CROATICA CHEMICA ACTA CCACAA **70** (1) 373–388 (1997)

ISSN-0011-1643
*CCA-2428*
*Original Scientific Paper*

# Towards Optimum Management of Total Suspended Solids in a Coastal Sea: The Case of Izmit Bay, Marmara Sea*

*Tarzan Legović,*[a] *Enis Morkoç,*[b] *Oya S. Okay,*[b] *Leyla Egesel, Huseyin Tufekci*[b] *and Vildan Tufekci*[b]

[a]*Ruđer Bošković Institute, Center for Marine Research, P.O.B. 1016, 10001 Zagreb, Croatia*

[b]*Marmara Research Center, TÜBITAK, P.O.B. 21, TR41470, Turkey*

Received February 20, 1996; accepted October 3, 1996

The distribution and transport of total suspended solids (TSS) is considered in order to propose the strategy which, when implemented, would lead to compliance with the water quality criterion. Currently, most of the water in Izmit bay has a TSS concentration in excess of the legal maximum of 30 mg/L TSS. Modelling and simulation shows that the majority of the TSS does not originate from the known land based sources but probably represents phytoplankton. Since excessive quantities of N and P are discharged into the bay, sometimes the growth of phytoplankton is limited by the natural silicate content of the water. However, it is found that most of the phosphorus discharged from land based sources is in fact utilized by the phytoplankton. Hence, reduction of the TSS concentration to the legal limit can be achieved by decreasing phosphorus sources. If the majority of total organic carbon emanating from land based sources were removed, this would imply a considerable decrease in phosphorus inflow. It is suggested that waste waters from residential communities and the remaining industry should be treated and released to the layer below the halocline using one outfall in the eastern part and one or several outfalls in the central part of the bay.

* Dedicated to Marko Branica on the occasion of his 65$^{th}$ birthday.

## INTRODUCTION

The interest in describing elevated concentrations of total suspended solids (TSS) in Izmit Bay (Figure 1) is due to two facts: a) concentrations frequently exceed the existing standard for coastal waters, and b) a serious effort has been already invested to improve the water quality in the bay. TSS measured in the seawater include two components: suspended solids released from land based sources and a part of phytoplankton.

According to the Turkish water quality criterion,[1] TSS in coastal waters should not exceed 30 mg/L. This criterion is used by many countries and it originates from the US EPA recommendation of 1976.[2]

In coastal as well as in open waters of the eastern Mediterranean, phosphorus is believed to be the nutrient that controls phytoplankton growth. By controlling the inflow of phosphorus, one would control phytoplankton production and subsequently phytoplankton concentrations in coastal waters. To some extent (to be determined below) one would also control the TSS concentration in seawater.

However, it has been shown[3] that phytoplankton production in Izmit Bay is controlled by the following nutrients (in the order of decreasing importance): silicate, phosphate and nitrate. The appearance of silicate as a major nutrient controlling phytoplankton growth is surprising. The current inter-

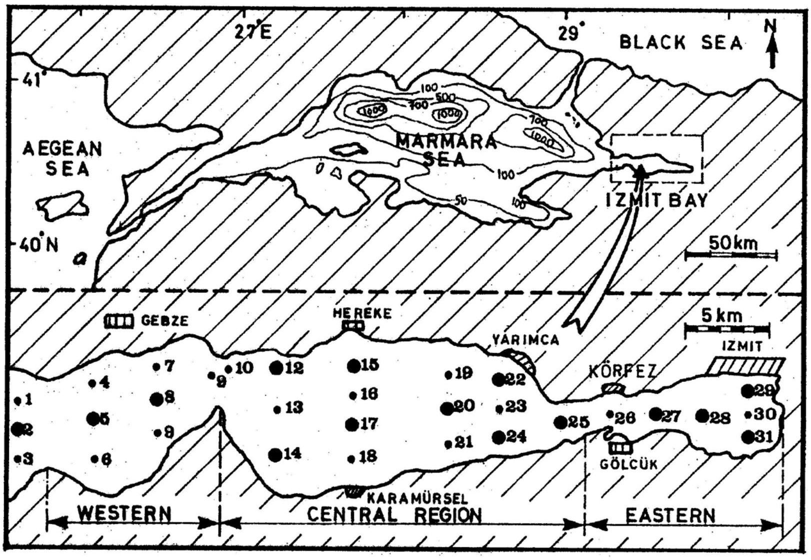


Figure 1. Marmara Sea. Izmit Bay. Distribution of measurement stations in Izmit Bay (measurements of TSS and TP were made at a subset of stations, see Figures 5 and 6).

pretation is that the phosphorus load is presently so excessive that the natural supply of silicate has become limiting for one group of phytoplankton species (diatoms). This interpretation is in agreement with recent results concerning coastal waters of the northern Adriatic and the Gulf of Mexico,[4] both of which receive excessive anthropogenic inflow of nutrients.

Finally, in the context of a better environmental management of Izmit Bay, we shall see that there are good reasons for considering the behaviour of total suspended solids and total phosphorus together.

Questions that we shall try to answer regarding TSS concentrations in Izmit Bay are:

1) What are the present concentrations of TSS in seawater?

2) Can we explain these concentrations as a direct consequence of land based sources?

