A Case Study of Contaminant Transport Modelling;

Tuzla Oil Spill

M.C. Kazezyılmaz[1], Ş.B. Güleç[2], E.N. Otay[3]

ABSTRACT

On February 13th, 1997, a tanker named TPAO exploded in Tuzla shipyards located on the northeastern coast of the Sea of Marmara. During the fire, an estimated amount of 215 tons of oil was spilled into the Aydınlık Bay. Based on field observations and computer simulations, the present paper investigates the water circulation and the distribution of contaminant concentrations in time steps following the accident. Two separate model grids are developed for the Sea of Marmara and the Aydınlık Bay to account for both the large scale effects of the water circulation and the local conditions determined by the physical boundaries. The simulation results for the distribution of surface currents and the fate of oil spill showed that the contamination mainly affected the immediate vicinity of the Aydınlık Bay. The shape of the bay and the local wind and current climate are found to be the key factors to limit contamination within the bay waters. Model runs for possible oil spill scenarios in the Sea of Marmara showed that the most critical point is located at the southern entrance of the Strait of Istanbul. At this location, strong coastal currents generated by the natural channel hydrodynamics, force the contaminant to take a shore parallel course either westerly or easterly depending on the wind induced circulation in the Sea of Marmara.

INTRODUCTION

Marmara Region (Figure 1) is an important coastal settlement in Turkey with rapidly increasing population and industrial activities. Being enclosed by this most industrialized region in Turkey, the Sea of Marmara and the Turkish Straits are subject to intensive navigation activity. With the recent increases in sea traffic, these waterways have become a prime site for oil spill pollution. In the Marmara Region, nearly 450 sea accidents have been reported within the last forty years. Some of these accidents resulted in historic oil spills with severe impacts on the environment. The present study investigates a recent accident in Tuzla, which is located off the Northeast Coast of the Sea of Marmara.

In this study, two separate model grids are developed, one for the Sea of Marmara and another one for the Aydınlık Bay to simulate the water circulation. Using the results of the hydrodynamic model, a contaminant transport model predicts the location and the concentration of the contamination for different time projections following the accident.

The main objective of the computer modelling is the prediction of the contaminant behavior, which is the key element for oil pollution control in case of an accident. This provides the opportunity to take the necessary immediate precautions by means of containment and removal. Once the model grids are developed, this study enables to develop scenarios for different physical conditions in the Sea of Marmara and the Turkish Straits (wind speed and direction, boundary conditions, type and amount of the spill etc.). The results of such a study can be used as a basis for a Regional Oil Spill Contingency Plan.

[1] **Grad. Asst., Dept. of Civil Engg,, Boğaziçi Univ., Istanbul, Turkey**
[2] **Grad. Asst., Inst. of Env. Sci., Boğaziçi Univ., Istanbul, Turkey**
[3] **Asst. Prof., Dept. of Civil Engg,, Boğaziçi Univ., Istanbul, Turkey**

Figure 1. Location Map of the Sea of Marmara and the Turkish Straits

SITE CONDITIONS DURING THE ACCIDENT

Aydınlık Bay, Tuzla, located Northeast of the Sea of Marmara, accommodates nearly 40 shipyards (Figure 2). On February 13th 1997, the tanker named TPAO exploded at the Gemsan Shipyard where it was anchored for repair work. The explosion set the tanker on fire followed by oil spill. The fire extinguishing efforts continued for four days resulting with loss of human life and economic damages. A portion of the oil found on the ship was burned during this fire the rest was mixed to the sea water. The financial and ecological costs of the accident caused by the oil contamination are still under legal investigation.

