FACTORS AFFECTING POLLUTION CONTROL STRATEGIES ALONG THE COASTAL ZONE OF ISTANBUL

O. Uslu(*), D. Orhon(**), Ü. Ünlüata(***), A. Filibeli(*)

*) Dokuz Eylül University, Department of Environmental Engineering, Izmir
**) Technical University of Istanbul, Department of Environmental Engineering, Istanbul
***) Middle East Technical University, Institute of Marine Sciences, Mersin, Erdemli

CONTENTS

1. INTRODUCTION

The city of Istanbul housing a population of about 8 million inhabitants and a large portion of Turkey's industrial activities, lies on the shores of the Marmara Sea and Bosphorus which connects it to the Black Sea. Bosphorus has a distinct, two layer density current system, the upper layer flowing from the Black Sea to the Sea of Maramara and the bottom layer running in the opposite direction. Mixing between the two layers occurs to a certain extent in the body of Bosphorus and in its outlet zone to the Marmara Sea.

Domestic and industrial wastewaters collected from 14 major areas are discharged without treatment into this marine system at a rate exceeding 15 m^3/sec, with an estimated daily pollution load of 365 tons of BOD_5, 60 tons of total nitrogen and 10 tons of total phosphorus. The resulting contamination along the coastal Marmara currently exceeds tolerable levels and calls for an immediate comprehensive remedial action.

The unique oceanographical and hydrodynamical structure of the Bosphorus-Maramara system and the adjacent coastal zone, together with the significant pollutants discharge from the city of Istanbul, makes the wastewater management plan one of the most interesting environmental engineering problems ever to be encountered, where adequate technical clarification needs to be provided to the following issues: What is the extent of land based pollution compared to natural pollutants carried by the receiving water system? What type and degree of treatment is required? To what type of pollutants (carbonaceous or nutrients) is the receiving water system most sensitive? What processes are responsible for pollution and oxygen depletion in the water body?

In this paper these issues are to be explored taking the significant dilution potential and self clarification capacity of natural flows which amount to 10 000 - 20 000 m^3/sec in each of the Bosphorus layers into account. Results of extensive investigations carried out on land based pollution sources and the receiving water system to generate necessary data will be presented and the above mentioned issues will be evaluated. Budgets of significant pollutants are calculated to reveal primary production as the most significant process for the pollution of the coastal zone. This observation calls for non-traditional wastewater management schemes for major discharges.

2. PHYSICAL OCEANOGRAPHY OF THE SYSTEM

2.1. Flows and Mixing Features

Turkish Straits System is a two-layer system which consists of there sections: the Bosphorus, the Marmara Sea and the Dardanelles (See Fig. 1). Its box model is described in Özsoy et al. (1986, 1988). This model determines quantatively the average water exchanges on the basis of water and salt content balances; the average salt content values on the adjacent parts of the boxes were determined from the measurements carried out between 1986 and 1988.

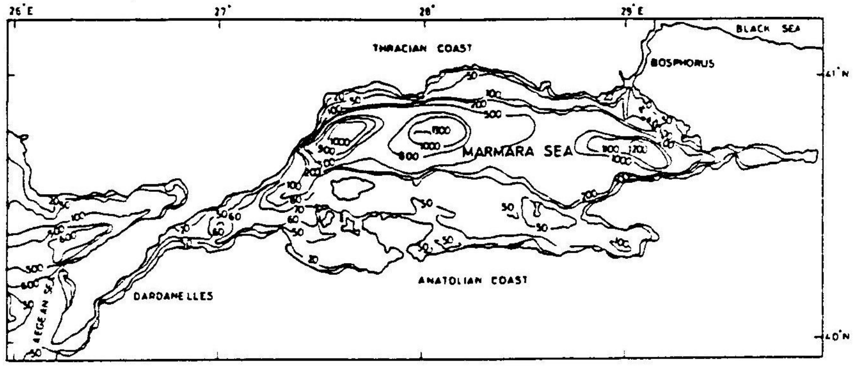


Fig. 1: The Sea of Marmara and the Turkish Straits System

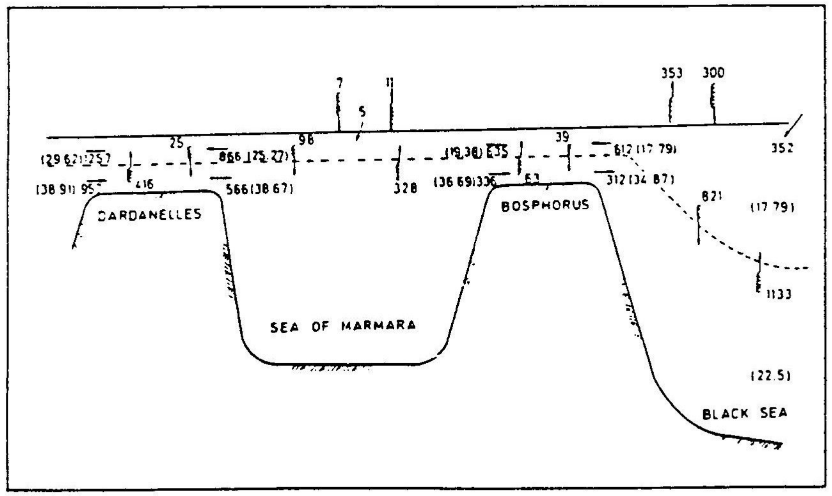


Fig. 2: Water Transfers (km^3/year) and Average Salinity Values (‰) in the Turkish Straits System (Salinities are given in Parantheses)

In Fig. 2, the average salt content values of the lower and upper layers are given in parentheses; it is seen from this figure that on the upper layer, water from the Black Sea enters the Bosphorus with a salt content of 17.8‰ and leaves it with 19.4‰. The salt content of the upper layer increases by 6‰ through the Marmara Sea and 4‰ through the Dardanelles. It thus reaches 29.6‰ when entering the Aegean Sea. Water on the lower layer enters the Dardanelles with a salt content of 38.9‰ but reaches the Marmara Sea with a value of 38.67‰. . The change is very small through the Marmara Sea until the entrance of the Bosphorus. At this point the salt content decreases by 2‰ and becomes 36.7‰; it decreases by another 2‰ through the Bosphorus and reaches the Black Sea with a value of 34.87‰. .

Water transfers from the middle layer to the upper and lower layers are given as km^3/year in Fig. 2. The computation of the water transfer is based on the average salt contents. It is assumed that the salt contents of the lower and upper layers in the Black Sea are 17.79‰ and 22.50‰, respectively, and the net water inlet is 300 km^3/year (9510 m^3/sec). This is the difference between the total rain water and fresh water inputs from the rivers and evaporation in the Black Sea. The main variable parameter affecting the net fresh water input is the amount due to rain water. The highest value for this particular input was given as 300 km^3/year by ozturgut (1971). This value is obtained by the multiplication of the average rain, which is 714 mm for the Black Sea, with the surface area of the Black Sea which is 420 000 km^2. Another computation, based on the average rain calculated from the long-term rain amounts is given in the "Weather in the Black Sea (1963)", "The Black Sea Pilot (1969)" and "Morskoi Atlas (1950)". The results given in these latter studies are very close to those calculated by özturgut (1971).

Computations based on the above assumptions show that the flow of the upper layer which is 612 km^3/year (19400 m^3/sec) when entering the Bosphorus from the Black Sea, increases to 635 km^3/year (20135 m^3/sec) when leaving the Bosphorus and entering the Marmara Sea. In the Marmara Sea the evaporation from the surface and the addition of fresh water are negligible; thus the increase in the flow is due only to the transfer of water from the lower layer caused by the vertical turbulence and this increase is calculated as 230 km^3/year (7290 m^3/sec). Through the Dardanelles, the increase in flow is computed as 391 km^3/year (12400 m^3/sec) and is again because of the transfers from the lower layer. Therefore the flow of upper layer is 1257 km^3/year (39860 m^3/sec) when it reaches the Aegean Sea.

The water flow in the lower layer enters the Dardanelles with a flow value of 957 km^3/year (30350 m^3/sec); looses large quantities due to the turbulence and transfers particularly at the southern section of the Dardanelles, and reaches the Marmara Sea with a flow value of 566 km^3/year (17950 m^3/sec) and the Bosphorus with a value of 336 km^3/year (10650 m^3/sec) The change through the Bosphorus is small and the flow at the exit to the Black Sea is 312 km^3/year (9,890 m^3/sec).

The most important part of the salt content and water flow computations discussed here is that only 30% of the lower water from the Aegean Sea reaches the Black Sea, the balance mixes with the upper layer water in the Dardanelles, Marmara Sea and Bosphorus, and returns to the Aegean Sea in the percentages of 41%, 24% and 3%, respectively.

Using the flows given in Fig. 2, and assuming the surface water volume as 345 km^3, the residence time of the surface water in the Marmara Sea is calculated approximately as 4.5 months. Similarly, the residence time of the lower layer water, which has a volume of 3033 km^3, is calculated approximately as 5 years. The results show that the residence time of water in the Marmara Sea is very short comparing to that in the Mediterranean (70 years) and Black Sea (500-2000 years) (Lacombe et al., 1981; östlund, 1969, 1986).

It is important to note that, because the box model gives the average value of water transfers between the layers, it is impossible to determine the characteristics of the mixing mechanisms and the regions where the density of the mixture is high. Hyrographical data show that the mixture in the Marmara Sea is the result of three different mechanisms. As discussed in Section 2.2, mixing phenomena are due to the hydraulic jump at the exit of the Bosphorus to the Marmara Sea and to the turbulence caused by the surface layer jet, and these are why considerable amounts of lower layer water are transferred to the upper layer. This action takes place in the region where the Bosphorus is connected to the Marmara Sea, where 5-6‰ increase in the average salt content is recorded.