3) What is the link between TSS and and total phosphorus?

4) To what extent should the intensity of the existing sources be changed and where should they be relocated around the bay in order to satisfy the water quality criterion?

## DEFINITIONS, METHODS AND AVAILABLE DATA

The optimum management plan means a plan for changing source intensities and locations to meet the standard of water quality in Izmit Bay with minimum investment.

The procedure of designing such a plan is to:

a) determine where and when TSS concentrations exceed 30 mg/L;

b) reconstruct the present concentration distribution from known sources using the transport equation;

c) suggest the best scenario to remedy the present situation.

### *Present State*

Maps of the TSS concentration distribution representing the average of the upper 10 m (0.5, 5 and 10 m), were drawn with the help of the objective analysis[5] of measured concentrations at 15 vertical transects in the bay (Figures 1) and one vertical transect in the Marmara Sea during six cruises in 1994 and 1995. Maps of total phosphorus (TP) were prepared from 23 vertical transects in the bay (Figure 6).

### *Estimation of Parameters in the Transport Equation*

The transport equation to be used is:

$$\Omega: \alpha\, \Delta C - v\, \nabla C - k\, C + \sum_{i=1}^{n} q_i = 0; \qquad \Gamma: \partial C/\partial n = 0.$$

where $\Omega$ denotes the region of the bay (a layer down to 10 m below the surface), $\Gamma$ denotes the boundary and $C$ stands for TSS concentration. The parameters $q_i$, $i = 1,...n$ denote TSS land based sources (both domestic and industrial) to the Izmit Bay.

Before using the transport equation, it is necessary to estimate the turbulent diffusion coefficient $\alpha$; the prevailing current field, $v$; sources, $q_i$; and loss of the TSS from the layer through sedimentation, uptake by biota and dissolution.

The turbulent diffusion coefficient $\alpha$ is taken according to the 4/3 law using the characteristic scale of the bay.[6] The scale is 29 km and the corresponding $\alpha$ is 42 $m^2/s$. Since the bay is very elongated (length/average width = 6.2), we also experiment with a characteristic scale of 5 km which corresponds to $\alpha = 4$ $m^2/s$.

The velocity field is constructed by minimizing the enstrophy (square of the vorticity over the field). This leads to the biharmonic equation for the stream function with $v = 0$ on the boundary. In order to take into account the direct current measurements, the procedure has been modified so that the total stream function is represented by a sum of stream functions[7] due to the open boundary and current measurements. The current measurements that we used to construct the current field may be found in Oğuz and Sur.[8]

The parameter $k$ characterizes the extinction of substance in the considered water column. It represents the sum of processes which contribute to the loss of TSS from the upper layer: sedimentation, dissolution and uptake by biota. Since there may be recirculation of substance through the halocline, this parameter stands for the total net specific extinction rate (the ex-

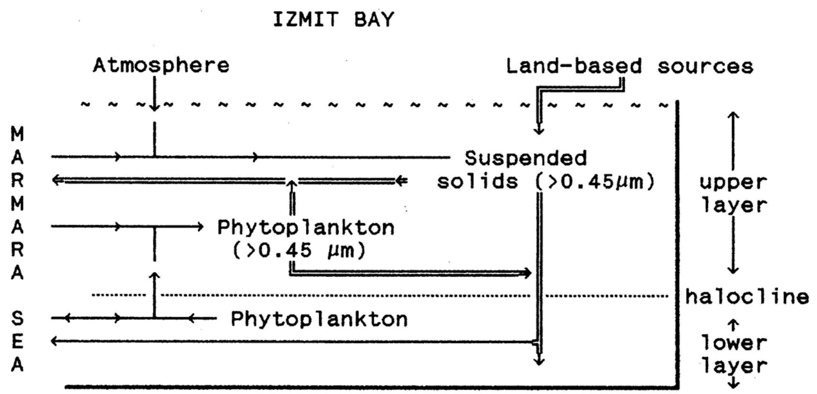


Figure 2. TSS (suspended solids of terrestrial origin + phytoplankton) in the upper and lower layers of Izmit Bay: sources, sinks and exchange with the Marmara Sea.

tinction rate is $k\ C$). Once the sources are known, parameter $k$ can be obtained by fitting the solution of the transport equation to the TSS data in the sea.

The TSS in seawater are operationally defined as the concentration of particles that are retained on a 0.45 μm filter. These particles may be organic or inorganic. The organic particles are composed of detritus and phytoplankton.

The sources and sinks of TSS in the upper layer (above the halocline) and in the lower layer (below the halocline) are depicted in Figure 2.

Land-based sources are by far the largest sources of the TSS inflow into the upper layer. They originate from domestic and industrial waste waters. TSS from domestic waste waters that are released from residential communities amount to approximately 94 *t*/day. TSS inflow from residential communities is given in Table I.

TABLE I.

