TÜBİTAK
MARMARA SCIENTIFIC AND INDUSTRIAL RESEARCH CENTER
CHEMICAL ENGINEERING RESEARCH DEPARTMENT

# TRANSPORT AND WATER QUALITY MODELLING IN THE BAY OF IZMIT

FINAL REPORT

by

Süleyman TUĞRUL
Enis MORKOÇ

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# ABSTRACT

A two-dimensional transport and water quality model developed by Delft Hydraulics Laboratory was used to assess the assimilative capacity and current pollutional level of the Izmit Bay. The model adapted to the bay was calibrated by using the measurements of 1986-1988. The findings of model and field studies demonstrate that the water circulation in the bay is highly influenced by horizontal water exchanges while the vertical flows are weak in summer due to permanent density gradients. The optimum vertical and horizontal dispersion coefficients were found to range from $10^{-5}$ to $10^{-6}$ $m^2$/sec, and from 4 to 500 $m^2$/sec, respectively.

From the application of the model, it can be concluded that about 90 tons of biodegradable organic carbon in particulate and dissolved forms find their way into the surface waters of the bay daily. However, in reality, they are not being received and purified steadily by the bay system. The quantities of nitrogen and phosphorus reaching the surface waters of the bay through discharges of wastewaters were determined to be 6 and 1.1 tons per day, respectively. According to the simulated chll-a concentrations and related phytoplankton biomass in the surface waters, the biological pollution under the present situation is as high as 6-8 times of the simulated 'natural' situation(zero discharge at all) in the eastern region of the bay, which is the most polluted part. As the waste loads are reduced or discharged into the bottom waters of the bay the phytoplankton production and related chll-a concentration show increasing trends with depth up to 15 meters in the summer months due to both sufficient light intensity in deep layers and consumption of dissolved inorganic nutrients in a short period in the surface layers.

The computed oxygen depletion rate 0.2 ppm/month in the central region of the bay well agreed to the observed rate in the region in the summer of 1987. Because of the low oxygen concentration in the deep water of the bay, the amounts of pollutants that can be given daily to the eastern region should be reduced to a level of 5% of the present waste loads used in the model so as to save water resources and improve water quality in the eastern and central parts of the Izmit Bay.

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## 1. INTRODUCTION

Over the last decades, eutrophication and deterioration of water resources have become increasing problems in semi-enclosed seas due to long residence time of water masses and significant land-based pollutants. Pollution is generally most severe in semi-enclosed marginal seas and coastal waters bordering highly polluted and industrialized zones. When the quantity of waste loads exceeds the self-purification capacity of a receiving water environment its water recources and natural ecological property are damaged.

Recently, a great attention has been paid to find out optimal solutions in water quality management in terms of efficiency and economy. However, due to the complex nature of the phenomenon affecting the water in the natural systems, basin planning involves a large and complex number of variables and considerations. One of the tools to solve water quality management problems is the use of mathematical models. It can be utilized to assess present conditions and assign future waste loading and/or treatment requirements to provide the desired water quality standards in any environment. The assessment of the capacity of the marine environment to wastes will require maximum allowable concentrations on water quality criteria to be set. Characteristics of contaminants, their environmental distributions and fates,and definition of boundaries of the impacted area are essential components for the quantification of the capacity. The hydrodynamic feature of the receiving environment governed by the factors, topography, currents and gradients of physical properties of the system, provides the conditions for a set-up modelling of flow pattern and water quality processes.

Although, so far, many studies have been accomplished on the characterization and treatment alternatives of waste effluents very limited work has been performed on measuring the oceanographic characteristics of the Izmit Bay(1-3). Finding acceptable solutions to the pollution problems are unlikely without having knowledge of physical and biochemical properties of the Bay. Therefore in order to assess the assimilation capacity of the Bay and examine alternative submerged outfalls and pollutional loads, reliable temporal and spatial variations of the oceanographic parameters must be provided by long-term studies in the area.

During the last decades the disposal of waste waters into the Bay of Izmit (see Figure 1) has increased seriously as a result of urban and industrial developments in the area. Both the solid and liquid wastes mostly find their way into the bay without any treatment. Consequently, the water quality and ecological system in the bay are gradually deteriorating, which have caused great concern to local and national authorities.

For the water quality management of the Izmit Bay a systematic research programme has been conducted to provide necessary data for the hydrodynamics and weter quality model, by which the assimilation capacity of the bay and effect of wastes on the water quality can be assessed.

In order to make a mathematical model more reliable for the water quality management it should describe the spatial and temporal variations on the relevant lenght and time scales of such parameters as salinity, temperature, dissolved oxygen, dissolved inorganic nutrients, phytoplankton biomass, particulate and dissolved organic carbon. The model must be calibrated and ultimately the simulated results should be verified by the relevant field data.