The phenomenon is also seen in Fig. 3. These two mixing mechanisms, as given in the box model, represent the majority of the mixture in the Marmara Sea. A third turbulence which causes the mixing can only be observed at times when there is a very strong wind, and as a result, The surface water is mixed between the surface and the "halocline" layer (20-25 m).

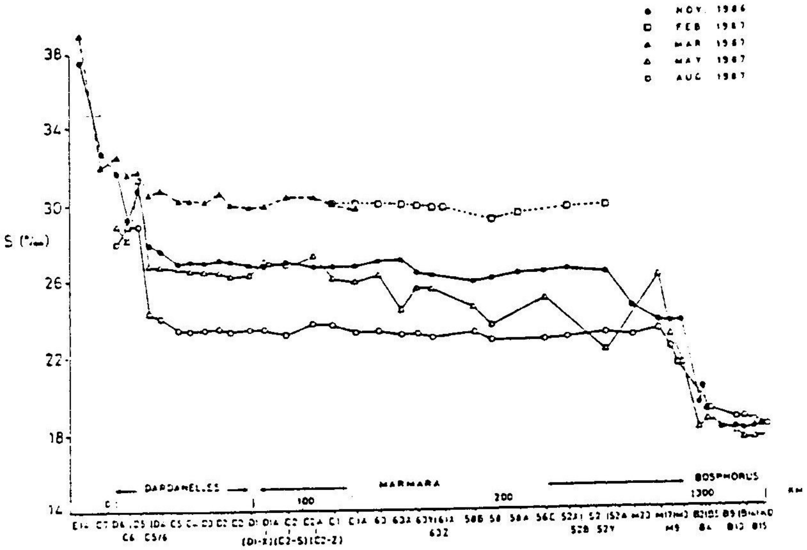


Fig. 3: Salinity Variations at the Surface Waters of the Turkish Straits System

2.6 Dynamic Features

The Turkish Straits System is a typical example of the dynamics of two-layer currents. Because of excess fresh water input to the Black Sea, the resulting barotropic pressure gradient causes a surface current flow from the Black Sea to the Aegean Sea. The lower layer flow, which is in the opposite direction, is the result of baroclinic pressure gradient due to the density difference between the Black Sea and the Aegean Sea which have very different salt contents. Defant (1961) gave the simplest dynamic explanation for the friction force and the equilibrium between the pressure gradients in the system. A detailed summary of the recent research on this subject is given in Tolmazin (1985) and özsoy et al. (1986).

The most important and interesting dynamic characteristic of the two-layer-flow system in the Turkish Straits is the hydraulic controls caused by hydraulic actions and internal jumps in connection to these actions. Monthly measurements taken in the Bosphorus and seasonal measurements taken in the Dardanelles, between 1986 and 1989, show that the hydraulic actions taking place are similar to those taking place in the Strait of Gibraltar (Arai and Farmer, 1985, 1988). This type of hydraulic actions in the Turkish Straits are due to the non-linear changes in the sectional salt content or density values and to the increasing mixing of the water between various layers. Furthermore, a mathematical model applied to the layer flows in the Bosphorus and the Dardanelles gives results supporting the presence of these actions (Oğuz and Sur, 1989; Oğuz et al., 1989).

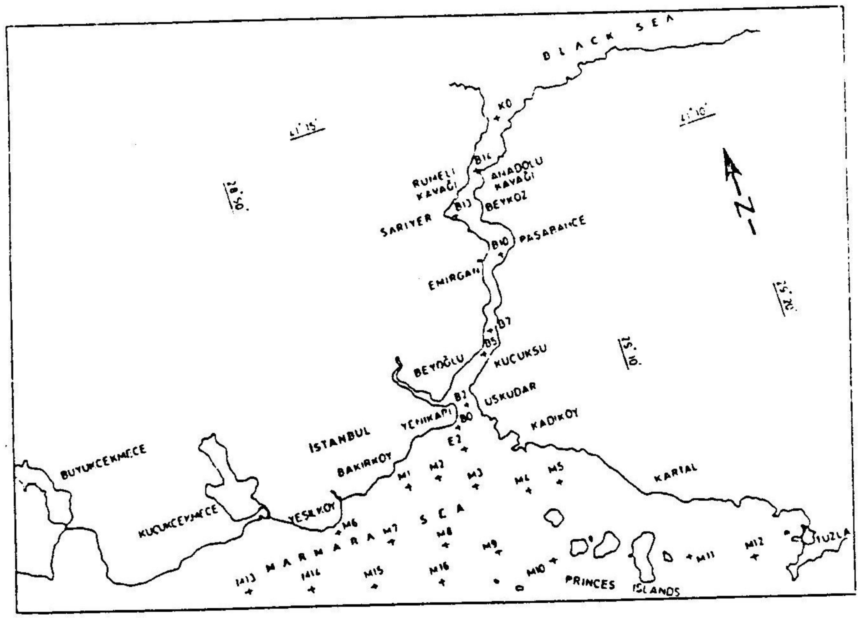


Fig. 4: Hydrographical Stations at the Bosphorus

Hydraulic actions in the Bosphorus happen mainly at the southern section of Station B8, where morphological structure of the canal changes significantly, and at the opening to the Black Sea (See Fig. 4). The results of the model given in Oğuz et. al. (1989), show that there are three different sections in the Bosphorus where the currents are supercritical. It is observed that the medium layer which is deeper at the northern parts rises suddenly to the surface at a section located between the stations B8 an B6; this section is about 2.5-3.0 km long and is situated at the narrow parts of the Bosphorus. Thus, the upper layer flow passes from subcritical flow status to supercritical flow condition. However, the supercritical condition of the upper layer flow ends after a while and the flow has a hydraulic jump and returns back to its norman subcritical condition (expressed with Froude number less than 1). All these actions are indicated by the salinity equilibrium lines of the middle layer which rises suddenly while passing through the critical control, and falls suddenly to lower layers.

The upper layer flow, which is subcritical, passes through a hydraulic control at the point of the sudden opening of the Bhosphorus to the Marmara Sea. This control is generally realized at the area between the stations B2 and E2, depending on the conditions. Results of the model (Oğuz et. al., 1989) indicate that in the upper layer, which flows along the narrow canal at the Üsküdar side, the critical flow conditions happen approximately 3 km north of the Marmara Sea entrance, Because of the narrowing due to the swirl at the Dolmabahçe-Beşiktaş section of the Bosphorus. The upper layer flow stays at the supercritical level until leaving the Bosphorus, but it has an initial jump at around the M3 station and becomes subcritical.

In addition to the hydraulic control mechanism due to sudden changes in the width of the Bosphorus, topographic steps also have the same effect. Lower layer flow which passes through the Dardenelles and the Sea of Marmara as subcritical, and goes to north through the Bosphorus, meets the hydraulic control on the steep step at the Black Sea entrance. On the other hand, even though it can not be seen clearly from the two layer model, hydrographical observations show that there may be a similar hydraulic control mechanism at the south step.

According to model studies by Oğuz et al. (1989), the lower layer flows are choked at the northern step of the Bosphorus only when the net water input (difference of upper and lower flows) is higher than 27 000 m^3/sec. This net water input is in accordance with the data given by Sümer and Bakioğlu (1981) and is equivalent to approximately 45 cm water level difference between the two ends of the Bosphorus. This amount of net water input or the level difference is observed only on certain days of the year when there are strong northern winds from the Black Sea and as a result water input increases higher than normal. Bogdanova and Stepanov (1974) showed that this action takes place only when upper layer flow velocity is more than 60 cm/sec at the Black Sea entrance by using a 2-layer salt block model. This rate is equivalent to the above given flow rate at a typical cross section at the Black Sea opening of the Bosphorus.

Internal hydraulic activities in the Turkish Straits System is in agreement with the theoretical explanations given by Farmer and Armi (1986) and Armi and Farmer (1987). In accordance with the results of this reseach, because of the narrowing in the Bosphorus and the north step, upper and lower layer controls form a system which produce the highest flow rates in both directions through the Bosphorus. Thus, flow in the Bosphorus and middle plane structure do not depend on the conditions at the adjacent basins except general density/salinity values and net water input; they are only affected by the hydraulic conditions in the Bosphorus. On the other hand, while the critical control at the entrance of the Bosphorus to the Marmara Sea is always present, the control at the narrow part does not happen when the upper level flow decreases to a certain value. Even in this situation the presence of the maximum flow at the Bosphorus is valid and is caused by the critical controls due to the step at the Black Sea section and the sudden opening at the south.

In parallel to the 2-layer model studies, the dynamic structure of the Bosphorus is also studied by using multi-layer models (Tolmazin, 1981; Jones and Oğuz, 1989). The model developed by Jones and Oğuz (1989) clearly shows that lower and upper layer flows are separated from each other by a fairly thick middle plane at certain points, and that the south step which causes an important amount of turbulence to the flow and produces vertical mixing actions and, as a result, part of the lower layer flow which comes from the Marmara Sea returns to the Marmara Sea by mixing with this surface water.