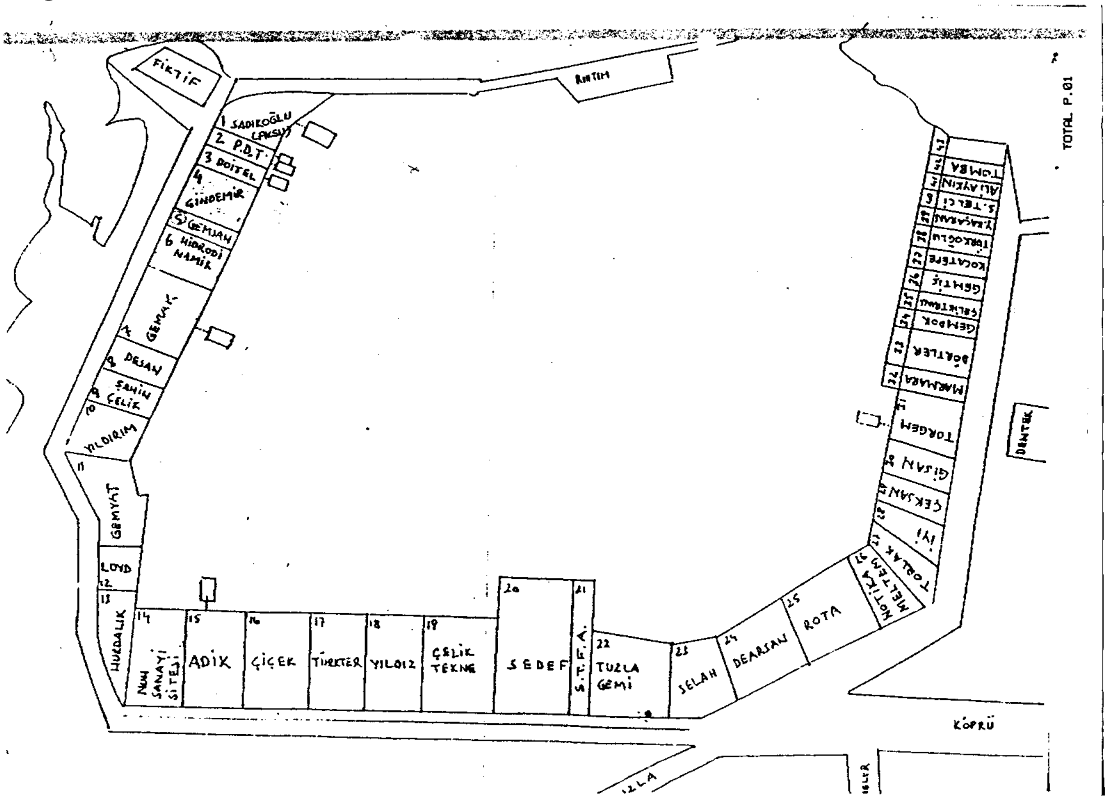

Figure 2. Location Map of the Shipyards at the Aydınlık Bay

According to the ship records the tanker was carrying 583 tons of fuel-oil, 29 tons of diesel oil and 9 tons of engine oil summing up to a total 621 tons of contaminant at the time of the accident. The spilled amount was estimated as 215 tons and the rest was burned during the fire (Aydın et al., 1998).

To investigate the physical conditions at the time of incident, wind data is obtained from the Göztepe meteorological station located approximately 30 km West of Tuzla. The data indicates winds from South–Southwest at the time of the accident and during the next two days. The surface wind is estimated to be 0.6 m/s when the accident occurred. The wind velocities during the following two days are given as 3.8 m/s and 0.25 m/s respectively.

COMPUTER MODELS OF THE SEA OF MARMARA AND THE AYDINLIK BAY

In this study, two numerical models are used to simulate the current circulation and the contaminant transport. Both models are developed by the United States Army Corps of Engineers (USACE), (Thomas and McAnally, 1990).

The first of these models, RMA-2, is a two-dimensional, depth averaged, free surface finite element model, which can simulate the current circulation. After a finite element mesh has been constructed and boundary conditions and material properties have been defined, the water surface elevation and flow velocity at each grid point can be computed.

Based on the hydrodynamic solution obtained by RMA-2, a second numerical model, RMA-4 is used to simulate the contaminant transport. The contaminant transport model requires as input the initial spill conditions as a set of point loads in addition to the physical parameters used in the hydrodynamic model.

