffusers was seen to be bending towards the north swept by the strong lower layer currents. In cases of weaker flows the plume would be rising to the interface levels, but was never observed to penetrate the strong density gradient at the interface and become incorporated into the upper layer flow.

Absolute acoustic backscatter in the water column was measured and extracted from the ADCP measurements as the ship moved along paths crossing it, as shown in Figure 3 and described in detail by Beşiktepe *et al.* (1995). These measurements additionally ensured us of the position of the buoyant wastewater plume, which was never observed to reach the surface even under the most adverse conditions.

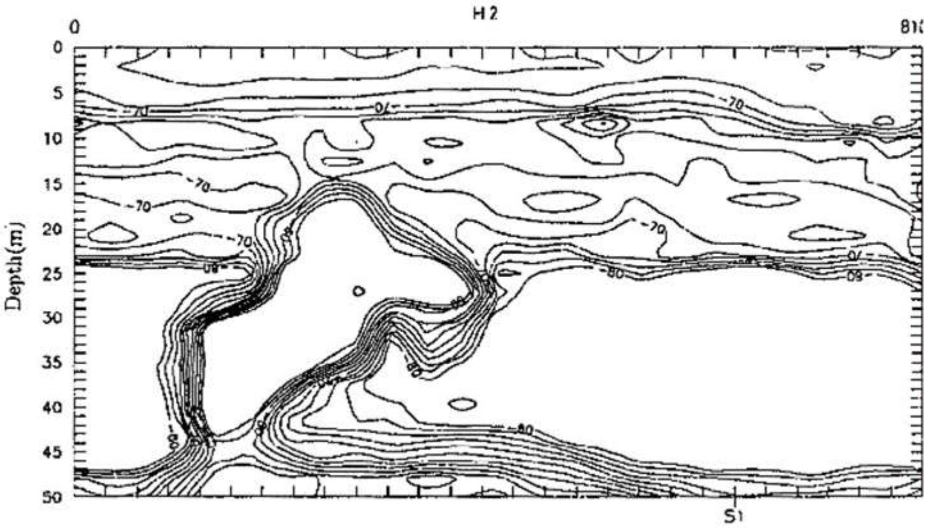

Figure 3. Absolute backscatter measured by the on-board ADCP of the R/V BİLİM near the Ahırkapı diffuser on 18 May 1992.

The dye study was performed by mixing dyed water of given fluorescent Rhodamine dye of given concentration to the wastewater at the İSKİ treatment facility at Yenikapı and later measuring the concentration in the water discharged into the Bosphorus through a vigorous tracking and sampling program in real-time along the Strait and its adjoining exit regions by two oceanographic ships and a small vessel. The measurements were carried out for instantaneous and continuous releases, repeated under normal and adverse conditions of flow blocking in the Bosphorus during several experiments outlined in Table 1.

Table 1. Dye release experiments

date	release method	dye mass (kg)	waste water flux (m^3/s)	lower layer flux (m^3/s)	tank conc. (ppb)	calculated source conc. (ppb)	measured source conc. (ppb)
Aug. 1992	Instantaneous	180	2	7500	100	54	52
Sep. 1992	Continuous	408	2	12000	1.7	1	4
Mar. 1993	Instantaneous	312	6	5000	130	31	21
Dec. 1993	Instantaneous	312	2	19000	86	36	79

ADCP measurements of currents together with fluorometric measurements of dye concentration (Figure 4) delineated the dye patches moving with the exchange flows in the Strait, as shown by the analyses of the measurements and computations presented in Özsoy *et al.* (1994, 1995). During the measurements, the fluxes of both layers changed over a wide range, including several cases of short-term blocking.

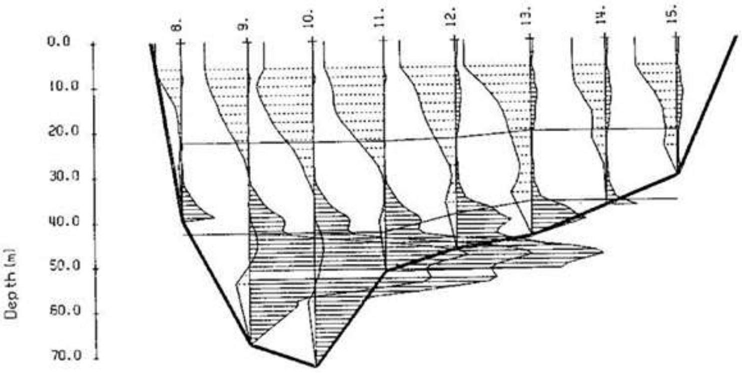

Figure 4. An example of a section of ADCP current (dotted line fill) and dye concentration (solid line fill) profiles at Section B5, 5 March 1993, used in the computation of dye mass transiting the Strait.