Average suspended solids inflow from waste waters of mayor residential communities.

| TSS source | Karamürsel | Izmit | City Körfez | Gölcük | Gebze |
|---|---|---|---|---|---|
| *t*/day | 6 | 40 | 9 | 12 | 27 |

The inflow of TSS from industrial sources along the northern coast of the bay, where the dominant industry is present, has been determined by direct measurements. According to the six seasonal measurements during 1994 and 1995, industrial sources vary by over an order of magnitude: from 4.3 to 61 *t*/day with a mean of 20 *t*/day or about 20% of the residential sources. Small sources of TSS are located on the southern coast. Since these are presently unknown, we are forced to neglect them. However, we do not expect their inclusion would alter our results significantly.

Reconstruction of the TSS concentration field in the upper layer and simulations of scenarios were run using the software package RECON.[10]

## RESULTS

### *Present Distributions of TSS in the Upper Layer*

Results from all six monitoring cruises are presented. They are arranged and will be discussed in the chronological order throughout one year, though there are data for two years. The intention is to display possible seasonal

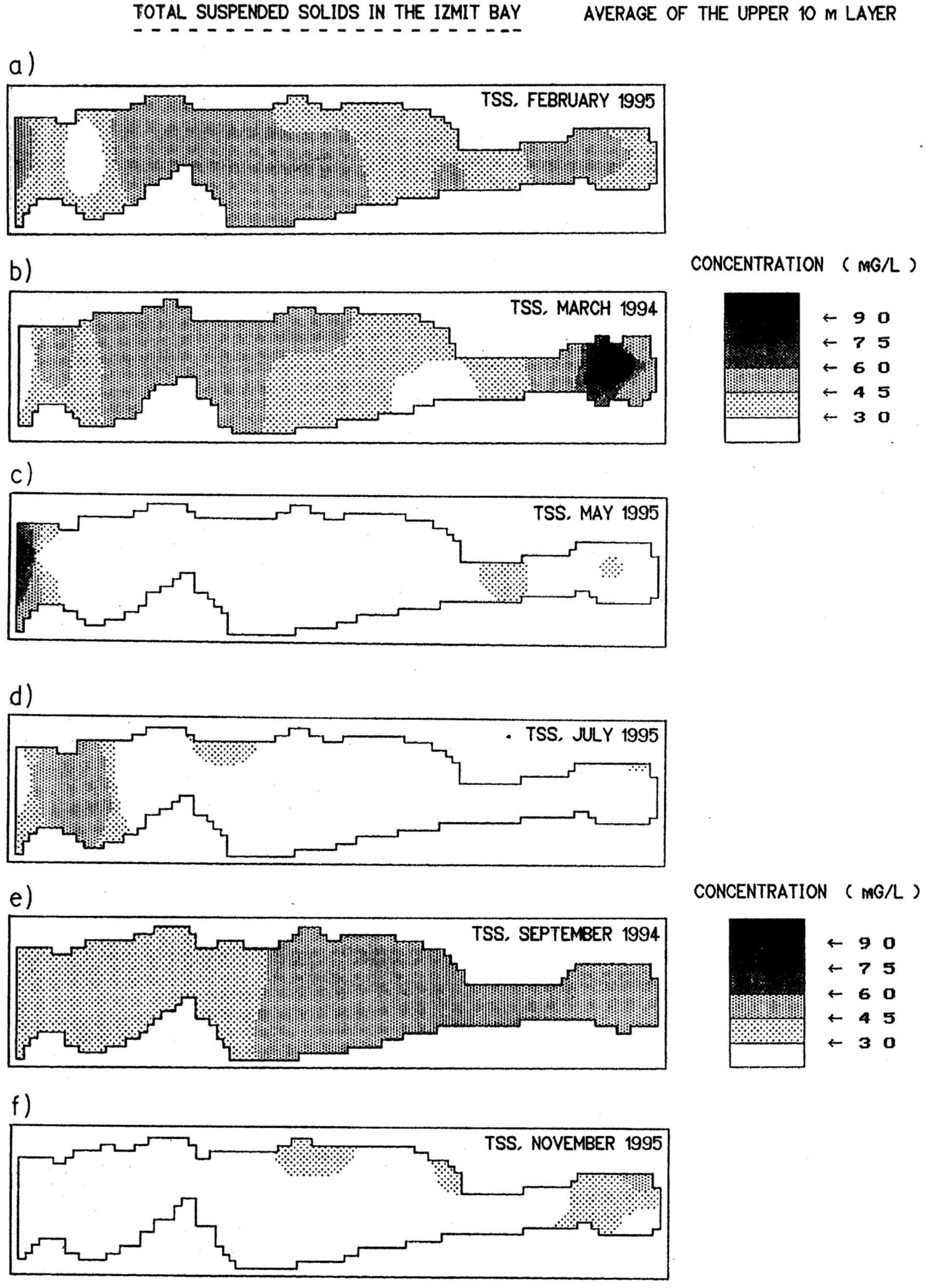


Figure 3. Distribution of TSS during 6 cruises: from March 1994 until November 1995 (in chronological order of one year).

variations, assuming that, within the naturally existing noise level, the two years are identical.

*February 1995 (Figure 3a)*

The concentration of TSS on the transect with Marmara is approximately equal to, or slightly lower than, the concentration in Izmit bay but it exceeds the water quality standard. The distribution is very diffuse and the exact location of sources is not visible although it is evident that they exist in the eastern and in the central parts of the bay. The diffuse distribution is in part a consequence of only 15 monitoring stations. Since monitoring stations are not located near the existing sources *i.e.* only concentrations further away from sources are observed, we expect that the displayed concentration gradients toward sources are smaller than in reality.

