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Oceanographic Investigations Related to a Sewerage Outfall in Mersin Bay

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Abstract

Oceanographic investigations were carried out for a sewerage outfall for the city of Mersin. The city, with a population of < 500.000 (1991-92) has planned to discharge municipal wastes via a ∼ 1 km long outfall pipe at a rate of 2.5 m^3/sec into the nearshore region in the vicinity of Merisn harbour. The effluent will be discharged after it has been primarily treated. The system is operational at present. The currents in the region are strongly correlated with the prevailing winds, and are either westerly or easterly. The breakwaters of the harbour act to block the current; and generate a small eddy near the shore, with the possibility of trapping the effluent in the Bay. In addition, the physical and chemical properties of the region, including stratification and oxygen content were determined on a seasonal basis. Faecal coliform decay (T-90) was determied by Rhodamine-B dye tracing experiment. The loads of pollutants from land-based sources were estimated.

Key Words: Sewerage; Ocenographic investigation; Waste; Currents; Faecal coliform decay.

Mersin Körfezinde Kanalizasyon Deşarjı ile ilgili Oşinografik Araştırmalar

Özet

Bu çalışma 500.000'den fazla olan (1991-92 için) Mersin ilinin 2.5 m^3/sn debili; kanalizasyon akıklarının ∼ 1 km'lik deniz deşarjıyla körfeze verilmesi konusunda yapılan oşinografik araştırmaları kapsamaktadır. Atıklar bu sistemle birincil arıtmadan sonra denize gönderilecektir ve halihazırda bu sistem işletilmeye başlanmıştır. Körfezde akıntılar genelde batı ve doğu rüzgarlarının etkisi altındadır. Mersin limanının dalga kıranları akıtıları bloke ederek kıyıya yakın bir bölgede küçük bir girdap oluşturmaktadır. Bu girdabın deşarj edilen kanalizasyon atıkları için tuzak olması söz konusudur. Bu çalışmada ayrıca körfez sularının fiziksel ve kimyasal özellikleri, tabakalaşma ve oksijen dağılımı gibi olgular mevsimsel bazda incelenmiştir. Körfez suları için Fekal koliform parçalanma hızı (T-90), Rodamin-B boya izleme deneyi yapılarak saptanmıştır. Karasal kaynaklardan gelen kirletici yük miktarları belirlenmiştir.

Anahtar Sözcükler: Kanalizasyon; Oşinografik araştırma; Atık; Akıntılar; Fekal koliform parçalanması

Introduction

The investigations described here were carried out in relation to a marine outfall system for the city of Mersin during December 1991-October 1992 period (Latif and Yılmaz, 1992). The study area is situated in the middle of a concave bay with very shallow depth (Figure 1). Thus it is isolated from the general circulation pattern of the Northeastern Mediterranean basin as well as from an effective exchange with the offshore waters. Two small creeks and a canal discharge into the region. The studies included the determination of the physical, chemical and biologial properties of the water column and the prevailing currents in the nearshore region as weell as the estimation of pollutant inputs from land-based sources. The closely spaced station network was chosen to determine the variations in these properties keeping in mind the small scale of the region and the possible influence of the obstruction presented by the harbour to the flow near the coast.

Measurements of the physical and chemical properties of the water column were carried out on a seasonal basis at the stations shown in Figure 1. The effluents were sampled bimonthly in order to estimate the pollutant inputs to the Bay. Current measurements were carried out twice during the investigation period. Currents were measured at current meter stations CM 1, CM 2, CM 4 and CM 5 during 22 April-12 May 1992, and during 22 July; 13 August 1992 at CM 3 and CM 6 (Fig. 1). Anderaa recording current meters were used for this purpose. Due to the relatively shallow depths, one current meter at mid-depth was deployed at each of the CM stations. The Decca trisponder system was used for positioning the boat and the current meters. It is worth to mention that the area close to the exit of the harbour (Fig. 1) has been exposed to domestic discharges of the city for a relatively long period. Starting from April 1994 the domestic wastes subjected to primary treatment are discharged 1 km offshore.