Modelling of the Current Circulation

For the simulation of the sea water circulation, two different model grids are developed; a coarse mesh for the Sea of Marmara and a fine mesh for the Aydınlık Bay in Tuzla. The inputs are the bathymetry of the region, the wind data, turbulent exchange coefficients, friction coefficient and the boundary conditions, which are the head difference and the flow rate. In order to construct the finite element mesh, nautical charts by the Turkish Naval Forces Command are used. The governing equations for shallow water circulation model are given as follows:

Continuity Equation: $\frac{\partial h}{\partial t} + \frac{\partial (uh)}{\partial x} + \frac{\partial (vh)}{\partial y} = 0$

Linear Momentum Equations:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -g\frac{\partial h}{\partial x} - \frac{\varepsilon_{xx}}{\rho}\frac{\partial^2 u}{\partial x^2} - \frac{\varepsilon_{xy}}{\rho}\frac{\partial^2 u}{\partial y^2} + \frac{\tau_{sx}}{h} - \frac{\tau_{bx}}{\rho h}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -g\frac{\partial h}{\partial y} - \frac{\varepsilon_{yx}}{\rho}\frac{\partial^2 v}{\partial x^2} - \frac{\varepsilon_{yy}}{\rho}\frac{\partial^2 v}{\partial y^2} + \frac{\tau_{sy}}{h} - \frac{\tau_{by}}{\rho h}$$

where,
t is the time
x, y are the horizontal directions
u, v are the water particle velocities
h is the water depth
g is the gravitational acceleration
ε_{xx}, ε_{xy}, ε_{yx}, ε_{yy} are the turbulent exchange coefficients

τ_{sx}, τ_{sy} are the surface shear stresses due to wind
τ_{bx}, τ_{by} are the bottom shear stresses
ρ is the water density

For the Marmara Model, the boundary conditions are given in terms of head difference between the Strait of Istanbul (Bosphorus) and the Strait of Çanakkale (Dardanelles) and the outflow rate at Dardanelles. These parameters are assumed to have relatively small effects on the final distribution of the contaminant concentrations in the fine grid model with respect to the main forcing caused by the wind shear. Wind conditions are taken for the accident day and the following two days. As a result, the distribution of the water velocities in the Sea of Marmara is obtained for 72 hours (Figure 5.).

For the Tuzla Model, the hydrodynamic conditions at the open boundary are obtained from the results of the Marmara Model. The same wind conditions are used previously in the Marmara Model. As a result, the current circulation in Aydınlık Bay is obtained for 72 hours of wind data (Figure 3).

Modelling of Contaminant Transport

The contaminant transport modelling is conducted with the RMA-4, a numerical model to simulate the migration and dissipation of the constituent for a given number of time steps by solving an advection-diffusion type differential equation. The model uses the following as input; the velocity distribution computed by the current circulation model, initial mass or concentration of the contaminant, the decay rate and the dispersion coefficient of the contaminant. For the TPAO oil spill, the amount of spill was 215 tons as indicated by Aydın et al. (1998). The governing convection-diffusion equation solved by RMA-4 is as follows:

$$h\left(\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} - D_x\frac{\partial^2 c}{\partial x^2} - D_y\frac{\partial^2 c}{\partial y^2} - \sigma + kc\right) = 0$$

where,

c is the concentration of the water surface contamination
D_x, D_y are the turbulent diffusion coefficients
t is the time
x, y are the horizontal directions
u, v are the water particle velocities
h is the water depth
σ is the local source or sink coefficient
k is the decay rate of coefficient

MODEL RESULTS

When the oil spill simulation is conducted for the Aydınlık Bay with the existing conditions of the accident, it is observed that the spilled oil has not been spread outside the Aydınlık Bay (Figure 4). This is due to the wind conditions, the amount of spill and the closed current patterns (Figure 3). Field observations confirm same type of behavior for the fate of the contamination indicating that the occurred spill had no large scale effect on other regions of the Sea of Marmara (Okuş et al., 1997). However, it was not possible to forecast the severity of its local effects on the Aydınlık Bay.

As it is stated before, the oil spill simulation is conducted for different locations (Silivri, Tekirdağ, Şarköy, Karabiga, Gemlik, Bosphorus) in the Sea of Marmara with the existing conditions after the modelling of current circulation (Figure 5). The evaluation of the findings of the Marmara Model put forth that the most critical point in terms of pollution is the entrance of the Bosphorus to the Sea of

Marmara (Figure 6a, 6b). This result was expected because of the strong surface currents at the entrance point.