*March 1994 (Figure 3b)*

The TSS concentration on the boundary with the Marmara sea satisfies the water quality standard. An intensive source in the eastern part of Izmit bay is visible and so is the gradient of TSS toward the central part of the bay. One third of the eastern part has at least a 3 times higher concentration than permitted by the water quality standard. The lower concentrations than the standard on the southern boundary between the eastern and central parts are not due to upwelling of supposedly better quality water from the lower layer (since the TSS concentration in the lower layer is high) but are a result of loss from the upper layer.

*May 1995 (Figure 3c)*

TSS concentrations along the transect with the Marmara are 2 to 2.5 times higher than the water quality standard. The concentration in the bay is lower than the standard, except for a small part of the eastern part where it is at most 50% higher than the standard.

*July 1995 (Figure 3d)*

Most of the bay has lower TSS concentrations than the standard. The effect of the existing sources in the bay is barely seen. Close to the transect with the Marmara sea the standard is violated by up to 100% higher TSS concentrations.

*September 1994 (Figure 3e)*

The water quality criterion is violated throughout the bay. The TSS concentration is nearly 100% higher than the standard in the eastern bay, but decreases to at most 50% above the standard as the western part of the bay is approached.

*November 1995 (Figure 3f)*

Only areas along the northern coast of the central and eastern parts of the bay have TSS concentrations above the standard.

*Average TSS distribution*

The average TSS distribution obtained from the six cruises shows that the concentration in most of the bay and for most of the time exceeds 30 mg/L. In addition, concentrations exceeding the standard by 66% are found in nearly half of the eastern bay (Figure 4a).

However, to assess the meaning of this result, we must consider the the dispersion around the mean, caused by seasonal fluctuations. If we add one standard deviation to the mean, we get a possible but not commonly found situation ( Figure 4b). The large dispersion of the mean suggests that there will be situations when most of the bay water will satisfy the standard.

In order to see more precisely by how much the distribution in Figure 4a violates the law, let us assume that the relevant isoline is 35 mg/L instead of 30 mg/L TSS. Replotting of Figure 4a would give Figure 4c. In other words, in nearly half of the bay, average concentrations are not much above 30 mg/L.

In addition, the concentration gradient seen in Figures 3a-f indicates that significant extinction of TSS occurs in the upper layer.

Let us mention five conclusions that follow from the above results:

A) The average concentration of TSS exceeds 30 mg/L in nearly all of the bay. In the western and central parts, the standard is exceeded by 20 to 40%, while in the eastern part it is exceeded by 66%.

B) On the average, water arriving from the Marmara sea is not of a better quality than that found in the western and most of the central parts of Izmit bay.

C) There are large seasonal fluctuations. Hence, there will be times when the standard will be exceeded by 200 to 300% in the eastern part and times when western and central parts will satisfy the standard.

D) If there were no sources in the bay, the concentration of TSS would be generally lower than along the transect with the Marmara sea due to intensive extinction of TSS in the upper 10 m layer.

E) From the existence of strong extinction processes, it is hypothesized that TSS concentrations exceeding the standard on the transect with Marmara come from the nearby coastal sources west of Izmit (Gebze, Darica and Tuzla).