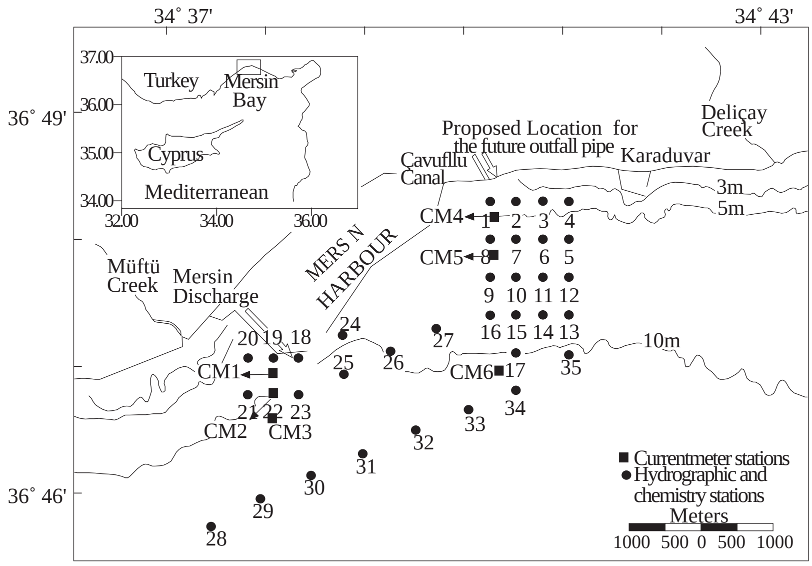

Figure 1. Location map of the study area and station network

Climatological Characteristics

Winds: The wind regime in the region is dominated by the passage of cyclonic systems from approximately October until April and a sea breeze pattern during the rest of the year. The dominant wind direction during the year are northeast and southwest. In winter, these winds are associated with the passage of cyclonic systems, and in summer with the land-, sea-breeze system. The region is also subject to occasional outbreaks of a strong wind from the northeast, known locally as Poyraz. Winds from the NE-NW sector are dominant during winter (November-March), while southwesterly winds dominate during the summer months. It is worth noting that while the relative frequency of winds from the southwest during the winter is low, srong winds are observed from the SW-SE sector during winter associated with the passages of storms.

Air and sea surface temperatures: In general, the lowest air temperature is about 5°C and occurs in February-March, while the highest temperatures are between 28°C-30°C, and are observed during July and August. The lowest sea surface temperatures range between 13°C-15°C and occur in February-March, while the highest temperatures of 28°C-29°C are observed in July and August. Considerable interannual variability exists in the air and sea surface temperatures. In particular the winter seasons of 1985 and 1987 were about 2°C-3°C cooler than the averages of recent years.

Methodolgy:

Table 1 covers the brief descriptions of the analytical methods followed during the measurements of physical, biochemical and pollution parameters in the present study.

Results and Discussion

Hydrographic properties: The seasonal variation of the temperature, salinity and density of he water column are illustrated by repesentative profiles selected in the Bay (Figure 2). The surface temperature ranges from about 19°C in December to about 29°C in August. The strong winds of the winter storms and the cooler air temperatures both result in mixing the water column vertically, resuling in a uniform vertical structure in winter. With the coming of the warming season in spring, the water column begins to attain a two-layer structure. With continued heating through the summer, and due to the relatively weaker winds, the sharp seasonal thermocline becomes well established during August and continues till the end of October.

Currents: The current structure in the nearshore region is of particular importance in the design of the marine outfall system. To determine the prevailing currents in the region, measurements were carried out in April-May and in July-August 1992 at the stations shown in Fig.1. Aanderaa current meters were used during the measurements. Time series of the east-west and north-south componens of the currents for the April-May deployment are shown in Fig. 3a-d. In these figures, currents towards north and eas aer taken as positive and point in the positive y-axis direction. The velocity scale is 1 cm=10 cm/sec. The x-axis is the number of days, the total period of deployment being 15 days. The currents are oscillatory, however the dominant flow is towards east at the offshore stations. This is seen clearly in the progressive vector diagrams for these stations shown in Fig. 4. The diagram fo CM Sta.4 indicates that a small eddy is present at this location. The eddy is apparently generated by the shear of the eastely flow on the water mass in he nearshore region.

The measurements during July-August confirmed that the extent of the eddy is limited to the small corner in the east of the harbour. Figs.5a-5b show the time series and Fig. 6 the progressive vector diagram for this deployment. The currents are again oscillatory, however the dominant direction is easterly.

Based on these measurements, the flow pattern in the region is shown schematically in Fig. 7. Thus, it was recommended that the outfall pipe should extend at least as far offshore as the location of the CM stations 3 and 6.

Pollutant inputs from the land based sources: Samples taken bimonthly from the sewage outfall and creeks flowing into the Mersin Bay, namely Mersin discharge, Deliçay and Müftü creeks and Çavuşlu canal were analyzed for their pollutant contents and biochemical characteristics. The average concentrations and the annual effluent discharges are displayed in Tables 2 and 3 respectively. By utilizing the information in these tables, the total annual pollutant inputs by the discharges have been calculated and the results are given in Table 4. The total annual biochemical oxygen demand (BOD) load emanating from the land based sources is 4 000 tons and 87.5% of it is due to domestic input (Table 4). The theoretical domestic BOD load of the Mersin area, assuming a BOD load of 25-70 g/capita/day (UNEP, 1989a) and an average population of 500 000 is approximately 4 500 t/y, impending our estimate from direct measurements. This load is lower than the loads from the major rivers in the Northeastern Mediterranean and constitutes only 5% of the total load; for example 40 000 t/y ard 45 000 t/y BOD loads are estimated for Ceyhan and Seyhan (including municipal wastes of Adana) rivers respectively (Yılmaz *et al.,* 1992). The chemical oxygen demand (COD) concentrations of the three creek waters were found to vary between 68 and 149 mg/l leading to a total of 23 800 t/y of COD load into the bay. The high COD/BOD ratio (20-75) in the creek waters is an indication of large industrial inputs to these effluents (Table 2). The average COD content of Mersin discharge was approximately twice its BOD content,approaching the general COD/BOD ratio observed for domestic wastewaters. The total COD load was calculated as 6 400 t/y for the Mersin effluent and its contribution is calculated as 21% (Table 4).