The field surveys performed between May 1984-July 1988 have shown that the bay water is highly stratified throughout the year and has low oxygen concentration in the deep layers(4-6). Lowering in the dissolved oxygen concentration in the deep waters of the bay mainly results from the mineralisation of organic matter, which directly or indirectly originates from waste disposal to the bay waters. Therefore, a more detailed analysis of dissolved oxygen in relation to waste inputs seems to be essential step in defining the needs for waste water treatment. Due to the complex interactions occuring in the aquatic environments the use of mathematical modelling techniques can be very helpful in determining the impact of pollutant inputs on ambient water quality. In this respect a modelling study was formulated as a part of the project "The determination of oceanographic characteristics and assimilation capacity of the Izmit Bay" within the framework of the NATO TU-WATERS project named "Waste water treatment and disposal studies" supported by the NATO- Scientific Affairs Division. At the beginning of the modelling study the Marmara Research Institute of TUBITAK, Gebze, collaborated with the Delft Hydraulics Laboratory, Dellft, Holland, to set up a water quality model for the Bay of Izmit.

In order to assess water quality of the Izmit Bay and use the results of the measurements in the modelling study, the measurements carried out during May 1984-July 1988 period were examined and unreasonable ones were excluded. The physical and biochemical parameters measured were evaluated and compiled in such a format that facilitates the calibration of the model. The technical report describing physical and biochemical characteristics of the Bay has been published recently(8).

The water transport model developed and adapted to the Izmit Bay by Delft Hydraulics is a two-dimensional and multi-layer model to calculate conservative and nonconservative parameters as a function of time. The results from calculation with the two-dimensional transport model acted as input to the water quality model used for the calculation of dissolved oxygen, phytoplankton production, detritus organic carbon, nutrients in (in)organic forms in various sections and water layers of the Bay segmented for the modelling study.

The description of the transport and water quality model given in the present report was prepared by the Delft Hydraulics Laboratory, Holland. Therefore, Part 2.1, Chapter 3 and description of Input File given in Appendix were quoted from the technical report of Markus et al.(7). The present report covers the general backgrounds of the model together with calibration and some application studies for the summer period, namely between April-October months as well as the results of sensitivity analyses computed for dispersion coefficients and some constant parameters used in the model, and the simulated results of three scenarios; no waste discharge at all(natural situation), the present situation computed by the estimated waste loads and various amounts of waste discharges to the surface and bottom water layers of the Izmit Bay. Ultimately, maximum allowable waste loads, which very likely improve the water quality of the Bay system, were estimated by the model.