In connection with the dynamics of the jet leaving the Bosphorus, Whitehead and Miller (1979) made some laboratory experiments. These experiments showed that if the entrance width of a strait is smaller than the baroclinical deformation radius, the jet leaving the strait makes an anticyclonic turbulence. Beardsley and Hart (1978), Nof (1978), and Preller (1985) used 2-layered, Wang (1987) used multi-layered models and found that water from the Bosphorus goes first to the left, then turns right and creates an anticyclonic turbulence. They explained this action by anticyclonic vorticity of water being at the same level with Coriolis parameter. Wang (1987) model, which has continuous vertical layering, shows that anticyclonic vorticity of flow is produced by the vertical water movements towards the surface when water flow is critical and there is a hydraulic control at the opening of the strait.

3. WASTE LOADS ORIGINATING FROM THE ISTANBUL METROPOLITAN AREA

In this study the Istanbul Metropolitan Area has been divided in 14 subregions with regard to wastewater origination. Presently all the wastewaters from these areas are discharged without treatment into the surface waters of the Marmara Sea. The only exception is the Yenikapı area, the collected wastewaters of which is discharged into the lower layers of the transition region at the Bosphorus-Marmara Sea junction with a deep sea outfall after a preliminary treatment. This marine outfall is under operation since 1988.

In Table 1, wastewater flowrates, BOD_5, suspended solids (SS), total Kjeldahl nitrogen (TKN) and total phosphorus (Tot-P) loads from each of the individual areas are summarized.

These areas can be grouped together in 3 distinct regions with respect to their potential wastewater receiving media:

Region I, discharging into the transition region at the southern entrance of Bosphorus to the Marmara Sea (Kadıköy and Yenikapı regions);

Region II, discharging directly into the coastal waters of Marmara Sea (Ataköy, Tuzla, Küçükçekmece, Büyükçekmece, Tuzla Tanneries, Princes Islands and regions west of Küçükçekmece);

Region III, discharging directly into the Bosphorus (Baltalımanı, Uskudar, Küçüksu, Tarabya and Paşabahçe).

Table 2 depicts the BOD_5, SS, TKN and Tot-P loads of each of the three groups of regions.

Table 1

Estimated Wastewater Flowrates and, BOD_5, SS, TNK and Tot-P Loads Originating from Individual Areas of Istanbul for 1990

	WASTEWATER FLOW RATE			BOD_5		SS		TKN		Tot-P	
	m3/day	m3/sec	%	t/day	%	t/day	%	t/day	%	t/day	%
1. Kadıköy	319 400	3.69	23.65	60.1	18.29	71.6	17.91	10.5	19.44	2.08	22.39
2. Yenikapı	313 000	3.63	23.17	63.9	19.45	73.9	18.48	10.3	19.07	2.04	21.95
3. Baltalimanı	198 700	2.30	14.71	45.5	13.85	52.2	13.06	7.4	13.70	1.46	15.72
4. Ataköy	105 200	1.22	7.79	25.1	7.64	29.2	7.30	4.0	7.41	0.80	8.61
5. Tuzla	92 500	1.07	6.85	19.5	5.93	24.1	6.03	3.2	5.92	1.12	12.06
6. Küçükçekmece	66 500	0.77	4.92	13.5	4.12	16.5	4.13	2.2	4.07	0.44	4.74
7. Büyükçekmece	49 000	0.57	3.63	10.5	3.20	12.5	3.13	1.7	3.15	0.33	3.55
8. Tanneries	48 700	0.37	3.60	58.8	17.89	84.0	21.01	10.5	19.44	-	-
9. Üsküdar	47 300	0.49	3.50	9.3	2.83	10.7	2.68	1.5	2.78	0.30	3.23
10. Küçüksu	30 700	0.36	2.27	6.2	1.89	6.6	1.65	1.0	1.85	0.20	2.15
11. Tarabya	20 200	0.23	1.50	3.7	1.13	4.3	1.08	0.6	1.11	0.12	1.29
12. Princes Islands	12 900	0.15	0.95	2.8	0.85	3.2	0.80	0.5	0.92	0.09	0.97
13. Paşabahçe	12 700	0.15	0.94	3.2	0.97	3.7	0.92	0.5	0.92	0.10	1.06
14. West of K.Çekm.	32 800	0.38	2.43	6.5	1.98	7.3	1.82	1.1	2.04	0.21	2.26
TOPLAM	1 350 600	15.38		328.6		399.8		54.0		9.29	

Table 2

Estimated BOD_5, SS, TNK and Tot-P Loads Originating from three Wastewater Collection Regions of Istanbul for 1990

	BOD_5		SS		TKN		Tot-P	
	t/day	%	t/day	%	t/day	%	t/day	%
Region I	124.0	37.74	145.5	36.39	20.8	38.51	4.12	44.35
Region II	136.7	41.31	176.8	44.22	23.2	42.95	2.99	32.17
Region III	67.9	20.66	77.5	19.39	11.0	20.36	2.18	23.47
Total	328.6		399.8		54.0		9.29	

4. ENVIRONMENTAL INDICES AND POLLUTANT CONTENTS CHARACTERIZING THE MARMARA SEA ECOSYSTEM

4.1. Upper and Lower Layer Volumes of the Marmara Sea

The total volume of the Marmara Sea is estimated as 3378 km^3 ($3.378x10^{12}$ m^3). The euphotic layer, where the parameters of concern exhibit significant differences from the deeper layers, consist of the upper 30 m. The volume of this layer is approximately 345 km^3 ($0.345x10^{12}$ m^3); the lower layer which shows typical characteristics of the Mediterranean Sea, except for nutrients and organic matter, which are greatly affected by internal processes within the Marmara Sea, is accepted to have a volume of 3033 km^3 ($3.033x10^{12}$ m^3).

4.2. Phosphorus Contents of the Marmara Sea

All the measurements so far carried out within the water body indicate that the average phosphorus concentration of the upper layer is around 0.3 µmoles P/L ($9.3x10^{-9}$ t/m^3). This value yields a total phosphorus contents of 3200 tons for this layer. In the lower layer the phosphorus concentrations is observed to vary within the range of 0.8-1.2 µmoles P/L ($25x10^{-9}$ - $37x10^{-9}$ t/m^3). This way, the lower layer phosphorus contents may be calculated as 94 000 tons, on the basis of a simplifying assumption of an average concentration of 1.0 µmoles P/L.

In the previous sections, the phosphorus input to the Marmara Sea originating from the Istanbul Metropolitan Area is estimated as 9.29 tons/day. The comparative evaluation of this load with the above figures show that the phosphorus content of the upper layer is equivalent to a land based load of 344 days (roughly 1 year) and that of the lower layer 10462 days (roughly 28 years).

4.3. Nitrogen Contents of the Marmara Sea

The dissolved oxygen contents of the Marmara Sea, although low in the lower layer never drops to zero; consequently the measured oxidized nitrogen forms (NO_2+NO_3) are estimated to reflect an accurate picture of the total nitrogen budget as the organic N and NH_3-N will eventually be converted to the oxidized nitrogen compounds through nitrification in the presence of dissolved oxygen.

The evaluations of the results show that a (NO_2+NO_3) concentration range of 0-4.0 µmoles N/L with an average value of 2.0 µmoles N/L = $28x10^{-9}$ t/m^3) may be used characterize the upper layer. Calculations based on the average concentration value reveal the total nitrogen content of this layer at any time as 9100 tons. Similarly (NO_2+NO_3) concentration of the lower layer is 10.0 µmoles N/L = $140x10^{-9}$ t/m^3) corresponds to a total oxidized nitrogen contents of 424 600 tons.

Istanbul Metropolitan Area yields a total daily load of 54.0 tons of TKN to the Marmara which are expected to be converted to oxidized forms through biological oxidation. The NO_2+NO_3 contents of the upper and lower layers of the Marmara Sea are equivalent to land-based inputs of 180 days (6 months) and 7863 days (21.5 years) respectively.

4.4. Carbonaceous Materials Contents of the Marmara Sea

The measurements so far conducted in the Marmara Sea associate an average total organic carbon concentration of 1.88 mg C/L ($1.88x10^{-6}$ t/m^3), corresponding to an organic carbon content of $0.65x10^6$ tons. Similarly, these figures are calculated as 0.59 mg C/L ($0.59x10^{-6}$ t/m^3) and $1.8x10^6$ tons for the lower layer.

The total BOD_5 load originating from the Istanbul Metropolitan area is calculated as 328.6 tons/day for 1990. The organic carbon equivalent of this load is around 239 tons C/day for a BOD_5/TOC ratio of 1.375. Taking the above load into consideration, the upper layer may be calculated to contain 2720 times the daily land based input (approximately 7.5 years). For the lower layer this ratio is 7530 days (approximately 21 years). It is known that organic compounds are usually subject to biological degradation in the receiving water within 1-2 weeks.

The upper layer nutrient contents of 6 months for phosphorus and 1 year for nitrogen and 7.5 years for organic carbon as compared to daily loads from wastewater discharges assign different importance and priorities for these parameters: Whereas nitrogen and phosphorus forms are noted to participate to all yearly periodical processes contributing to the pollution of the receiving water (photosynthesis and bacterial degradation), organic carbon input originating from wastewater has relatively no effect in view of the rate of degradation of water quality in the whole of the Marmara Sea,

4.5 Primary Productivity in the Marmara Sea

In Table 3 the overall spatial averages of primary productivity and chl-a values measured in the Marmara Sea are summarized. Fig.5 depicts the local variations of average productivities. If a general evaluation is made for the whole of the Marmara Sea using an average primary productivity rate of 7.0 gC/m²/month, (84 tC/km²/year), a yearly primary productivity equivalent to 966 000 tons of organic carbon (TOC) can be associated to 11 500 km² surface area of The Marmara Sea. As the TOC load from wastewater discharges is given as 239 tons C/day (87 200 tons C/year) in the previous section, the TOC generated by the Marmara Sea is computed to be 11 times higher than the land-based input.