Total suspended sediment load from the land-based sources of Mersin area was estimated as 2.940 t/y which constitutes only the <%1 of the total Northeastern Mediterranean loads (Yılmaz *et al.*,1992).

A significant fraction (72%) of the total phosphorus in creeks is introduced to the Bay as dissolved inorganic phosphate and total phosphorus input was calculated as 7.2 t/y. The inorganic phosphate and total phosphorus discharges from the Mersin sewerage system were 42 and 67 t/y respectively, much larger than the total inputs from the creeks and again the contribution of inorganic phosphate is relatively high for the domestic effluent. On the other hand, total oxidized nitrogen annual inputs from the creeks were estimated to be 241 tons whereas the input from the Mersin outfall system was approximately only 1 ton/year (Table 4). This high quantity of nitrogenous material can be attributed to extensive use of fertilizers since the area is effectively used as agricultural are a besides as industrial area and such materials are transported via the effluents.

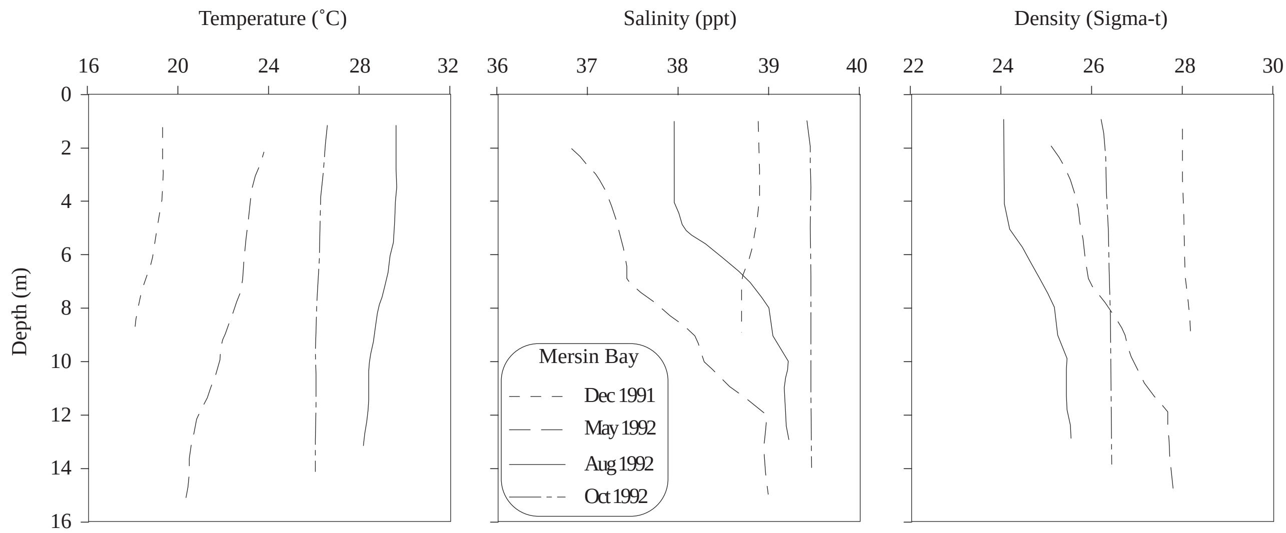

Figure 2. Property profiles at selected stations in Mersin Bay

Table 1. Material and methods used in the present study

Parameter	Outline of Method	Detection Limit	Reference
T, S, σ_t	CTD-Probe, *In Situ*	-	Sea Bird Model 9 Manual
SD	Visual observation, white 30cm disk	-	-
pH	pH-meter	∓0.03(0-14)	-
TSS	Gravimetric	0.05 mg/L	APHA, AWWA, WPCF Standard Methods, 1985
FC	Membrane filtration, MFC-Broth medium	93%	APHA, AWWA, WPCF Standard Methods, 1985
o-PO_4-P	Phoshomolibdate complex formation, Autoanalyzer	0.015 μM	Strickland and Parsons, 1972; Grasshoff, 1983
T-P	Persulphate oxidation, phospho-molibdate complex formation, autoanalyzer or Spectrophotometer	0.1 μM	Strickland and Parsons, 1972; FAO, Fisheries Tech. Rep. No. 137, 1975
NO_3+NO_2-N	Cd-Cu column reduction, Azo-dye formation, Atoanalyzer	0.05 μM	Strickland and Parsons, 1972; Grasshoff, 1983.
BOD_5	Incubation at 20 °C for 5 days, dilution and seeding, Winkler titration	0.05 mg/L	APHA, AWWA, WPCF Standard Methods, 1985
COD	$K_2Cr_2O_7+H_2SO_4$ Oxidation, Titrimetric	0.05 mg/L	APHA, AWWA, WPCF Standard Methods, 1985
PAH	n-hegzan extraction, Fluorometer	0.01 μg/L	APHA, AWWA, WPCF Standard Methods, 1985 UNESCO, 1984.
Hg_w	Cold vapor, AAS	0.25 ng/L	Yemenicioğlu, 1990; Tuncel *et al.*, 1980
Cd_w	Digestion with Aqua regia, AAS	0.02 ng/L	Ediger *et al.*, 1974
Cd_{TSS}	Digestion with hot HNO3, AAS	0.02 ng/L	Ediger *et al.*, 1974