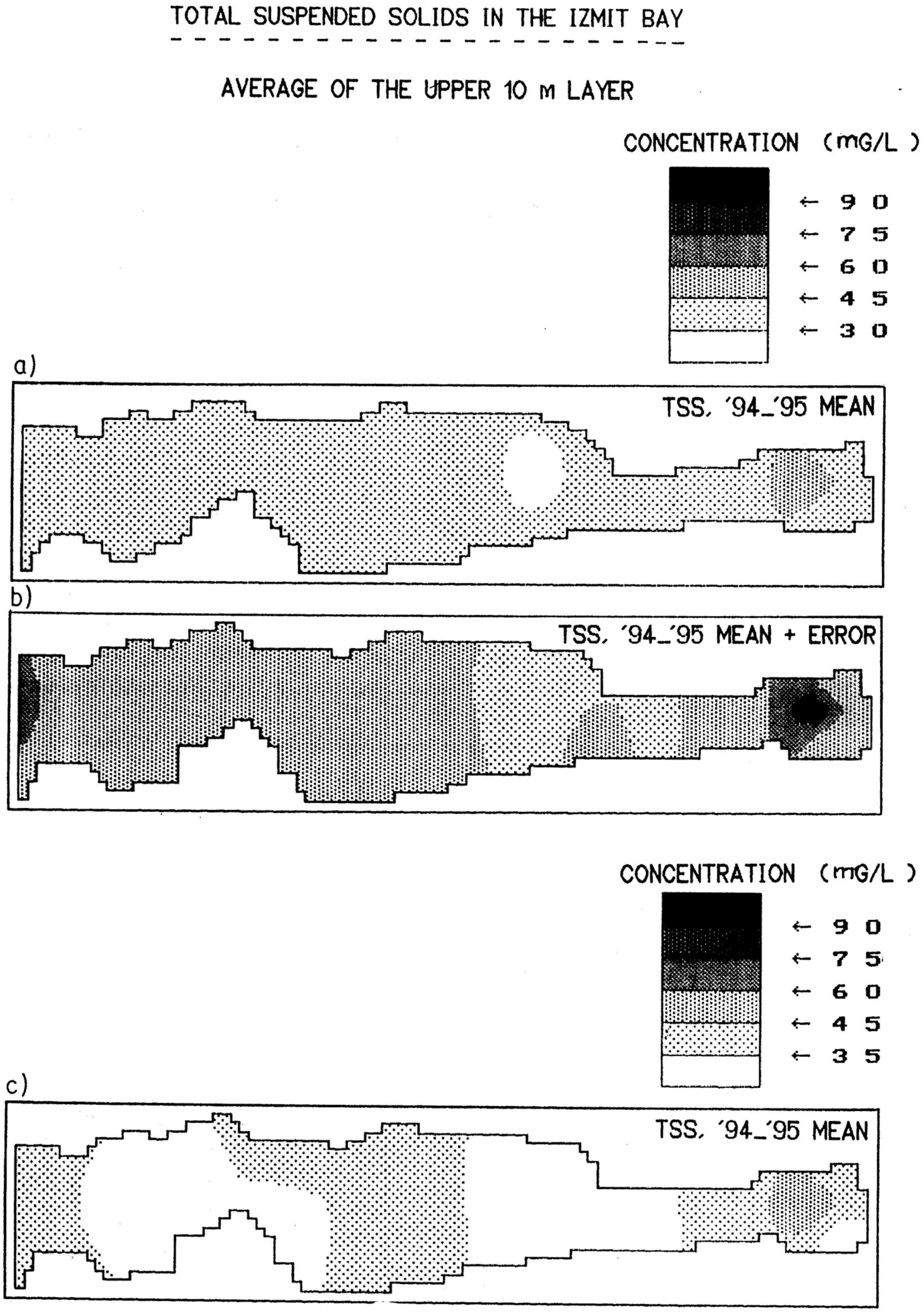


Figure 4. Distribution of TSS in Izmit Bay: a) average, b) average plus one standard deviation, c) same as a) with isoline 35 mg/L TSS.

### *An Attempt to Reconstruct Concentration of TSS Using the Transport Equation*

By optimizing the solution to the transport equation of TSS supplied by domestic and industrial sources, we were able to obtain the highest possible concentrations above the background, as shown in Figures 5b and 5c.

The distribution in 5b is obtained by assuming a turbulent diffusion coefficient of $\alpha = 42$ m$^2$/s. The distribution in Figure 5c is obtained by decreasing the turbulent diffusion coefficient to 4 m$^2$/s.

Parameter $k$ corresponds to a half life of 12 days. As for the measured values, the mean concentration from all six cruises has been used. Figures 5b and 5c were obtained using a zero current field. If the current field as measured in May 1984 were used, peaks of TSS concentrations would be even smaller.

Reconstructed maximum concentrations of only 10 mg/L TSS above the standard (Figure 5b) were obtained. Note that measurements suggest concentrations up to 60 mg/L TSS above the standard. It is clear that the majority of elevated TSS concentrations observed in Izmit Bay cannot be explained by the existing direct inflow of TSS from land based sources.

In order to explain this discrepancy, let us turn to the second component which contributes to the TSS in water (Figure 2): phytoplankton. Hence, we must investigate whether, given the phosphorus inflow from land based sources, we could obtain agreement with the observations of total phosphorus.

### *Reconstruction of the Total Phosphorus Concentration (TP)*

It has been shown earlier[11] using only the data from March 1994 that the answer to the above question is likely to be positive.

Here, we present a reconstruction of the average TP distribution using all the data available from the first five cruises.

Figure 6a shows the average TP distribution in the upper layer, based on an objective analysis of measurements of the first five cruises. Gradients from sources may be seen, but again few sources are directly visible. The reason is that there are few stations in the bay which are close to the sources, especially sources from the southern coast. Hence, as we move closer to the sources, we expect the concentrations in Figure 6a to be smaller than in reality.

Location of sources and measurement stations in the sea are shown in Figure 6b. The number of stations is 23 *versus* 15 for the case of TSS. The number of assumed sources is 9, the same as in the case of TSS.

Figure 6c represents a reconstruction with a velocity field $v = 0$, the extinction rate of TP equivalent to a half-life of 6 days and a characteristic