On the other hand, using the following simplified stoichiometric relationship for algae production through photosynthesis,

$$106\ CO_2 + 16\ NO_3^- + HPO_4^{=} + 112\ H_2O + 18\ H^+ \text{--->}$$

$$\text{--->}\ C_{106}H_{263}O_{110}N_{16}P + 138\ O_2$$

the primary productivity related to 54.0 tons N/day (3.86×10^6 moles N/day) and to 9.29 tons P/day (0.30×10^6 moles P/day) may be calculated respectively as

$$3.86\times10^6\times365\times(106/16) = 9.33\times10^9 \text{ moles C/year} = 112\ 000 \text{ tons C/year}$$

for nitrogen and

$$0.30\times10^6\times365\times106 = 11.61\times10^9 \text{ moles C/year} = 139\ 000 \text{ tons C/year}$$

for phosphorus.

Since the N/P ratios of Istanbul wastewaters and in the upper layer of the Marmara Sea are respectively,

$$N/P = 3.86\times10^6/0.30\times10^6 = 12.87 < 16$$

and

$$N/P = 2.0/0.3 = 6.67 < 16$$

nitrogen is clearly the rate limiting parameter for photosynthesis. Consequently, 112 000 tonsC/year is the appropriate primary productivity value associated with nutrients. Therefore, the total organic carbon input originating from Istanbul wastewaters and triggered by primary productivity is

Table 3

Average Primary Productivity and Chl-a Values in the Marmara Sea

Months		Primary Productivity (gC/m²/month)	Chlorophyll-a (µg/L)
March	1986	11.35	2.50
April	1986	6.53	1.31
July	1986	3.72	0.62
September	1986	3.80	0.81
November	1986	4.62	1.73
January	1987	3.85	1.84
February	1987	6.08	2.21
May	1987	16.90	3.83
June	1987	3.95	0.75
July	1987	4.90	0.87
August	1987	4.73	1.11

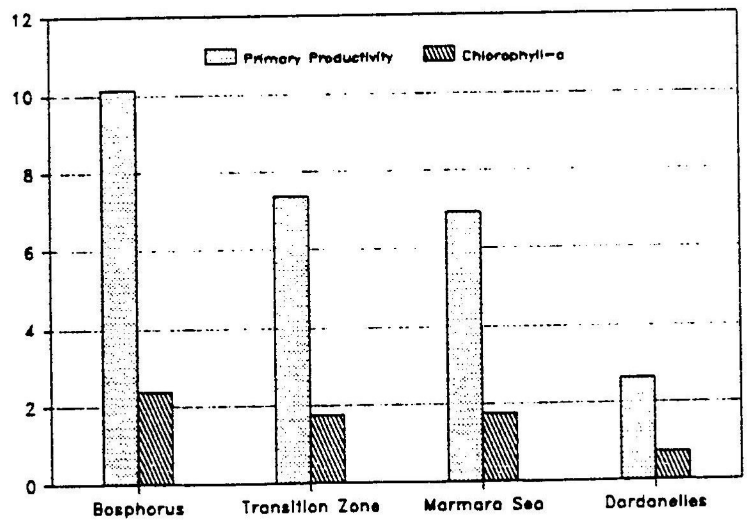


Fig. 5: Change of Primary Productivity (gC/m²/month) and Chlorophyll a Values (µg/L) Along the Sea of Marmara

239x365 + 112 000 = 87 200 + 112 000 = 200 000 tons TOC/year

This value also shows that the nutrients are likely to cause environmental problems that are much more significant as compared to those initiated by carbonaceous material of wastewater origin.

5. UPPER AND LOWER FLOWS OF THE BOSPHORUS AND WASTEWATER FLOWS ENTERING AND LEAVING THE MARMARA SEA

Wastewater effects of the Istanbul metropolitan area on the Marmara Sea is discussed generally in Section 4. In this section, natural material transfers and the relations between the wastewater impacts, due to their close relations especially with the Istanbul deep water discharge systems will be elaborated.

5.1. Flow Rates

Because of the difference in climatic and hydrological conditions between the Black Sea and the Mediterranean Sea, excess water from the Black Sea follows a route through the Bosphorus, Marmara Sea, and the Dardanelles, and reaches the Aegean (Mediterranean) Sea as a net mass transfer. Physical oceanography of the system is discussed in detail in Section 2 of this paper.

Calculations based on average salt contents show that the flow rate entering the Bosphorus from the Black Sea by the upper layer is approximately 612 km^3/year (19 400 m^3/sec); through the Bosphorus transfer from the upper layer to the lower layer is approximately 39 km^3/year (1 240 m^3/sec) and from lower layer to the upper layer is approximately 63 km^3/year (2000 m^3/sec). Thus, at the Marmara cross-section, Bosphorus upper layer flow rate reaches to 635 km^3/year (20 140 m^3/sec). Average lower layer flow rates are 336 km^3/year (10 630 m^3/sec) at the Marmara cross-section and 312 km^3/year (9 900 m^3/sec) at the Black Sea cross-section.

The results of the long-term measurements on the currents at Anadolu Kavağı cross-section of the Bosphorus carried out by Marine Sciences Institute of Dokuz Eylül University are tabulated In Table 4. These are the results totally independent from the calculations based on average salt contents. In Fig. 6 average cross-section position, based on the geometry of the cross-section and lower/upper layer salt contents and the temperatures, is shown. In Table 4, the flow rates of lower and upper layer calculations, using the above mentioned measurements, are given.

Table 4

Averages and Standart Deviations of Salt Content, Temperature, Velocity and Flow Rate Measurements of Upper and Lower Layer Bosphorus Flows at the Anadolu Kavağı Cross-Section

	OBSERVATION PERIODS				
	19.5-09.6 1985	17.6-24.7 1985	28.1-05.2 1986	06.2-25.2 1986	25.2-06.4 1986
Upper Layer					
Salt Content (%.).	-	20.86±1.85	18.66±0.17	-	18.82±0.35
Temperature (°C)	-	7.56±1.34	7.82±0.39	5.91±1.05	3.66±1.05
Velocity (m/s)	-	0.43±0.16	0.68±0.10	0.38±0.53	0.56±0.15
Flow Rate (m^3/sec)	-	20670	32680	18260	26920
Lower Layer					
Salt Content (%.)	-	36.30±0.54	34.13±6.82	35.51±1.14	-
Temperature (°C)	13.93±0.22	13.79±0.35	13.48±2.66	13.70±0.64	9.78±4.72
Velocity (m/s)	0.31±0.15	0.34±0.12	0.45±0.24	0.76±0.21	0.54±0.30
Flow Rate (m^3/sec)	5930	6510	8610	14540	10340

Total Cross-Sectional Area = 67 200 m2
Area of the Upper Layer = 48 060 m2
Area of the Lower Layer = 19 140 m2

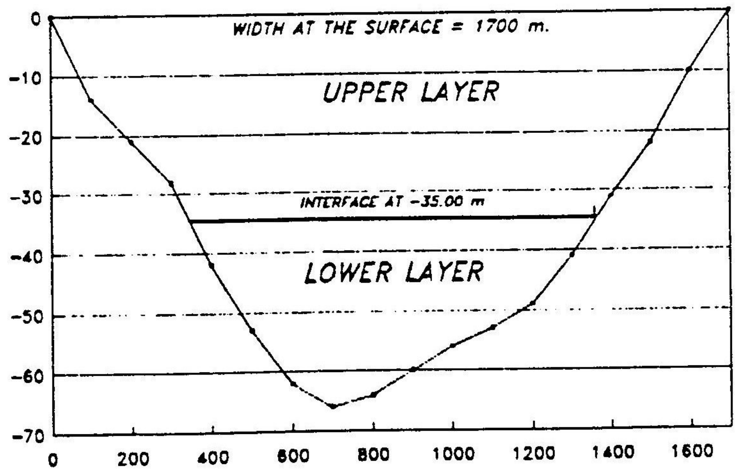
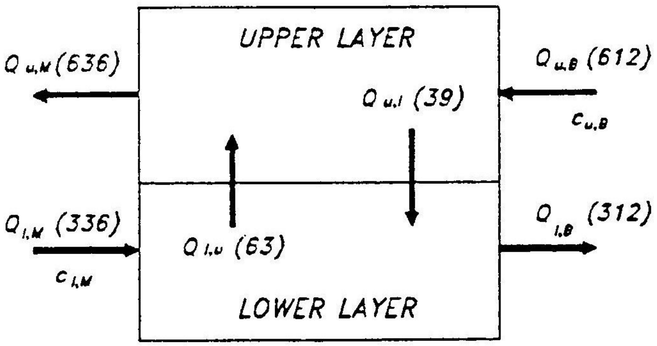


Fig. 6: Bosphorus Cross-section at Anadolu Kavağı

Weighed averages of flow rates measured for five different pediods according to the length of the periods are 23 360 m^3/sec for the upper layer and 9 050 m^3/sec for the lower layer.

Since the results based on the calculations and measurements carried out by different and independent establishments are in close agreement, it is believed that the calculated results of flow and balance for nitrogen, phosphorus and organic carbon given below are dependable. Furthermore, because the minimum time scale for the effects of wastewater of the Istanbul Metropolitan area on the Marmara ecosystem is of the order of months as shown by calculations in Section 4, Bosphorus "closure" of the lower layer flows in the Bosphorus, dependent on meteorological conditions and of the order of days, has no effect on the microscale mass transfer calculated from average flow rates given below. For the calculations, average flow rates given by the Marine Sciences Institute of the Middle East Technical University have been used.