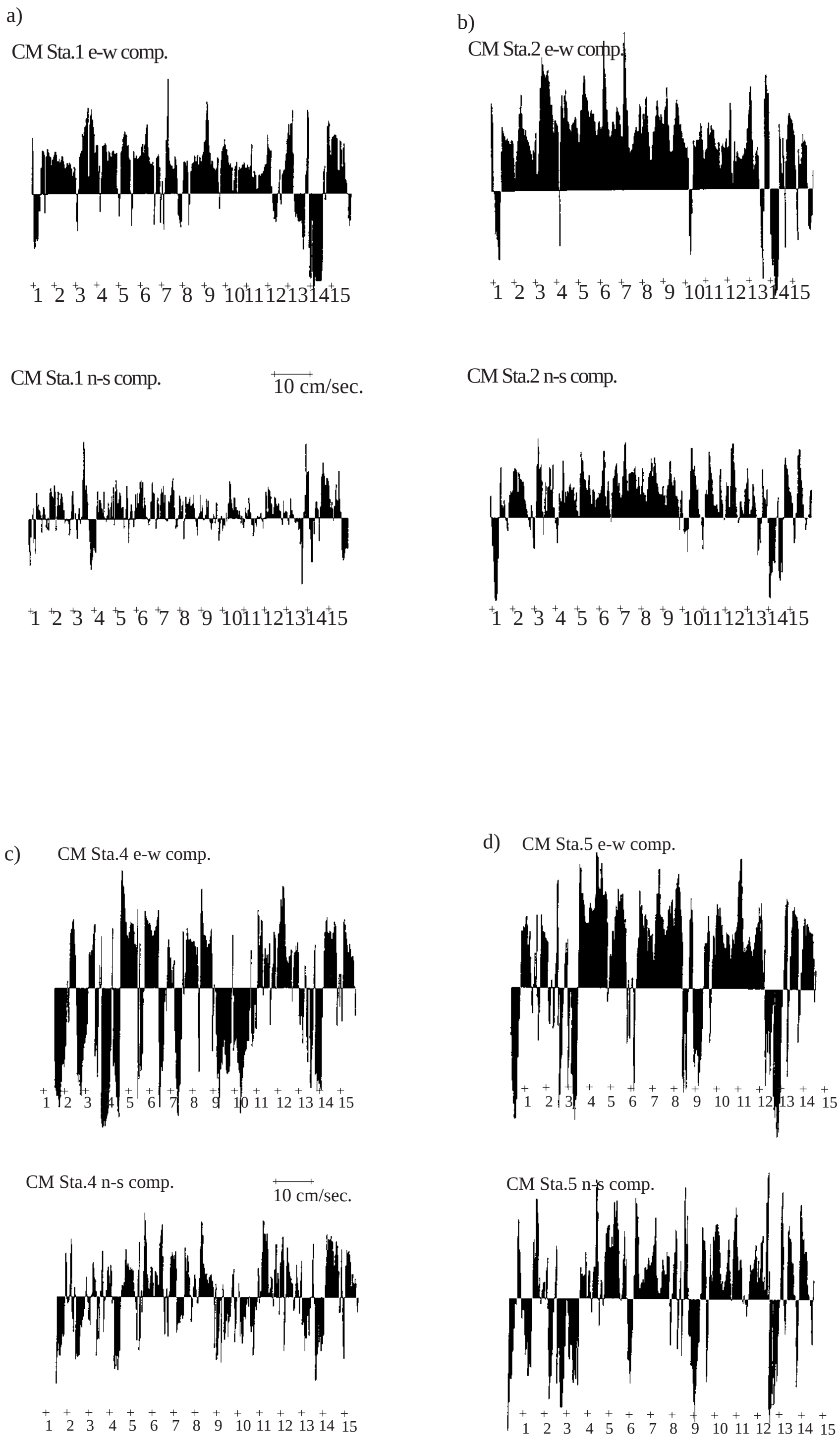

Figure 3. Time series of current velocity components, April-May deployment

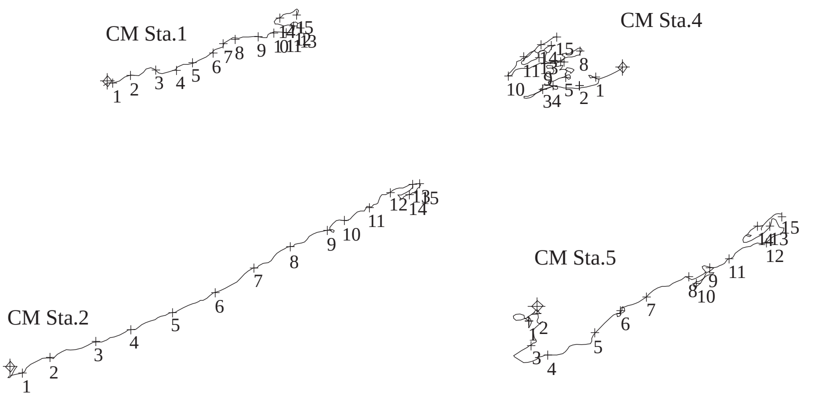

Figure 4. Progressive vector diagram of current velocity April-May deployment

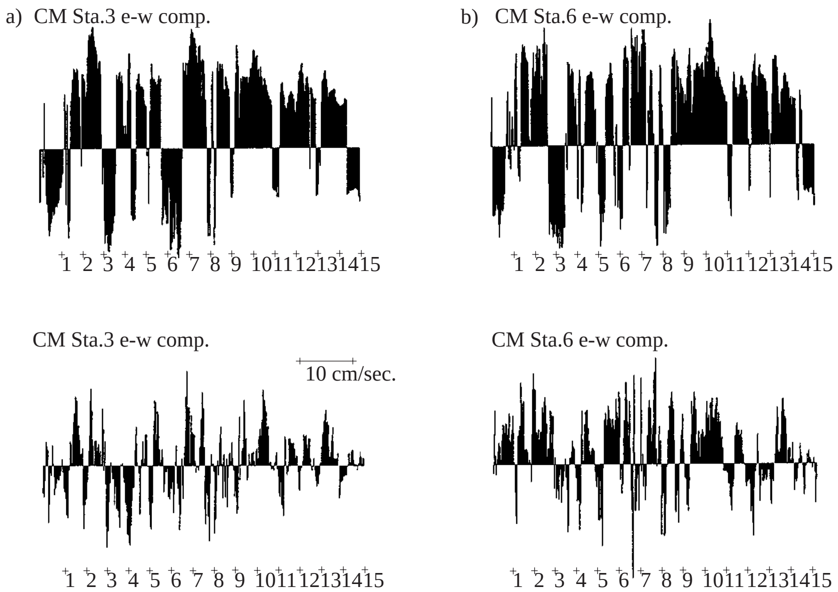

Figure 5. Time series of current velocity components, July-August deployment

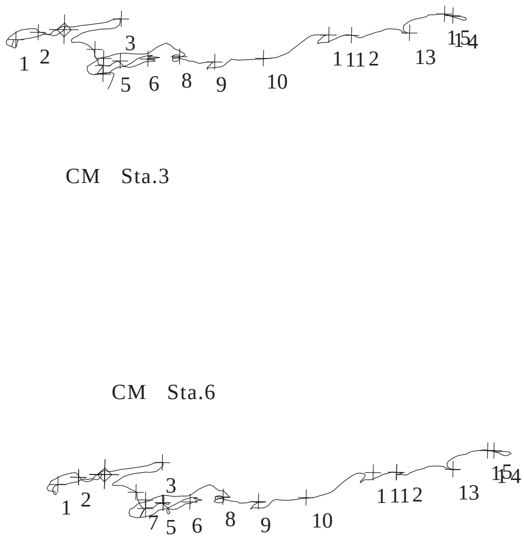

Figure 6. Progressive vector diagram of current velocity, July-August deployment

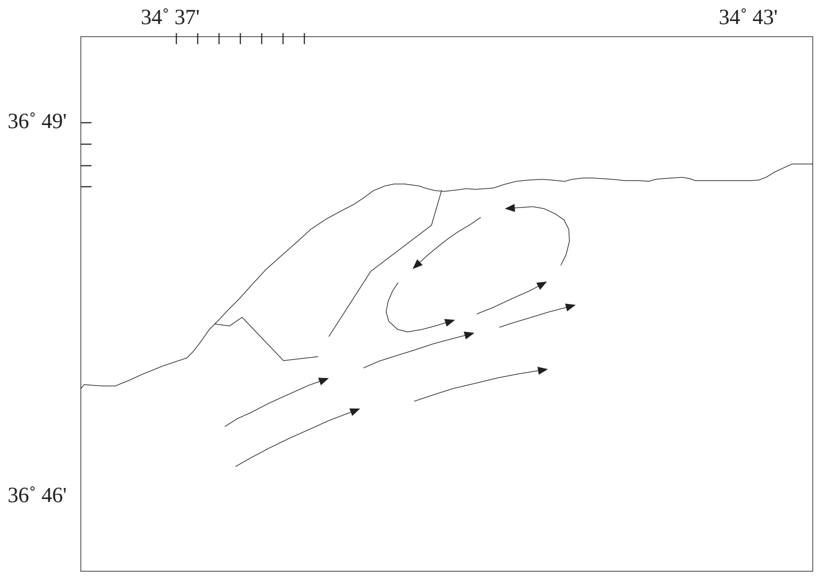

Figure 7. Schematic current pattern for Mersin Bay

Table 2. Pollutants and biochemical parameters measured at three creeks and Mersin sewerage outlet (concentratiosn are averages of six sampling periods during December 1991-October 1992 period)

Source	pH	DO μM	BOD_5 mg/l	COD mg/l	TSS mg/l	o-PO_4-P μM	NO_3+NO_2-N μM	T-P μM	PAH μg/l	Hg_w ng/l	Cd_w ng/l	Cd_{TSS} ng/l	FC#/100 ml
Deliçay Creek	8.05	296	2	149	4.4	0.45	116.2	1.02	3.1	1.7	1.3	189	1618
Çavuşlu Canal	7.64	233	3.3	68	4.8	7.91	159.9	7.93	0.5	2.3	0.7	129	1307
Müftü Creek	8.47	318	2.6	128	9.3	0.59	63.3	0.78	0.4	3.0	0.8	116	769
Mersin Discharge	7.31	267	186	338	100	71.0	80.3	116	148	3.7	2.0	1058	4.65×10^8

Table 3. Effluents and their annual discharges in Mersin region

Effluent	Discharge
Deliçay Creek	$94\times10^6 m^3/y$
Çavuşlu Canal	$10\times10^6 m^3/y$
Müftü Creek	$72\times10^6 m^3/y$
Mersin Discharge	$18\times10^6 m^3/y$
Total Volume	$194\times10^6 m^3/y$