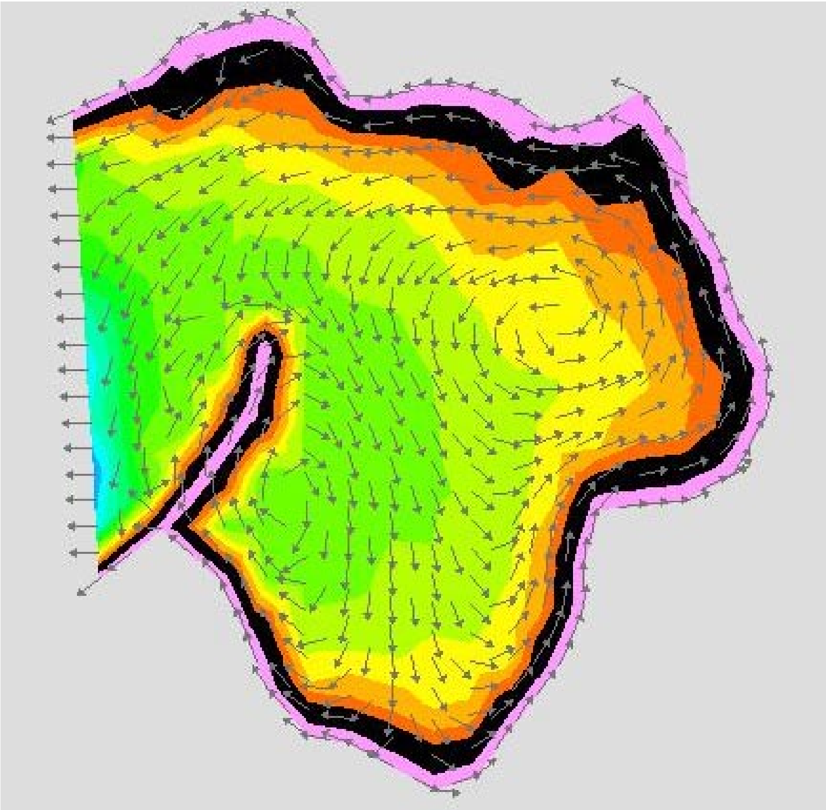

Figure 3. Current Circulation in Aydınlık Bay (Feb. 13th, 1997)

Figure 4. Contaminant Concentration Distribution in Aydınlık Bay (33 hours after the spill)