(Values in Parantheses Represent Flows in km³/year)

Fig. 7: Control Volume for the Determination of Mass Transfers Between the Marmara Sea and the Bosphorus

5.2. Bosphorus Phosphorus Balance

In Fig. 7, the control volume, which represents the section between the Black Sea and Marmara Sea connections and which is used for the calculations of phosphorus, nitrogen, and total organic carbon fluxes is given. By using the notation given in this figure, the amount of material entering the Marmara Sea with the upper layer current at the Bosphorus-Marmara cross-section is calculated using the following equation:

$$Input = Q_{u,B} \cdot c_{u,B} + Q_{l,u} \cdot c_{l,M} - Q_{u,l} \cdot c_{u,B}$$

At the same section, the amount leaving the Marmara Sea with the lower layer is calculated as follows:

$$Output = Q_{l,M} \cdot c_{l,M}$$

The reason to choose this method by using the concentrations for the nothern entrance for the upper layer and Marmara Sea lower layer concentrations for the lower layers is to eliminate the impact of wastewater from the Istanbul metropolitan area given to the surface of the Marmara Sea and the Bosphorus for the mass balance calculations. This will provide an idea on the natural nutrient and contaminant flows.

Detailed long term measurements of PO_4-P concentrations have been carried out by the Marine Sciences Institute of the Middle East Technical University for the upper layer in the opening section of the Bosphorus-Black Sea and for the lower layer in the opening section of Bosphorus-Marmara Sea. In the phosphorus balance calculations which are given in Table 7, the annual averages of these monitoring results as summarized in Tables 5 and 6, are used. These values are as follows:

Upper Layer Phosphorus (PO_4-P) Concentration at Bosphorus-Black Sea Opening Section : 0.13 µmol/L

Lower Layer Phosphorus (PO_4-P) Concentration at Bosphorus-Marmara Sea Opening Section : 0.89 µmol/l

Because of upper/lower layer current systems in the Bosphorus, the balance calculations show that a net amount of 168.48×10^6 mol/year (5222.9 ton/year) phosphorus is transferred from the Marmara Sea to the Black Sea. If partial flows are taken into consideration, instead of the total values, the results are even more interesting. Phosphorus flow which enters the Bosphorus from the Black Sea (out of system) with the upper current is 76.56×10^6

Table 5

Upper Layer Average PO4-P Concentrations (µmol P/l) at the Bosphorus-Black Sea Opening

		STATIONS B14	B15	KO	Ave.
February	1987	0.41	0.37	0.28	0.35
May	1987	0.08	0.09	0.07	0.08
June	1987	-	-	-	-
July	1987	-	0.06	-	0.06
August	1987	-	0.03	0.04	0.04
September	1987	-	-	-	-
October	1987	-	-	-	-
January	1988	0.18	0.17	-	0.18
March	1988	0.07	0.09	-	0.08
May	1988	0.19	-	0.05	0.12
July	1988	0.14	0.12	0.12	0.13
August	1988	-	-	-	-
September	1988	0.10	-	-	0.10
Average					0.13

Table 6

Lower Layer Average PO_4-P Concentrations (µmol P/l) at the Bosphorus-Marmara Sea Opening

		STATIONS B1	B2	M1	M2	M3	Ave.
February	1987	0.35	0.37	2.83	1.07	-	1.16
May	1987	1.05	0.08	-	1.05	-	0.73
June	1987	0.72	1.00	-	0.93	0.70	0.84
July	1987	0.44	0.07	0.39	0.11	0.51	0.30
August	1987	-	0.61	-	0.82	0.62	0.68
September	1987	1.22	1.11	-	0.86	0.70	0.97
October	1987	1.22	0.33	-	1.07	0.73	0.84
January	1988	0.53	1.18	0.95	1.13	-	0.95
March	1988	1.07	0.52	-	1.09	0.96	0.91
May	1988	1.15	1.08	-	1.14	1.22	1.15
July	1988	1.06	1.15	-	1.09	-	1.10
August	1988	1.44	0.40	-	1.19	1.25	1.07
September	1988	1.16	0.69	-	-	-	0.93
Average		0.95	0.66	1.39	0.96	0.83	0.89

Table 7

Phosphorus Balance at Marmara Sea - Bosphorus Entrance Section

	Average Flow Rate (10^9 m^3/year)	Phosphorus Concentration (mmol PO_4-P/m^3)	Mass Transfer (10^6 mol PO_4-P/year)
From the Black Sea to Bosphorus with Upper Flow	612	0.13	79.56
Transfer from Upper Layer to Lower Layer in the Bosphorus	-39	0.13	-5.07
Transfer from Lower Layer to Upper Layer in the Bosphorus	63	0.89	56.07
Load Entering to the Marmara Sea			130.56
Load Leaving the Marmara Sea	336	0.89	299.04
Net Phosphorus Output from the Marmara Sea			**168.48** =5222.9 t/year

mol/year (2373.4 ton/year). When this amount is compared with the 9.29 ton/day (3390.1 ton/year) phosphorus input originating from the wastewater as given in Section 4, it can be concluded that the anthropogenic phosporus introduced from out of system is 1.42 times of the "natural system" flows into the Marmara Sea.

5.3. Bosphorus Nitrogen Balance

Detailed long term measurements of total oxidized nitrogen (NO_2+NO_3) concentrations have been carried out by the Marine Sciences Institute of the Middle East Technical University for the upper layer in the opening section of the Bosphorus-Black Sea and for the lower layer in the opening section of Bosphorus-

Table 8

Upper Layer Average NO_2+NO_3 Concentrations (µmol N/L) at the Bosphorus-Black Sea Opening

		B14	B15	KO	Average
February	1987	4.38	4.97	5.04	4.80
May	1987	1.15	1.70	1.59	1.48
June	1987	-	-	-	-
July	1987	-	0.75	-	0.75
August	1987	-	1.64		1.64
September	1987	0.15	0.08	-	0.12
October	1987	0.08	0.09	-	0.09
January	1988	1.35	1.21	-	1.28
March	1988	0.23	0.20	-	0.22
May	1988	3.06	3.08	2.23	2.79
July	1988	0.15	0.37	0.12	0.21
August	1988	0.16	0.15	0.08	0.13
September	1988	0.12	0.13	-	0.13
Average					1.14

Table 9

Lower Layer Average NO_2+NO_3 Concentrations (µmol N/L) at the Bosphorus-Marmara Sea Opening

		B1	B2	M1	M2	M3	Ave.
February	1987	2.99	3.66	-	8.69	-	5.11
May	1987	9.18	3.60	10.90	10.71		8.60
June	1987	4.42	4.29	-	10.43	3.47	5.65
July	1987	11.07	-		-	4.77	8.02
August	1987	-	-	11.04	13.58	14.18	13.20
September	1987	11.57	11.76	8.87	12.08	12.39	11.33
October	1987	15.00	9.05	-	9.87	9.26	10.80
January	1988	6.48	10.20	9.31	9.79		8.94
March	1988	5.84	5.40	-	11.32	11.03	8.40
May	1988	11.04	11.19	-	11.42	12.08	11.43
July	1988	8.41	11.00	-	10.91	11.10	10.36
August	1988	11.13	3.07	-	11.30	9.85	8.86
September	1988	11.41	5.13	-	-	-	8.27
Average		9.04	7.12	10.23	10.92	9.81	9.15

Table 10

Nitrogen Balance at Marmara Sea - Bosphorus Entrance Section

	Average Flow Rate (10^9 m^3/year)	Nitrogen (NO_2+NO_3) Concentration (mmol N/m^3)	Mass Transfer (10^6 mol N/year)
From the Black Sea to Bosphorus with Upper Flow	612	1.14	697.7
Transfer from Upper Layer to Lower Layer in the Bosphorus	-39	1.14	-44.5
Transfer from Lower Layer to Upper Layer in the Bosphorus	63	9.15	576.4
Load Entering to the Marmara Sea			1229.6
Load Leaving the Marmara Sea	336	9.15	3074.4
Net Nitrogen Output from the Marmara Sea			1844.8 =25827 t/year

Marmara Sea. In the nitrogen mass balance calculations which are given in Table 10, the annual averages of these monitoring results, as summarized in Tables 8 and 9, are used. These values are as follows:

Upper Layer Total Oxidized Nitrogen (NO_2+NO_3) Concentration at Bosphorus-Black Sea Opening Section : 1.14 µmol/L

Lower Layer Total Oxidized Nitrogen (NO_2+NO_3) Concentration at Bosphorus-Marmara Opening Section : 9.15 µmol/L

Balance calculations show that a net amount of 1 844.8x10^6 mol/year (25 827 ton/year) nitrogen is transferred from the Marmara Sea to the Black Sea. As done for phosphorus previously, using partial flows instead of the total values, gives interesting results. Nitrogen which enters the Bosphorus from the Black Sea (out of system) with the upper current is 697.7x10^6 mol/year (9767.8 ton/year). When this amonut is compared with the 54 ton/day (19 710 ton/year) nitrogen impact originating from the wastewater as given in Section 4, it can be concluded that the anthropogenic nitrogen introduced from out of system is more than twice as much as the "natural system" flows.