Table 4. Total annual land-based loads into the Mersin Bay

Pollutant	Quantity	% Domestic Input (Mersin outfall)
Total Volume	$194\times10^6 m^3$	9.4
BOD_5	4.000 tons	87.5
COD	30200 tons	21
TSS	2.940 tons	62
0-PO_4-P	47 tons	89
T-P	74 tons	90
NO_3+NO_2-N	242 tons	<0.5
PAH	3 tons	90
Hg	0.5 kg	14
Cd	37 kg	45

The major source of the polyaromatic petroleum hydrocarbons (PAH) for Mersin Bay seems to be the domestic effluents. Totaly 3 t/y of petroleum origin wastes are discharged into the bay which is only % 1 of the total Northeastern Mediterranean loads (Yılmaz *et al.,*1992). Deliçay creek drains the effluents of quite a high numberof small compexes processing crude oil or petroleum prodcts and is more polluted than the other creeks in terms of petroleum pollution. There is also a refinery (Ataş Refinery) in this district.

Among heavy metals, with 37 kg/y cadmium input is significant and total mercury input is as low as 0.5 kg/y (Table 4).

Faecal coliforms (FC) were remarkably high in all discharges (ranged between 150-4000 cells/100ml in creek waters) and very high in the wastewater (ranged between 1.7×10^4-1.4×10^9 cells/100ml).

Biochemical characteristics of the coastal waters: Some biochemical and pollution parameters were measured in sea water samples collected at a limited number of stations in Mersin Bay. Two station grids-one of them was in the vicinity of the existing outall near Mersin harbour and the other one was across to the proposed outfall pipeline in Çavuşlu canal-Karaduvar region- are shown in Figure 1. These grids were visited five times during December 1991-October 1992 period and a summary of the data is presented in Table 5.

The influence of the existing outfall on its immediate vicinity is pronounced, i.e. TSS concentrations measured at Stations 18, 19, 20 and in very near coastal stations of the Karaduvar grid, e.g. 1, 2, 3, 4 are relatively high (ranged between 5-120 mg/l) while for the other coastal stations, it is approximately 12 mg/l on average (Table 5). Most of the coastal stations had TSS concentration lower than 5 mg/l and the results are in good agreement with the data (ranges between 0.1-4.8 mg/l for the Northeastern Mediterranean including the coastal regions) reported by Saydam *et al.,* (1984). Mersin Bay study area is very near shore area thus the concentration level of TSS is found to be relatively high. Main sources of suspended particles in the water column are mostly the land-based sources, biological activity and primary production in the lighted zone and the resuspension from the bottom sediment. However, relatively high concentraions of TSS determined in Mersin Bay led to measures of Secchi disc depth ranging between 0.5 and 4m. These values are very low when compared to Secchi disc depth, exeeding 25-30m in the offshore water of the Norheastern Mediterranean for most of the year (Megard and Berman 1989; Berman et al., 1986; Yılmaz *et al.,*1994).