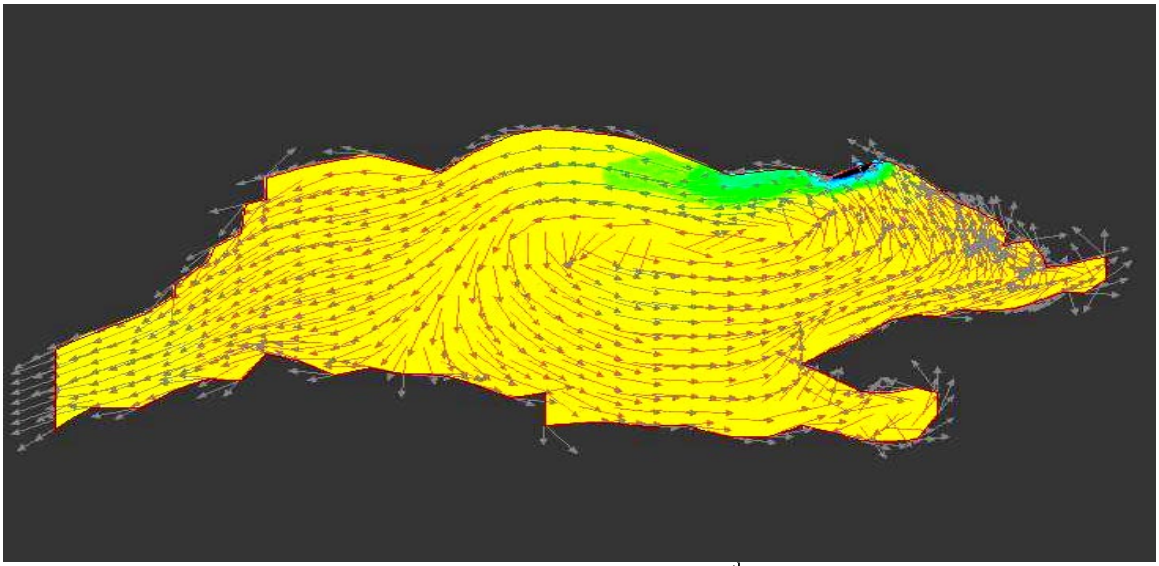

Figure 5. Current Circulation in the Sea of Marmara (Feb. 13th,1997)

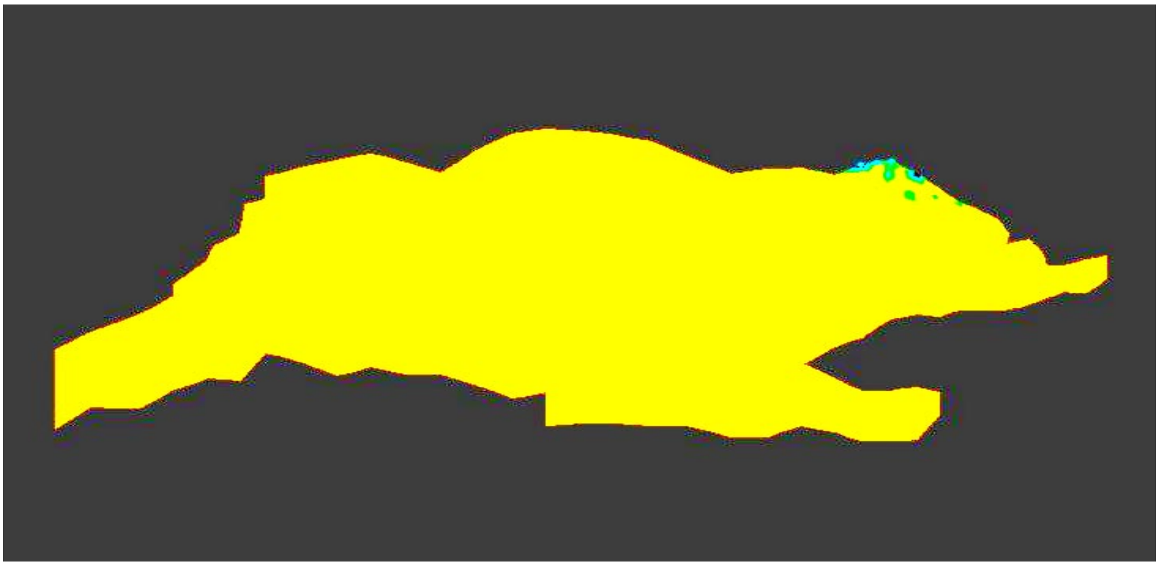

Figure 6a. Contaminant Distribution in the Sea of Marmara (12 hours after the spill)