5.4. Bosphorus TOC Balance

Spatial averages of TOC measurements carried out by the Marine Sciences Institute of the Middle East Technical University for the upper layer in the opening region of the Bosphorus-Black Sea and for the lower layer in the opening region of Bosphorus-Marmara Sea are summarized in Tables 11 and 12. The TOC calculations which are given in Table 13, are based on the time averages of these monitoring results. These values are as follows:

Table 11

Upper Layer Average TOC Concentrations (mg/L) at the Bosphorus-Black Sea Opening

		TOC (mgC/l)
August	1986	1.44
September	1986	1.42
November	1986	7.56
February	1987	1.96
May	1987	2.69
June	1987	2.50
July	1987	2.08
August	1987	2.27
September	1987	2.40
October	1987	2.04
Average		2.26

Table 12

Lower Layer Average TOC Concentrations (mgC/L) at the Bosphorus-Marmara Sea Opening

Ay		E2	M1	M2	M3	M4	M5	B1 B0	B2	B3	B4 B5
February	1987	0.56	0.90	0.70	-	-	-	0.72	-	-	-
May	1987	0.62	-	0.74	-	-	-	0.72	-	-	-
June	1987	0.53	-	0.54	1.22	-	-	1.28	-	-	0.64
July	1987	1.07	-	1.37	0.99	-	-	2.00	1.52	-	1.01
August	1987	0.57	-	0.53	0.59	-	-	-	-	0.83	0.73
September	1987	0.86	-	0.72	0.74	-	-	0.64	0.68	-	1.65
October	1987	-	-	0.73	0.88	-	-	0.61	0.66	-	0.71
January	1988	-	0.79	0.68	-	-	0.78	-	0.65	-	0.73
March	1988	0.59	-	0.56	0.66	-	-	1.14	1.47	-	0.72
May	1988	0.42	-	0.44	0.47	-	-	0.30	0.33	-	0.39
July	1988	-	0.79	-	0.63	0.74	-	1.06	0.92	-	0.89
August	1988	0.92	-	0.62	0.73	-	-	0.66	1.74	-	1.86
September	1988	0.58	-	-	-	-	-	0.72	1.22	-	1.12
Average		0.67	0.83	0.69	0.77	0.74	0.78	0.90	1.02	0.83	0.95

Upper Layer TOC Concentration
at Bosphorus-Black Sea Opening Section : 2.26 mg/L

Lower Layer Concentration
at Bosphorus-Marmara Sea Opening Section : 0.82 mg/L

Because of upper/lower layer current systems in the Bosphorus, the balance calculations show that a net amount of 1 068 200 ton/year TOC is transferred from the Black Sea to the Marmara Sea. This amount is about 12 times greater than the TOC inputs originating from the wastewaters of Istanbul. If partial flows are taken into consideration, instead of the total values, the results are even more striking. TOC flow which enters the Bosphorus from the Black Sea (out of system) with the upper current is then 1 380 100 t/year, which corresponds to 16 times the antropogenic input in the same time period.

Table 13

TOC Balance at Marmara Sea - Bosphorus Entrance Section

	Average Flow Rate (10^9 m^3/year)	Total Org. Carbon (TOC) Concentration (g/m^3)	Mass Transfer (10^6 kg/year)
From the Black Sea to Bosphorus with Upper Flow	612	2.26	1380.1
Transfer from Upper Layer to Lower Layer in the Bosphorus	-39	2.26	-88.1
Transfer from Lower Layer to Upper Layer in the Bosphorus	63	0.82	51.7
Load Entering the Marmara Sea			1343.7
Load Leaving the Marmara Sea	336	0.82	275.5
Net Carbonaceous Input to the Marmara Sea			1068.2 = 1 068 200 t/year

6. WASTEWATER MANAGEMENT SCENARIOS

In the preceding sections environmental stresses caused by wastewaters originating from the metropolitan Area of Istanbul on the Marmara Sea ecosystem has been discussed. In this section various wastewater management strategies to reduce these impacts will be created and compared to give a rough idea about their effectiveness. Before initiating this discussion, however, estimations about the future increase of pollutant loads have to be made.

As it is well known, the urban populations in Turkey is presently increasing at a very rapid pace. Istanbul, as the largest Turkish

city, inhabits about 8 million people and the annual rate of increase at the present date is 5.5 % . In this study, two projections about the future population of Istanbul have been made, which are summarized in Table 14. The underlying assumption to the first projection is that the rate of increase will remain constant at the present level in the next 50 years. This assumption leads to the unimaginable population of 116 million people by the year 2040. It is authors' opinion that a megapolis of this size will become unmanageable in every respect. The second population projection is based upon the assumption that the rate of increase, starting with a value of 5 % in the period of 1990-2000, will slow down by 1% in each consecutive decade. According to this assumption, the ultimate population of Istanbul will reach a level of 35 million people by the year 2040.

Table 14

Population Projections for Istanbul

	Constant Rate of Increase			Decreasing Rate of Increase		
Years	Rate of Increase	Factor of Increase	Estimated Population	Rate of Increase	Factor of Increase	Estimated Population
1990	5.5	1.00	8 000 000	5.0	1.00	8 000 000
2000	5.5	1.71	13 680 000	4.0	1.63	13 030 000
2010	5.5	2.92	23 360 000	3.0	3.24	25 910 000
2030	5.5	8.51	68 080 000	2.0	3.95	31 600 000
2040	5.5	14.54	116 320 000	1.0	4.36	35 000 000

The wastewater loads originating from the three distinct regions as defined in Section 3 of this paper are increased by the population increase factors given in Table 14.

To cope with the impacts of wastewater discharges into the Sea of Marmara, six alternative management scenarios have been developed and elaborated as follows:

a) No action (coastal discharge of untreated wastewaters);
b) Surface discharge to coastal wastewater after secondary (biological) treatment;
c) Surface discharge to coastal water after secondary and tertiary treatment (nutrients removal);

a*) Deep sea discharge after preliminary treatment (screening and grit removal);
b*) Deep sea discharge after secondary treatment;
c*) Deep sea discharge after secondary and tertiary treatment.

In these scenarios the TOC, N and P inputs from each of the there regions into the upper and lower layers of Marmara Sea have been calculated. The results are summarized in Tables 15 to 20. Since the future spatial expansion of the city is known exactly, it has been assumed, that the relative amounts of pollutant loads produced in each of the regions of wastewater origination will remain the same. It has been further assumed that if the wastewaters are introduced into this system by coastal discharges, the pollutant loads will remain in the Marmara Sea. Alternatively, if deep sea outfalls are used, the relative amounts of pollutants allocated between the lower and upper layers would be 50 to 50 % in Region I, 60 to 40 % in Region II (transition zone) and 80 to 20 % in Region III (Bosphorus).

In a further analysis, the results of the management scenarios have been brought together with the natural fluxes existing between the Marmara Sea and the Black Sea via Bosphorus, as found in Section 5 of this paper. This way, the final results of alternative scenarios have been obtained as gross inputs or outputs to the Sea of Marmara as demonstrated in Figs. 8 to 10.

Table 15

Antropogenous Pollutant Production According to Strategy (a)
(All Values are Given as tons/day)

	TOC			N			P		
Years	I	II	III	I	II	III	I	II	III
1990	90.18	99.42	49.38	20.80	23.20	11.00	4.12	2.99	2.18
2000	146.99	162.05	80.49	33.90	37.82	17.93	6.72	4.87	3.55
2010	217.33	239.60	119.01	50.13	55.91	26.51	9.93	7.21	5.25
2020	292.18	322.12	159.99	67.39	75.17	35.64	13.35	9.69	7.06
2030	356.21	392.71	195.05	82.16	01.64	43.45	16.27	11.81	8.61
2040	393.18	433.47	215.30	90.69	101.15	47.96	17.96	13.03	9.50

Table 16

Antropogenous Pollutant Production According to Strategy (b)
(All Values are Given as tons/day)

	TOC			N			P		
Years	I	II	III	I	II	III	I	II	III
1990	9.02	9.94	4.94	16.64	18.56	8.80	3.30	2.39	1.74
2000	14.70	16.21	8.05	27.12	30.26	14.34	5.38	3.90	2.84
2010	21.73	23.96	11.90	40.10	44.73	21.21	7.94	5.77	4.20
2020	29.22	32.21	16.00	53.91	60.14	28.51	10.68	7.75	5.65
2030	35.62	39.27	19.51	65.73	73.31	34.76	13.02	9.45	6.89
2040	39.32	43.35	21.53	72.55	80.92	38.37	14.37	10.42	7.60

Table 17

Antropogenous Pollutant Production According to Strategy (c)
(All Values are Given as tons/day)

	TOC			N			P		
Years	I	II	III	I	II	III	I	II	III
1990	4.51	4.97	2.47	2.08	2.32	1.10	0.41	0.30	0.22
2000	7.35	8.10	4.02	3.39	3.78	1.79	0.67	0.49	0.36
2010	10.87	11.98	5.95	5.01	5.59	2.65	0.99	0.72	0.53
2020	14.61	16.11	8.00	6.74	7.52	3.56	1.34	0.97	0.71
2030	17.81	19.64	9.75	8.22	9.16	4.35	1.63	1.18	0.86
2040	19.66	21.67	10.77	9.07	10.11	4.80	1.80	1.80	0.95

Table 18

Antropogenous Pollutant Production According to Strategy (a*)
(All Values are Given as tons/day)