Table 5. Concentration ranges of biochemical parameters measured in Mersin Bay coastal waters. Stations were cassified as the ones in front of existing discharge (Stations 18, 19, 20), in front of proposed discharge around Çavuşlu canal (1, 2, 3, 4) and the other stations in the Bay. The mean concentrations are also presented for the Bay excluding the above given stations

Parameter	Existing DischargeRegion Range	Çavuşlu Canal Region Range	Other Stations in Mersin Bay Range	Mean
pH	8.00-8.33	8.00-8.33	8.00-8.36	8.18
DO(μM)	165-372	186-336	167-355	235
BOD_5(mg/l)	BDL-10	0.5-4	BDL-4	1.5
COD(mg/l)	2-22	2-7	0.5-24	3.6
o-PO_4-P(μM)	0.04-12.20	0.05-20.32	0.02-6.48	0.44
NO_3+NO_2-N(μM)	0.65-27.16	0.27-35.80	0.05-38.08	3.49
SD(m)	0.5-2.5	2-2.5	2-4	2.5
FC(#/100ml)	4-3.000.000	0-218	0-400	27
TSS(mg/l)	5.3-120	5.1-19.9	2.6-26.4	11.8

BDL: Below Detection Limit

The oceanographic investigations carried out during 1991-1992 period, showed that the DO ranged between 165 and 372 μ M in the waters of Mersin Bay (Table 5). The concentrations of DO in subsuraface waters were observed to be relatively high at all locations in the Bay. The values exceeding 250 μM and close to saturation valuse were obtained during the April 1992 cruise, probably due to both atmospheric input and production by photosynthetic activity. During the summer-autumn period, the thermocline established in subsurface waters prevented the diffusion of DO from the surface to the lower depths. Thus, DO decreased remarkably with depth at the stations influenced directly by wastewater discharges of terrestrial origin. The DO concentration in the surface waters decreased with the increase in the water temperature during the summer due to the low solubility of atmospheric oxygen in water at higher temperature. However, even the minimum DO concentration exceeded the limit value (155 μM) for life in the marine environment.

The BOD_5 measured in the surface waters of the Bay was generally less than 5 mg/l, ranging from undetectable levels (<0.1 mg/l) to 10 mg/l. As expeceted, the largest BOD values were recorded at the locations under the direct influence of the Mersin effluent (Table 5). The COD measurements were performed on suspended particles collected from the Bay and the concentration was approximately twice of the BOD_5 concentration. The average COD concentration was 3.6 mg/l where the maximum values was determined as >20 mg/l infront of land-based source points (Table 5).

The level of inorganic phosphate concentrations was found to range between 0.02 μM and 20.3 μM in the coastal waters of the Bay. The Eastern Mediterranean Sea is known to be impoverished in primary nutrient elements (phosphate and nitrate) and particularly the phosphate concentration diminishing below 0.05 μM levels in the surface waters of the open waters, is very likely to limit phytoplankton production in the Levantine Basin (Krom *et al.,* 1991; Yılmaz *et al.,* 1994; Yılmaz and Tuğrul, 1998). As previously mentioned, the nutrient inputs to the coastal regions originate primarily from terrestrial sources and partly from regenerative processes within the system. Relatively high concentrations of nitrate + nitrite in sea water were observed in the Karaduvar region where the Çavuşlu creek carries the highest nitrogenous material when compared with the other clreeks and the Mersin effluent. At the stations located near the existing sewerage outfall the concentrations in subsurface seawaters were also relatively high and it ranged between 0.05 and 38.1 μM in the Bay waters (Table 5).

The FC bacteria analysis carried out in the waters of Mersin Bay on a seasonal basis showed that, the waters are microbially polluted due to the input of large quantities of the domestic wastes. The FC limit given by the World Health Organization (WHO) for bathing waters and/or for very near coastal waters is 100 cells/100mL of sea water

(UNEP/WHO, 1985; UNEP, 1989b). In Mersin Bay, the FC ranged from insignificant numbers (<10) to the levels as large as 3.000.000 cells/100 mL of sea water. The highest counts were obtained in the vicinity of the existing outfall. Occasionally the FC determinede in the Karaduvar region also exceeded the WHO limit, indicating microbial pollution of fresh water origin.