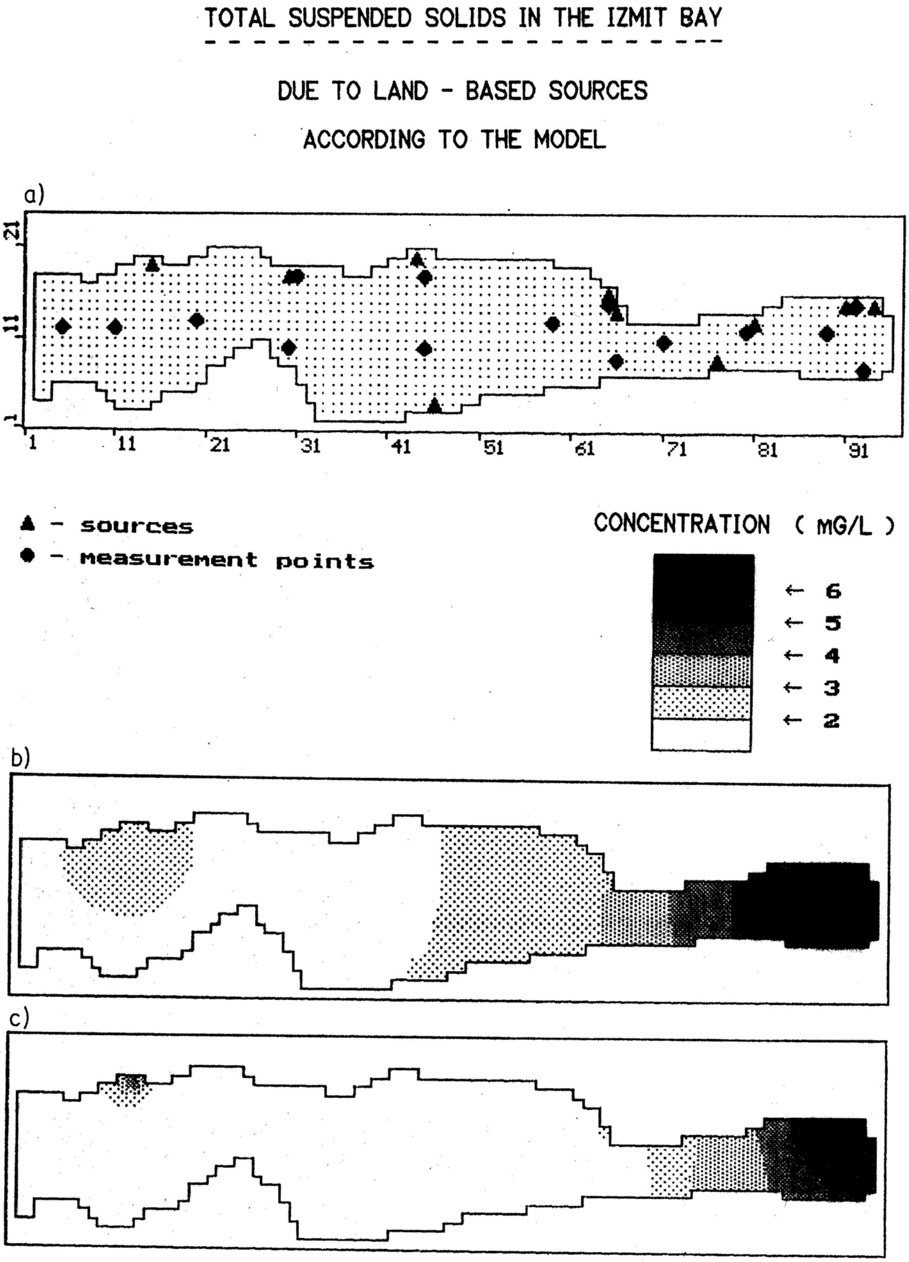


Figure 5. a) Location of TSS land based sources (Δ) and measurement stations in the sea (o); b) reconstruction of TSS above the background with $\upsilon = 0$, turbulent diffusion coefficient $\alpha = 42\ m^2/s$ and the halflife of TSS in the upper layer is 12 days; c) reconstruction of TSS above the background using the same parameters as in b) except that $\alpha = 4\ m^2/s$.