Years		TOC I	TOC II	TOC III	N I	N II	N III	P I	P II	P III
1990	lower l.	51.40	47.22	37.53	11.86	11.02	8.36	2.35	1.42	1.66
	upper l.	34.27	47.22	9.38	7.90	11.02	2.09	1.56	1.42	0.41
2000	lower l.	83.78	76.97	61.17	19.32	17.96	13.63	3.83	2.31	2.67
	upper l.	55.86	76.97	15.29	12.88	17.96	3.41	2.55	2.31	0.67
2010	lower l.	123.88	113.81	90.45	28.57	26.56	20.15	5.66	3.42	3.99
	upper l.	82.58	113.81	22.61	19.05	26.56	5.04	3.77	3.42	1.00
2020	lower l.	166.54	153.01	121.59	38.41	35.70	27.09	7.61	4.60	5.36
	upper l.	111.03	153.01	30.40	25.61	35.70	6.77	5.07	4.60	1.34
2030	lower l.	203.04	186.54	148.24	46.83	43.53	33.02	9.27	5.61	6.54
	upper l.	135.36	186.54	37.06	31.22	43.53	8.26	6.18	5.61	1.64
2040	lower l.	224.11	205.90	163.63	51.69	48.05	36.45	11.24	6.19	7.22
	upper l.	149.41	205.90	40.91	34.46	48.08	9.11	6.82	6.19	1.80

Table 19

Antropogenous Pollutant Production According to Strategy (b*)
(All Values are Given as tons/day)

Years		TOC I	TOC II	TOC III	N I	N II	N III	P I	P II	P III
1990	lower l.	5.41	4.97	3.95	9.98	9.28	7.04	1.98	1.20	1.39
	upper l.	3.61	4.97	0.99	6.66	9.28	1.76	1.32	1.20	0.35
2000	lower l.	8.82	8.10	6.44	16.27	15.13	11.47	3.23	1.75	2.27
	upper l.	5.88	8.10	1.61	10.85	15.13	2.87	2.15	1.95	0.57
2010	lower l.	13.04	11.98	9.52	14.06	22.36	16.97	4.76	2.88	3.66
	upper l.	8.69	11.98	2.38	16.04	22.36	4.24	3.18	2.88	0.84
2020	lower l.	17.53	16.10	9.60	32.35	30.07	22.81	6.41	3.88	4.52
	upper l.	11.69	16.10	2.40	21.56	30.07	5.70	4.27	3.08	1.13
2030	lower l.	21.37	19.64	15.61	39.44	36.66	27.81	7.81	4.73	5.51
	upper l.	14.25	19.64	3.90	26.29	36.66	6.95	5.21	4.73	1.38
2040	lower l.	23.59	21.68	17.22	43.53	40.46	30.70	8.62	5.21	6.08
	upper l.	15.73	21.68	4.31	29.02	40.46	7.67	5.75	5.21	1.52

Table 20

Antropogenous Pollutant Production According to Strategy (c*)
(All Values are Given as tons/day)

Years		TOC I	TOC II	TOC III	N I	N II	N III	P I	P II	P III
1990	lower l.	2.71	2.48	1.98	1.25	1.16	0.88	0.25	0.15	1.18
	upper l.	1.80	2.48	0.49	0.83	1.16	0.22	0.16	0.15	0.04
2000	lower l.	4.41	4.05	3.22	2.03	1.89	1.43	0.40	0.24	0.29
	upper l.	2.94	4.05	0.80	1.36	1.89	0.36	0.27	0.24	0.07
2010	lower l.	6.52	5.99	4.76	3.01	2.80	2.12	0.59	0.36	0.42
	upper l.	4.35	5.99	1.19	2.00	2.80	0.53	0.40	0.36	0.11
2020	lower l.	8.77	8.05	4.80	4.04	3.76	2.85	0.80	0.48	0.57
	upper l.	5.84	8.05	3.20	2.70	3.76	0.71	0.54	0.48	0.14
2030	lower l.	10.69	9.82	7.80	4.93	4.58	3.48	0.98	0.59	0.69
	upper l.	7.12	9.82	1.95	3.29	4.58	0.87	0.65	0.59	0.17
2040	lower l.	11.80	10.84	8.62	5.44	5.06	3.84	1.08	0.65	0.67
	upper l.	7.86	10.84	2.15	3.63	5.06	0.96	0.72	0.65	0.19

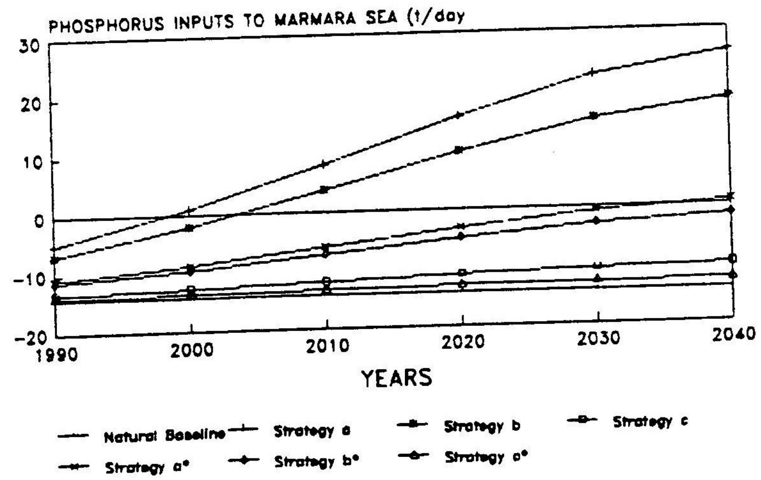


Fig. 8: Overall Phosphorus Inputs (t P/day) from the Marmara Sea According to Alternative Wastewater Management Scenarios (Negative Values Indicate Outputs), (Uslu et al. 1990)

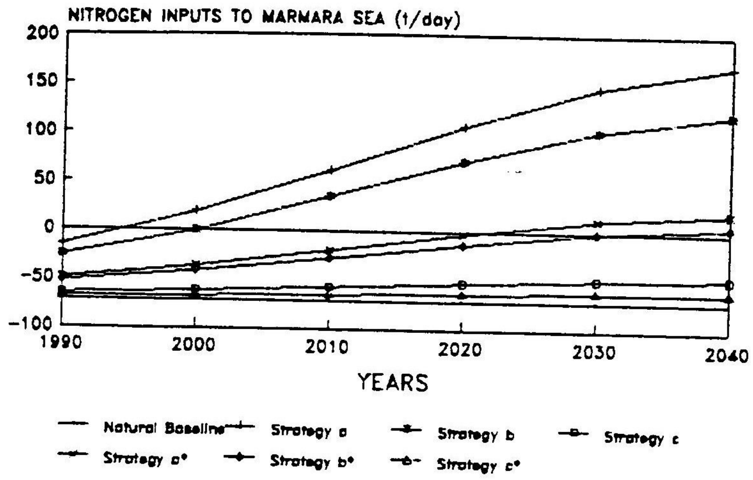


Fig. 9: Overall Nitrogen Inputs (t N /day) from the Marmara Sea According to Alternative Wastewater Management Scenarios (Negative Values Indicate Outputs), (Uslu et al. 1990)

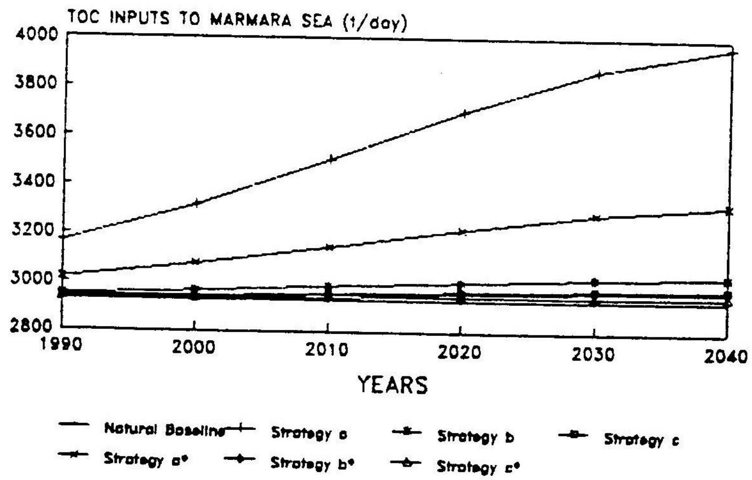


Fig. 10: Overall Organic Carbon Inputs (t TOC/day) to the Marmara Sea According to Alternative Management Scenarios (Uslu et al. 1990)

These results of the wastewater management scenarios show clearly that among all alternatives the deep sea outfalls bring highest marginal benefits with respect to the reduction of pollutant inputs into the Sea of Marmara. This result is especially important for the management of nutrient inputs into this system. In section 4 and 5 of this paper the significance of nutrients in the ecological degradation of the Marmara Sea has been underlined. The rapid increase of these loads in the coming decade will very probably reverse the direction of overall nutrient fluxes towards the Marmara Sea, which is already suffering under increasing eutrophication.

The management scenarios indicate that the receiving system is relatively insensitive against antropogenous carbonaceous inputs, since the natural fluxes towards the Marmara Sea is at least one order of magnitude greater than the loads originating from wastewaters of Istanbul. Although the organic carbon input from Istanbul is expected to rise substantially in the next 50 years, the environmental impact of this component to the Marmara Sea as a whole is by far not as important as the predicted impact of nutrients. However, due to the very weak dilution, dispersion and transport capacity of the receiving medium especially of Region II, which discharges presently directly into the coastal waters of the Marmara Sea, the immediate coastal stripe of this region is highly polluted. The management scenarios indicate again, that deep sea outfalls will very likely provide significant and immediate quality improvement in this region.

In this study no reference has been made to the problem of toxic compounds originating mainly from industries. This is not because that these constituents are regarded as unimportant with regard to the Marmara sea pollution. The reason for their exclusion is the entirely different practices required for their management. These type of constituents should be controlled at source, before they are introduced into the wastewater mainstream.