T-90 Measurements and Rhodamine-B Dye Tracing Experiment: In order to determine the time necessary for the decay of 90% of FC of domestic origin in the receiving medium, *in situ* T-90 measurements were performed in Mersin Bay during October 1992 cruise. In this work, 5 liters of commercially available Rhodamine-B solution (containing 2 kg of pure dye dissolved in 40% acetic acid solution) was introduced instantaneously to the surface waters of the Bay at the discharge point of Mersin main sewage system. Then the cloud of dye was followed using a sensor sensitive only to the dye (*in situ* flurometer probe with appropriate excitation and emission filters) giving the real-time concentrations at defined locations. The exact location of dye measurements were determined by using a Decca Trisponder Navigation system. The dye patch could be followed for about 2.5 hours and the time intervals between the measurements at two different stations were in the range of 4-19 minutes (Figure 8a). At each measurement location, sea water samples were taken for further fluorometric analyses with a bench type spectrofluorometer and for the determination of FC in the same samples. The dye clouds were monitored until 10^4 times dilution was reached. The results of laboratory fluorescence measurments are shown in Figure 8b. The dye became broken up into two patches. The main branch flowing in the east direction was monitored first. The second branch was directed first towards the west and then to the northwest direction. A similar trend in FC values was obtained and the results are depicted in Figure 8c. The correlation between the decreasing trend of FC numbers and dilution of Rhodamine-B was not too strong due to the contamination of the dye-containig water parcels with the surrounding waters having various levels of FC and the decay of FC during their transport from source point to the nearby area.

The T-90 value estimated from the data of this experiment was in the range of 1 to 2 hours. If the FC and current measurements are considered together, the T-90 value can be indirectly estimated. The mean current is determined as 20-50 cm/sec in the Bay and the distance between the main source and the station where the number of FC is close to zero is in the range of 500-1000 m. As a consequence, the T-90 value can be recalculated as e.g. >1-<1.5 hours for Mersin Bay.

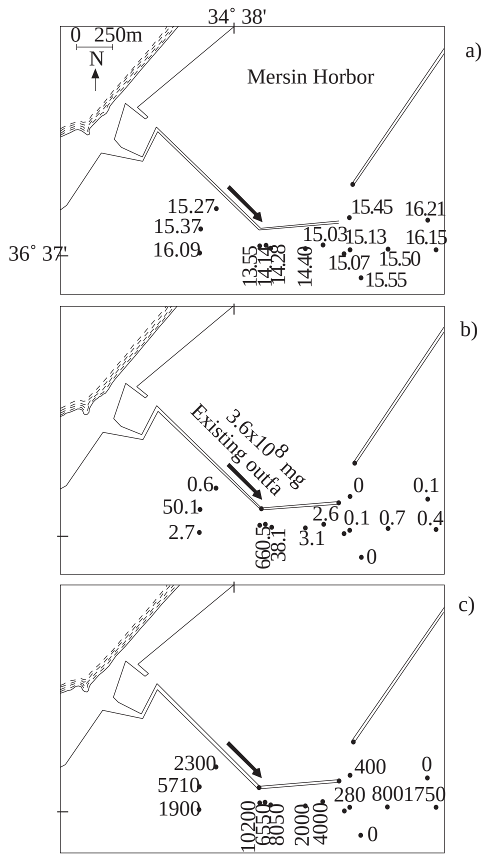

Figure 8. Dye tracing and T-90 experiment results for the Mersin discharge and the Bay (2.10.1992)

Conclusions

The results related to the current patterns of the present study may be extended to cover conditions existing throughout the year. The winds in winter are mainly from the NE-NW sector, while during the summer SW winds dominate. In accordance with the current measurements presented earlier, it is expected that the currents near the shore would be either to the offshore (in winter) or towards the east (in summer). In order to prevent trapping of the effluent near the coast during the southwesterly wind regime in the summer, it was recommended that the existing and the proposed discharge pipes be at least long enough to bring the effluent to the vicinity of CM 3 and CM 6 respectively.

The effluents (creeks and municipal waste discharges) carry significant quantities of pollutants into the Bay influencing the physicochemical characteristics of the sea water. The assimilative capacity of the Bay seems to be under stress.

The lifetime of FC in sea water, where the salinity (~38.5ppt) and the solar radiation are high, is 1-2 hrs, which is considerably low. However this is expected to be high in winter since salinity decreases to 37ppt and solar light is less effective.

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Nomenclature:

Symbol	**Meaning**	**Unit**
T	Temperature	[°C]
S	Salintiy	[ppt,%o]
σ_t	Sigma-theta, Density	
SD	Secchi Disk Depth	[m]
pH	Acidity	
TSS	Total Suspended Solid	[mg/l]
DO	Dissolved Oxygen	[μM]
BOD_5	Biochemical Oxygen Demand	[mg/l]
COD*	Chemical Oxygen Demand	[mg/l]
o-PO_4-P	Ortho-phosphate	[μM]
NO_3+NO_2-N	Total Oxidized Nitrogen (Nitrate + Nitrite)	[μM]
FC	Faecal Coliform	#/100ml
T-P	Total Phosphorus (Organic+Inorganic)	[μM]
PAH	Polyaromatic Petroleum Hydrocarbons	[μg/l]
Hg_w	Total Mercury in Water	[ng/l]
Cd_w	Total Cadmium in Water	[ng/l]
Cd_{TSS}	Total Cadmium in Suspended Solid	[ng/l]

*Because of the high chloride content of seawater, COD was measured in the particulate fraction of seawater by filtering through glass fiber filters. Creek and effluent waters were directly analyzed.

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