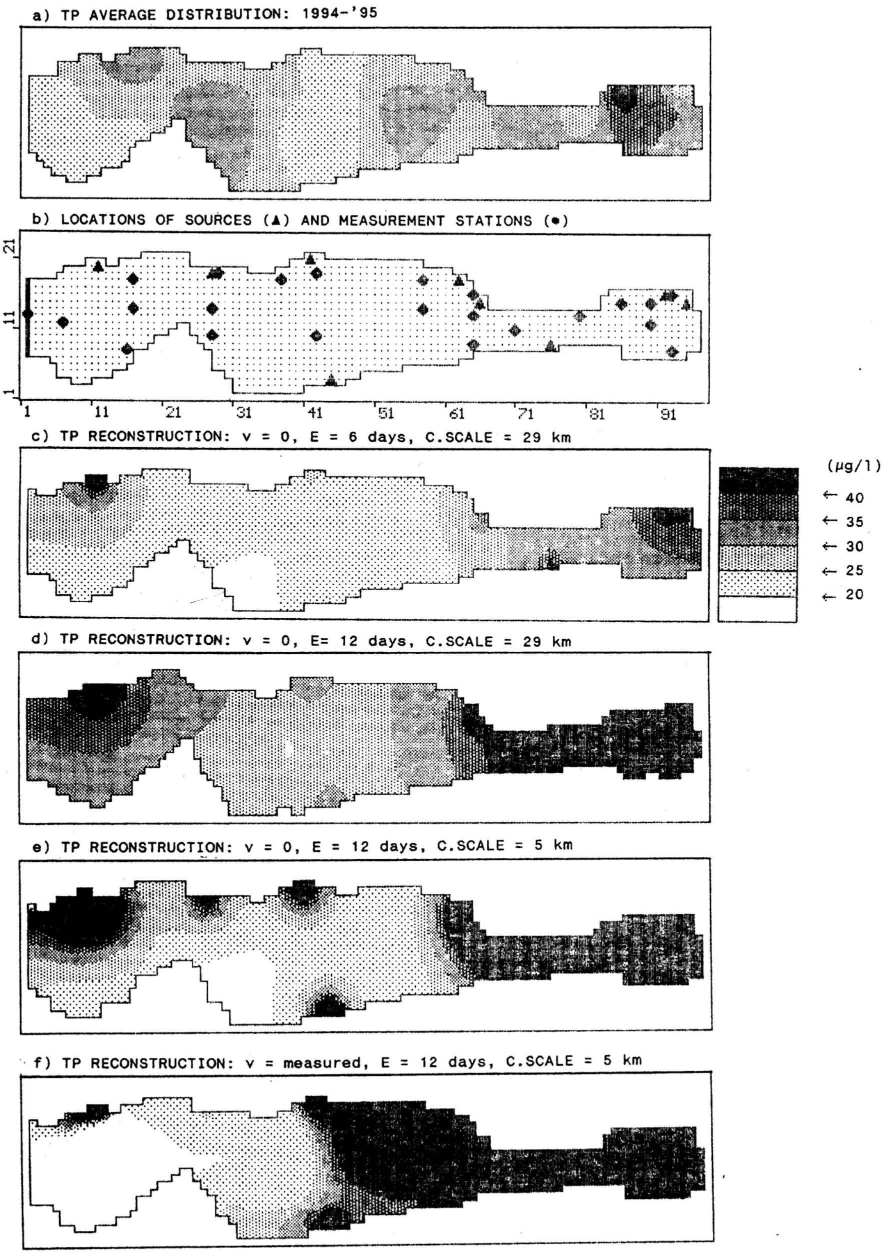


Figure 6. a) average distribution of TP in Izmit Bay; b) location of sources and measurement stations of TP; c) reconstruction of TP using $\upsilon = 0$, halflife = 6 days, $\alpha = 42$ m$^2$/s; d) same as a) except that the half-life is 12 days; e) same as b) except that $\alpha = 4$ m$^2$/s; f) same as e) except that the current field is reconstructed from data at six stations during March 1984.

scale of 29 km. This figure and the subsequent figures are obtained using a directly estimated total inflow of 2.96 *t*/day P.

Figure 6c should be compared with Figure 6a.

If we know that values close to the sources are higher than those displayed in Figure 6a, then we may conclude that concentrations in these two distributions are close. However, there are also some disagreements. First, Figure 6a points to a source on the south coast close to the western part of the bay that is entirely absent in Figure 6c. Since we had no direct information on this possible source, we have not included it in the simulation.

Overall, figure 6a implies somewhat higher concentrations in the central part of the bay. This may be due to extinction time longer than 6 days (Figure 6c) but shorter than 12 days (Figure 6d).

The rest of the difference in details depend on the prevailing current field, the existence of some minor sources and adjustments to the intensity of directly estimated sources.

Figure 6e shows the effect of decreasing eddy diffusion coefficient. The distribution of TP has higher values near the sources and lower values far from sources than previously.

Finally, the effect of residual currents as reconstructed from measurements in March 1984 is seen in Figure 6f. Currents increase the dispersion of TSS in the eastern part of the bay but would also clean up the excess concentration of TP in the western part.

The main conclusion from the above simulations is that the inflow of total phosphorus from land based sources does correspond to the elevated concentrations of total phosphorus observed in the upper layer of the bay.

It follows that the environmental control procedure to reduce TSS in seawater of Izmit Bay must include reduction of land based sources of phosphorus.

### *How Much to Decrease the Intensity of Sources and Where to Relocate Sources to Satisfy the Water Quality Criterion?*

As we have seen, the TSS inflow from land based sources accounts for only 1/10 to 1/3 of the observed concentrations in excess of the background. This means that one should concentrate on reducing nutrients that control phytoplankton growth. In the last several decades, anthropogenic inflows of phosphorus and nitrogen have increased so much that now the natural supply of silica seems to limit diatoms growth. This means that either phosphorus or nitrogen have to be drastically reduced in order to accomplish a significant improvement in TSS concentration.

Let us take the case of phosphorus and assume that the supply of phosphorus is such that whereas limitation has just been exceeded for diatoms, the growth of other groups of phytoplankton species is still limited by phosphorus. This is clearly a better case hypothesis. In part, the justification for this hypothesis is the fact that the orthophosphate concentration in seawater in the productive season is not very high and that the gradient toward the Marmara sea is barely seen. This means that nearly all of the anthropogenic supply of phosphorus does get used.

Thus, a 50% reduction in the phosphorus inflow to the upper layer would decrease the TSS due to phytoplankton by at most 50%. At times of small phytoplankton production, the situation would be approximately as it is now or somewhat better. This means that the water quality criterion would be satisfied in most of the bay including most of the eastern part. At times of high phytoplankton production, nearly half of the bay would satisfy the standard, but the eastern part would not. To satisfy the criterion in the upper layer of the eastern bay by only a 50% reduction of phosphorus, the processed waste water must be released into the lower layer.