7. CONCLUSIONS

To cope with the precarious situation caused by the uncontrolled discharges of untreated wastewaters collected from the Metropolitan Area of Istanbul to the Marmara Sea, rapid action is required. However, this undertaking will be one of the most expensive wastewater abatement actions in the history of sanitary engineering. On the other hand, it is well known that Turkey is in a very rapid process of transformation to catch up with the economic level of her European partners. This requires high investments in every sector of the economy. The financial constraints imposed by this situation, imperatively requires the expenditure of every unit of currency to bring the highest benefits.

The thorough scientific understanding of both the ecosystem and the stresses thereupon and a good knowledge of technical possibilities is very important to make decisions under economic constrains. In this paper an attempt has been made to demonstrate at least from the ecological point of view, how a complex problem of environmental protection should be approached.

A systematic approach to complex waste management problems not only gives sound indications about the effectiveness of various management alternatives, but also provides the decision maker with information about the approppriate timing an sequencing of actions. It is therefore not only important "which" action is taken, but also "when" each step in a sequence of feasible actions is accomplished. With regard to this point, the created scenarios indicate that the first step in the realization of pollution abatement scheme for Istanbul has to be construction of deep sea outfalls, which clearly produce maximum decrease of pollutant input into the Sea of Marmara per completed unit. After completion of the deep sea outfalls, other treatment options can be seqenced.

In this study economic dimensions of the problem have not been included explicitly to the systems analysis considerations. In a further step, economical implications of decision alternatives have to be appraised together with the technical possibilities and ecological boundary conditions.

8. REFERENCES

Dokuz Eylül University, (1987): "Data Report for Anadolu Kavağı Current Measurements", (in Turkish), DEÜ-DBTE, Izmir.

Armi,L. ve D.M.Farmer, (1987): "A Generalization of the Concept of Maximal Exchange in a Strait". J. Geophys. Res., 92, 14679-14680.

Black Sea Pilot (1969): 11th Ed. Hydrographer of the Navy, Taunton, Somerset, Great Britain.

Bogdanova,A.K., ve V.N.Stepanov, (1974): "Hydrodynamic Estimate of the Blocking Conditions of the Lower Bosphorus Current." Oceanolg. Acta, 14, 37-40.

DAMOC (1971): "Master Plan and Feasibility Report for Water Supply and Sewerage for the Istanbul Region", DAMOC Consorsium, Los Angeles.

Farmer,D.M., ve L.Armi, (1986): "Maximal two-layer Exchange over a Sill and through the Combination of a Sill and Contraction with Barotropic Flow". J.Fluid Mech., 164, 53-76.

Jones,B. ve T.Oğuz, (1989): " The Modelling of the Flow of Water through the Bosphorus". Dyn.Atm. and Oceans'de yayınlanacak.

Lacombe,H., J.C.Garcard, J.Gonella,J.P.Bethoux, (1981): "Response of the Mediterranean to the Water and Energy Fluxes Across its Surface on Seasonal and Interannual Scales." Aceanol. Acta, 4,247-255.

Latif,M.A., E.Özsoy, T.Oğuz, Ü.Ünlüata, Ö.Baştürk, C.Saydam, A.Yılmaz, I.Salihoğlu (1989a): "Oceanographic Characteristics of the Region Surrounding the Northern Entrance of the Bosphorus as Related to the Planned Sewage Outfalls." First Annual Report, METU-IMS, 111pp.

Latif, M.A., E. Özsoy, T. Oğuz and Ü. Ünlüata, (1989): Observation of the Mediterranean Inflow into the Black Sea, Submitted for publication to the Deep Sea Research.

Morskoi Atlas, (1950): V.II (Black Sea). USSR. Admiralty

Nof,D., (1978): "On Geostrophic Adjustment in Sea Straits and Wide Estuaries: Theory and Laboratory Experiments. Part II, Two-layer system". J. Phys. Oceanog., 8, 861-872.

Oğuz,T. ve H.I.Sur, (1989): "A two-layer Model of Water Exchange through the Dardanelles Strait". Oceanol. Acta, 12, 23-32.

Oğuz,T., E.Özsoy, M.A.Latif, H.I.Sur, Ü.Ünlüata, (1989): "Modelling of Hydraulically Controlled Exchange Flow in the Bosphorus Strait".

Ovchinnikov, I.M., (1974): "On the Water Balance of the Mediterranean Sea". Oceanology, 14, 198-202.

Östlund,H.G., (1986): "Renewal Rates of the Black Sea Deep Water". Extended abstract, presented at meeting on "The Chemical and Physical Oceanography of the Black Sea, Göteborg.

Özsoy, E., T.Oğuz, M.A.Latif, Ü.Ünlüata (1986): "Oceanography of the Turkish Straits, First Annual Report, V.I." METU-IMS, 269pp.

Özsoy,E., T.Oğuz,M.A.Latif, Ü.Ünlüata, H.I.Sur, S.Beşiktepe, (1988): "Oceanography of the Turkish Straits, Second Annual Report, V.I". METU-IMS, 110pp.

Özturgut,E., (1971): "Physical Oceanographic Study of the Bosphorus". Doktora Tezi, Istanbul Üniversitesi, Coğrafya Enstitüsü.

Preller, R., (1985): "Numerical Model Study of Circulation in the Alboran Sea". Mesoscale Air-Sea Interaction Group, Technical Report, Florida State Univ., 125pp.

Sümer,M. ve M.Bakioğlu, (1981): "Sea-Strait Flow with Special Reference to Bosphorus." ITÜ, Inşaat Mühendisliği Fak., 25 sayfa.

Sverdrup,H.U., M.W.Johnson, R.H.Fleming, (1946): "The Oceans". Prentice-Hall Co., New-York, 1087pp.

Tixeront, F., (1970): "Le bilan hydrologique de la Mar Noire et de la Mediterranee". Cahiers Oceanog., 22, 227-237.

Tolmazin, D., (1981): "Two Dimensional Circulation in Straits". Ocean, 81, 820-823, Proc. of IEEE Conference, 1981, Boston.

Tolmazin, D., (1985): "Changing Coastal Oceanography of the Black Sea, II: Mediterranean Effleuent." Progr. in Oceanogr., 15, 277-316.

Environmental Problems Foundation of Turkey, (1989): "Environmental Profile of Turkey'89", Ankara, 478s.

UNEP/UNESCO/FAO (1988): "Eutrophication in the Mediterranean Sea: Receiving Capacity and Monitoring of Long Term Effects". MAP Technical Reports Series No.21. UNEP, Athens, pp. 199.

Uslu, O., D. Orhon, Ü, Ünlüata, A. Filibeli, (1990): "Environmental Impact Assessment Report: Impact of Municipal Wastewaters of Istanbul and Bosphorus Inflows on the Ecological Situation of Marmara Sea", (in Turkish) ISKI, Istanbul.

Ünlüata Ü. and E. Özsoy, (1986): Oceanography of the Turkish Straits, First Annual Report, Volume II, Health of the Turkish Straits, I. Oxygen Deficiency of the Sea of Marmara, METU, Institude of Marine Sciences, 88pp.

Ünluata, Ü., T. Oğuz, M. A. Latif, E. Özsoy, (1989): "On the Physical Oceanography of the Turkish Straits". To appear in: The Physical Oceanography of Sea Straits, L.J.Pratt (Ed.) NATO-ASI Series, Kluwer Publication.

Ünlüata Ü., T. Oğuz, M. A. Latif and E.Özsoy, (1990): On the Physical Oceanography of the Turkish Straits, The Physical Oceanography of Sea Straits, L.J. Pratt (Ed.), NATO/ASI Series, Kluwer Acedemic Publishers, in print.

Wang,D.P., (1987): "The Strait Surface Outflow". J.Geophys. Res., 92, 10807-10825.

Weather in the Black Sea (1963): Meteorological Office, H.M. Stationary Office, London.

Whitehead, J.A. ve A.R. Miller, (1979): "Laboratory Simulation of the Gyre in the Alboran Sea." J. Geophys. Res., 90, 7045-7060.

EINFLUSS DER VORFLUTER-RANDBEDINGUNGEN AUF DIE WAHL DER ABWASSERREINIGUNGSSYSTEME DARGESTELLT AM BEISPIEL EINIGER TÜRKISCHEN GROSSSTAEDTE

Prof.Dr.-Ing. O. Uslu
Dokuz Eylül Universität, Abteilung für Umweltingenieurwesen

INHALT

1. EINLEITUNG

Hinsichtlich ihrer geographischen Lage kann die Türkei als eine Halbinsel betrachtet werden, die vom Mittelmeer und Ägäis sowie dem Schwarzen Meer umgeben ist. Das Land befindet sich in der subtropischen Klimazone und hat begrenzte Süsswasserresourcen.

Die Türkei befindet sich z.Zt. in einer dynamischen Phase ihrer Entwicklung. Die gesellschaftliche und wirtschaftliche Stabilität ist noch nich erreicht. In den nächsten 20-25 Jahren wird mit einer Verdoppelung der Bevölkerungszahl (auf 100 Millionen) und einer Verzehnfachung der Industrieproduktion gerechnet. In den vergangenen vierzig Jahren sind die türkischen Grossstadte explosionsartig gewachsen. Dieses Wachstum war einerseits bedingt durch die traditionell hohe Fruchtbarkeit der Bevölkerung und andererseits durch Landflucht von den ländlichen Gebieten in die Städte. Der Grund für dieses Siedlungsstrukturwandels ist das