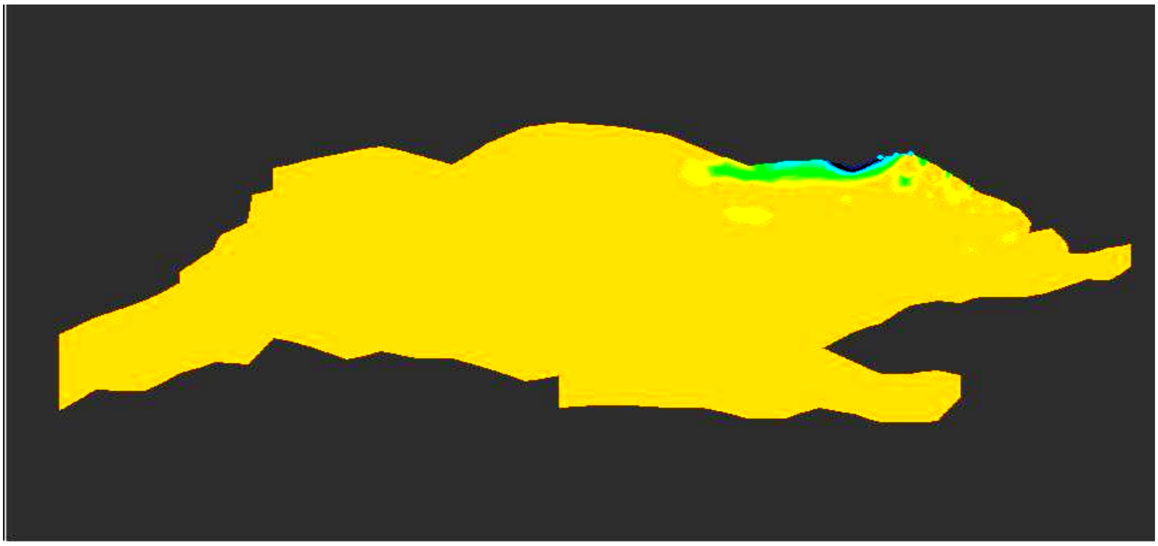

Figure 6b. Contaminant Distribution in the Sea of Marmara (33 hours after the spill)

RESPONSE AND RECOVERY

Ideally there are mainly six response alternatives to combat an oil spill (OSRL, 1995): (1) Monitor and evaluate, (2) disperse the oil with chemicals, (3) contain and recover the oil at sea, (4) protect vulnerable resources, (5) burning and (6) clean-up the shoreline.

In the case of the TPAO oil spill, it is seen that an ideal containment couldn't be performed, instead the oil was collected by skimmers only where ever it was observed at the sea surface (Sarıkaya et al., 1997). However, this operation was not fully effective to control the spill and the oil came to the shore. The shore portion of the oil was collected by mechanical pick-up equipment and through hydraulic cleaning. In Tuzla, the effectiveness of these clean-up operations is questionable due to the continuous contamination coming from the shipyards. The lack of the prediction of oil movement made it more difficult to control the spill.

During an oil spill accident, the following initial actions should be taken (OSRL, 1995); source isolation and containment, data collection, prediction of the trajectory of the oil spill, spill surveillance, consideration of strategies and equipment requirements and finally the response. These steps couldn't be carried out for the TPAO Spill, therefore it can't be called a planned response. The present study is an example of modelling efforts to help to predict the movement of the spill immediately after the accident following the data collection. This may be used for determining the strategy alone in the case where detailed surveillance is not possible and the response (containment, equipment planning etc.) can be planned according to the modelling results.

CONCLUSION AND FUTURE RECOMMENDATIONS

In the present study, hydrodynamic and contaminant transport models of the Sea of Marmara and the Aydınlık Bay were developed. The TPAO Oil Spill simulation is conducted for the Aydınlık Bay using the existing conditions of the accident. It is observed that the impact of the spill was localized within the Aydınlık Bay. This is mainly due to the mild wind conditions, the relatively small amount of the spill and the closed circulation patterns in the bay (Figure 3). It is a fact that the spill had no large-scale effects on the Sea of Marmara, however, it is not possible to forecast the long-term effects on the Aydınlık Bay.

The computer simulation of the oil contamination is shown in Figure 4. According to the observations made by Okuş et al. (1997), the affected area is located between the Sadıkoğlu and the STFA shipyards (Figure 2). When the predicted movement of the oil slick is compared with the observed distribution of the contamination, it can be concluded that the model findings are consistent with the actual observations.

Several oil spill scenarios are simulated for different locations and wind conditions at the Sea of Marmara. Model results showed that the most critical point is the entrance of the Bosphorus Strait. This is reasonable due to the strong currents at this point (Figure 5).

The response to the TPAO spill can not be called a planned response. Modelling efforts can effectively contribute to the response and planning phases and they can be used for determining the strategy, the containment locations and the equipment planning.

The use of computer modelling in oil spill predictions can be integrated into a *National Oil Spill Contingency Plan.* In conjunction with the integrated computer simulation, a contingency plan should include components such as an early warning system combined with a rapid response mechanism to control the spreading of the oil in case of a tanker accident.

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