If this measure were adopted, phytoplankton blooms in the upper layer of the eastern bay would remain but they would be much smaller both in terms of concentration and spatial coverage. In addition, blooms would be shorter and would be limited to the entrainment (upwelling) events that follow strong E winds. On the average such entrainment brings about 10% of sea water from the lower layer into the upper layer.

Which is the easiest way to achieve a 50% reduction in phosphorus inflow from land based sources?

A straightforward reduction of phosphorus by 50% is too costly. Furthermore, the associated total organic carbon (TOC) inflow to the lower layer would decrease the already too low dissolved oxygen concentration in the lower layer.

The optimum measure would be to reduce TOC input as much as possible, say by 90% from both the domestic and the remaining untreated industrial sources. The treated waste water should be released as far down into the lower layer as possible. This measure, which could be achieved by extending the present activated sludge treatment of industrial sources, would have the following beneficial effects:

a) the inflow of TOC into the lower layer would be much smaller than now;

b) phosphorus inflow into the lower layer would be nearly halved;

c) dissolved oxygen in the lower layer would increase (except in the immediate vicinity of the outfall);

d) phytoplankton blooms in the upper layer would be less frequent and shorter. The highest concentrations of phytoplankton in the upper layer would be smaller while the spatial extent of water quality violation would be much smaller than now. The largest change would be observed in the upper layer of the eastern bay.

Hence, the best solution would be to construct: a) an outfall that collects processed waste from the eastern part; b) one or more outfalls that collect processed waste from land based sources of the central part. All outfalls should be extended well into the lower layer.

The optimum location of the outfall in the lower layer is critical in the eastern part of the bay. The aim is to find a location wherefrom the waste would leave the eastern bay along the shortest path. To determine the optimum location, a study is needed which would involve: a) detailed Eulerian measurements of T,S; b) Eulerian and Lagrangian measurements of currents in the eastern part and the channel toward the central part of the bay; c) detailed reconstruction of the present hydrodynamics; d) simulation of hydrodynamics as modified by the inflow of processed waste water.

*Acknowledgments.* – We are grateful to Mr. A Geveci, head of the Environmental Engineering Dept. at the Marmara Research Center for his help throughout this project. This research has been financed through a grant from TÜBITAK, Turkey, the World Bank and the National Science Foundation of Croatia.

## REFERENCES

1. Resmi Gazete, *General Water quality Criteria*, 4 July 1988, p.42.
2. EPA, *Water Quality Criteria for Water*, Environmental Protection Agency, Washington, 1976.
3. E. Morkoç, S. Tuğrul, O. S. Okay, and T. Legović *Eutrophication of the Izmit Bay, Marmara Sea. Croatica Chemica Acta* **70** (1997) 347–359.
4. D. Justić, N. N. Rabalais, R. E. Turner, and Q. Dortch Estuarine, *Coastal and Shelf Science*, **40** (1995) 339–356.
5. D. Shepard, *A two dimensional interpolation function of irregularly spaced data.* Proc. 23 Nat Conf of the ACM, ACM Press, New York, 1968, pp. 517–524.
6. A. Okubo, *Diffusion and Ecological Problems: Mathematical Models*, Springer, Berlin, 1980.
7. T. Legović and N. Limić, *International Journal of Environmental Pollution* **1** (1991) 87–96.
8. T. Oğuz and H. I. Sur, *A numerical modelling study of circulation in the Bay of Izmit.* Rep. no. 187, Marmara Res. Center, TÜBITAK, Gebze, Turkey, p. 97.
9. S. R. Quasim, *Wastewater Treatment Plants: Planning, Design and Operation,* CBS College Publication, New York, 726 pp.
10. T. Legović and N. Limić, *RECON Users Manual,* ITEA, Zagreb, 1992, p. 102.
11. T. Legović, E. Morkoç, O. S. Okay, L. Egesel, V. Tufekci, and H. Tufekci, *Water Science and Technology*, **32** (1995) 193–198.

## SAŽETAK

**Prema optimalnom upravljanju ukupne suspendirane tvari u priobalnom moru: slučaj zaljeva Izmit u Mramornom moru**

*Tarzan Legović, Enis Morkoç, Oya S. Okay, Leyla Egesel, Huseyin Tufekci, i Vildan Tufekci*

Promatra se raspodjela i transport ukupne suspendirane tvari (TST) kako bi se predložila strategija koja bi nakon implementacije dovela do zadovoljavanja postojećih kriterija kvalitete mora uz obalu.

Trenutno, glavnina vode u zaljevu ne udovoljava standardu. Zaključuje se da glavnina TST ne potječe direktno od izvora uz obalu već predstavlja plankton. S druge strane, ukupan fosfor u vodi s uspjehom je povezan s obalnim izvorima fosfora. Prema tome, strategija se usmjerava prema smanjenju izvora fosfora.

Kao najjeftinija mjera predlaže se redukcija ukupnog organskog ugljika iz otpadnih voda. To bi induciralo znatno smanjenje donosa fosfora. Predloženo je da se tako obrađivane vode ispuštaju u vodeni sloj ispod halokline i to u obliku jednog ispusta u istočnom dijelu zaljeva te jednog ili više ispusta u središnjem dijelu zaljeva.