Normal discharge conditions prevailed in the first two dye release experiments, with upper and lower layer discharges respectively of Qu = 10000− 17000 m3/s, Qℓ = 5000 − 7500 m3/s in August 1992, and Qu = 3000 − 5000 m3/s, Qℓ = 11000 − 15000 m3/s in September 1992.

In March 1993, the upper layer flux was increased significantly (Qu = 20000− 27000 m3/s), leading the lower layer discharge to be significantly reduced (Qℓ = 1000 − 3000 m3/s), almost to the level of lower layer blocking. The transit time for the dye cloud in the lower layer was therefore considerably larger than the first experiment in Figure 3.

In December 1993, the identification of the layers was less straightforward because the upper layer was actually blocked (Qu = 0). The Black Sea water (Su < 18) was found only at the north end of the Bosphorus before the dye release started but then receded to the contraction area during the dye measurements. Elsewhere Marmara surface water (S ≃ 24 − 26) and the underlying Mediterranean water flowed towards the Black Sea (total Qℓ = 20000 m3/s), and submerged under the low salinity wedge of Black Sea water.

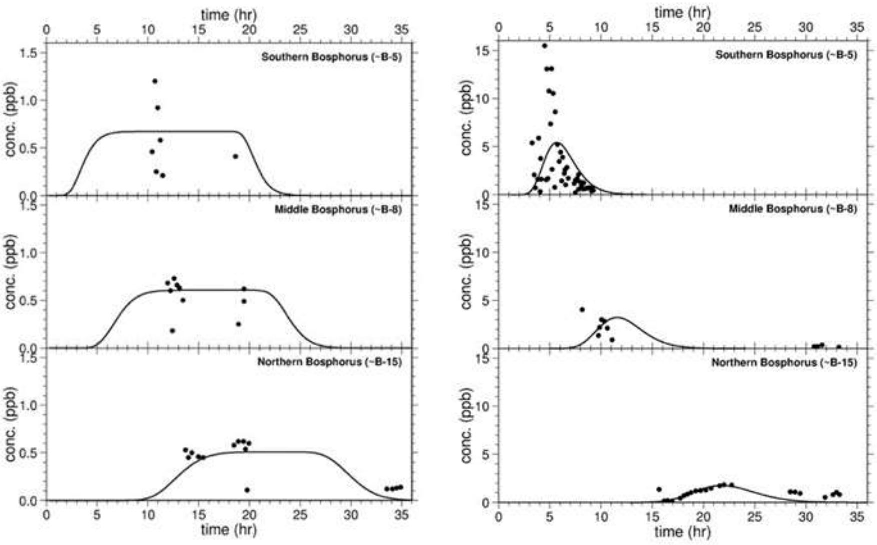

Figure 5. Lower layer average Rhodamine-B concentration at different locations along the Bosphorus, after (a) continuous dye release, September 1992, and (b) instantaneous release, March 1993. Data points are measurements, and the solid lines are the predicted concentrations at the 7.5, 15 and 28 km distances from the source (respectively near stations B5, B8 and B15) obtained from diffusion model calculations.

In Figures 5 and 6, measurements of the lower layer average dye concentration at various stations along the Bosphorus are compared with model calculations following Özsoy and Ünlüata (1988) for the several cases of continuous and instantaneous release experiments.

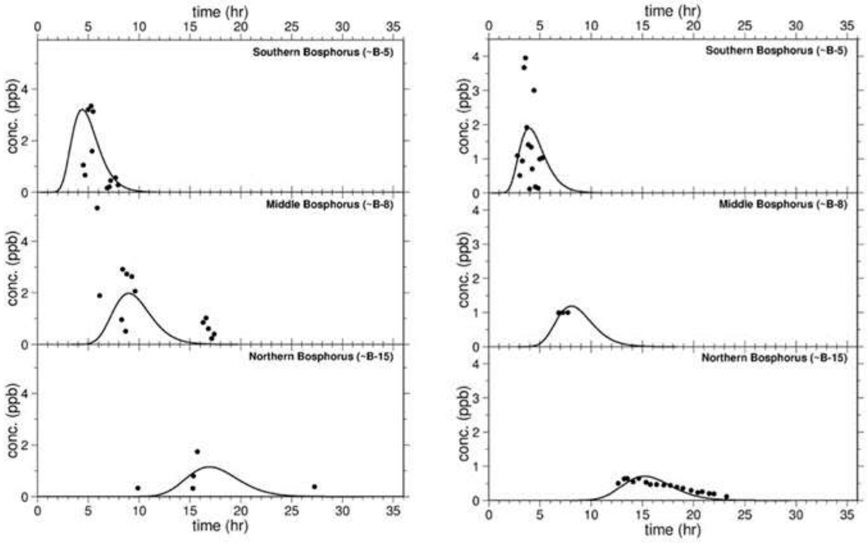

Figure 6. Lower layer average Rhodamine-B concentration at different locations along the Bosphorus, after (a) instantaneous dye release, August 1992, and (b) instantaneous release, December 1993. Data points are measurements, and the solid lines are the predicted concentrations at the 7.5, 15 and 28 km distances from the source (respectively near stations B5, B8 and B15) obtained from diffusion model calculations.

Measured fluorescence intensities following the addition of Rhodamine B to the waste showed the dye, and therefore the waste water, to be dispersed to become almost uniform in the lower layer at a distance of 6-8km from the discharge. Measurements of the dispersion showed the mixing times to be about 2.5 days, 9 hours and 5 minutes along, across and in the vertical direction respectively within the lower layer of the Bosphorus, suggesting that the lower layer mixed patch would reach the Black Sea without finding time to be entrained into the upper layer and carried back to the Marmara Sea. Simultaneous measurements of current velocity and of Rhodamine concentrations across the Bosphorus confirmed the soundness of the observations and of their analysis, the mass of dye computed to be passing the cross section of the Bosphorus; being of the same order of magnitude as that known to have been dissolved in the wastewater initially. When the Rhodamine was added instantaneously dilution factors of 10−5 to 10−6 were observed. Continuous release of Rhodamine gave dilution factors of 10−3 to 10−4 and it was evident that the concentration of water soluble waste became approximately constant throughout the bottom layer of the Bosphorus and tailed off upwards towards the halocline. The fluorescence due to the transport of Rhodamine from the bottom to the top layer of the Bosphorus was little larger than the background fluorescence observed before the release of the dye. The background level was equivalent to 0.4ppb of Rhodamine in the Bosphorus. Consequently it was difficult to determine dye concentrations in the upper layer accurately. All our observations are consistent with dye - and hence soluble waste being transported into the upper layer of the Bosphorus in the same manner as salinity. In an experiment in which Rhodamine was injected continuously into the city waste for 17 hours 12% of the lower layer flux appeared to be transported into the upper layer. The fluorescent dye concentrations in the upper layer remained at low levels throughout the Bosphorus and its adjacent areas. Under blocked flow conditions, contamination of the surface waters was minimal, and flushing of the wastes out of the system was rapid. Longitudinal dispersion coefficients governing the transport of waste along the Bosphorus were estimated by the measurements. The turbulent plume of waste is found to be capped by the pycnocline, and therefore the transport of waste into the top layer of the Bosphorus is small under all conditions. The results showed limited surfacing of the wastes discharged from diffusers at the bottom of the Bosphorus. The total quantity of dye computed by integrating the dye patches in transit through the system confirmed recovery of the injected amount, checking the consistency of the measurements.

The most significant pathway of entrainment of lower layer material into the upper layer would in fact be expected in the southern part of the Bosphorus in the dissapative region south of the central constriction, where the Ahırkapı diffuser is located. Despite this expectancy, the levels found in the upper layer were confirmative of the design, which showed that the estimates based on mass budgets were not exceeded in any way.

The accompanying measured distributions of halocarbons have been reported in Fogelqvist *et al.* (1996), and faecal coliforms were counted in addition to the dye study based on Rhodamine dye added to the waste and dispersion patterns of waste followed throughout the Bosphorus, as reported by Özsoy *et al.* (1994, 1995), Beşiktepe *et al.* (1995).

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