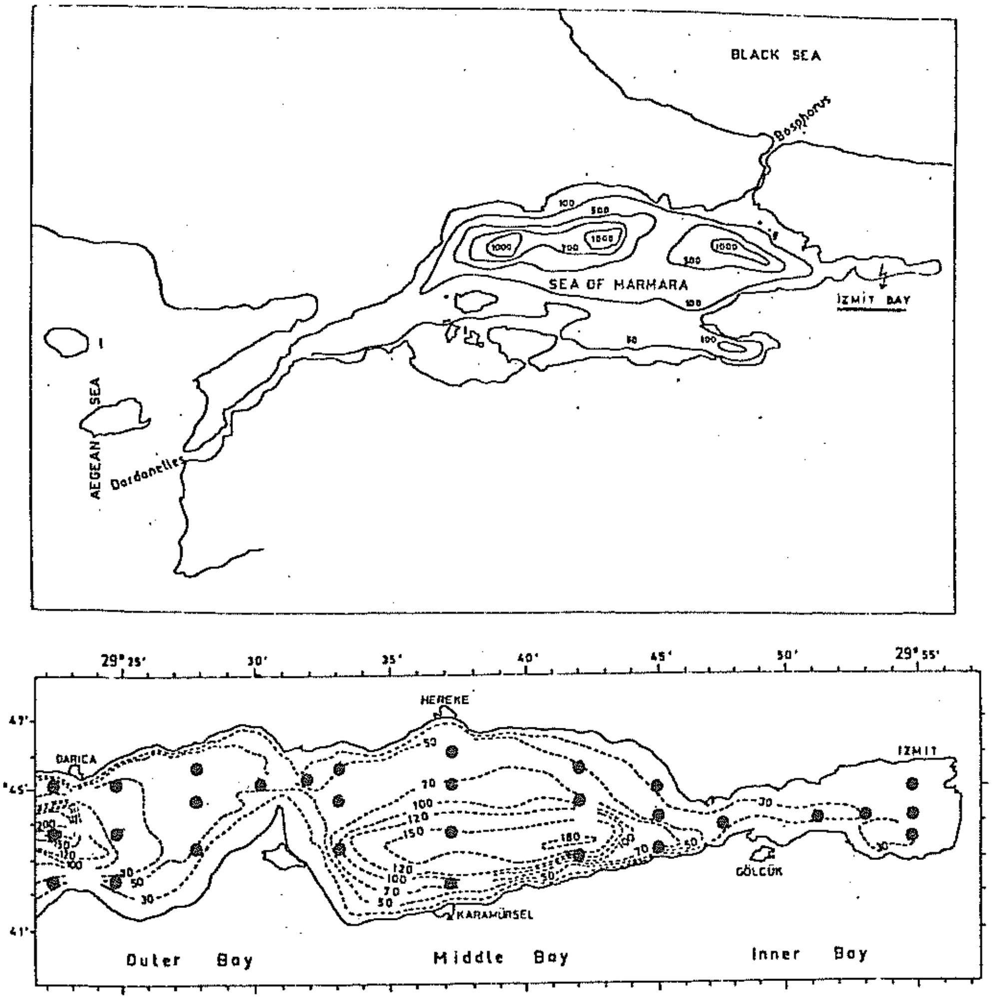


Figure 1a. Location of the Izmit Bay and sampling stations of 1984-1988 field survey.

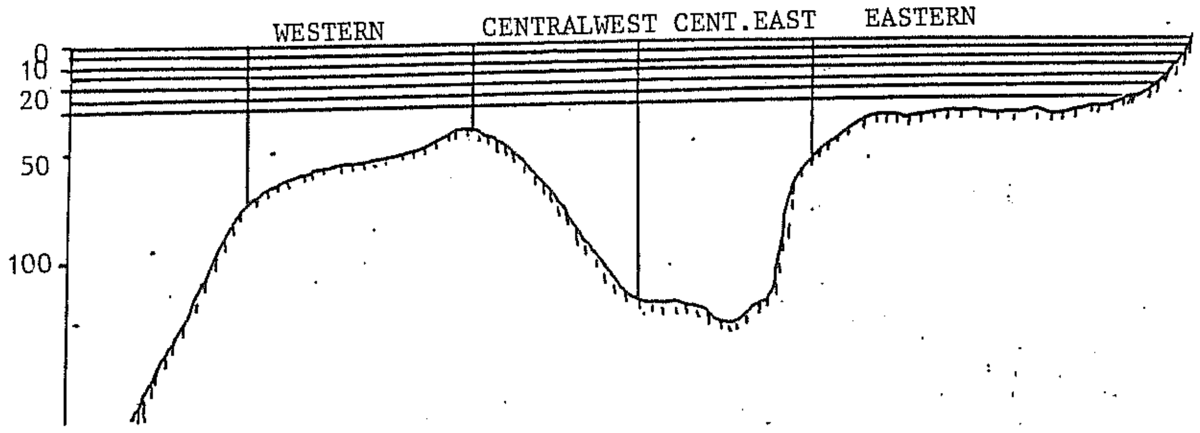


Figure 1b. Discretisation of the Izmit Bay within the waterquality model.

## 2. MODELLING OF THE TRANSPORT PROCESSES

Recently Delft Hydraulics has developed a set of models to simulate the water quality and ecology in the North Sea(9,10) and a salt water lake in the deltaic region of the Netherlands(11). To set up a water quality model for the Izmit Bay the framework of these models was used to develop PC and VAX versions which allow an easy transfer of the model from Delft Hydraulics Laboratory to the Marmara Research Institute, TUBITAK.

The model is a tool to solve numerically the set of partial differential equations that describe the transport and water quality processes in the bay. The description of the model is divided in two parts. In the next chapter we give an extensive outline of the water quality processes involved (e.g. the algal processes in the water and the bacterial processes in the bottom). In this chapter we describe the modelling of the transport processes.

### 2.1 General description

The basic principle of the mathematical description is the law of conservation of mass. From a certain volume the amount of matter can only change as a result of advective and dispersive transport, waste loads or water quality processes. In the first case the amount that disappears from this one volume should reappear in another volume. In the last case an amount of matter will be converted into another kind. For instance dissolved nitrate can be consumed by algae and is thereby converted into organic nitrogen. By the presence of waste loads the amount of matter is increased.

The complete partial differential equation therefore reads:

$$\begin{aligned} \frac{\partial C}{\partial t} = \; & \frac{\partial}{\partial x} \left( D_x \frac{\partial}{\partial x} - u_x \right) C + \\ & \frac{\partial}{\partial y} \left( D_y \frac{\partial}{\partial y} - u_y \right) C + \\ & \frac{d}{\partial z} \left( D_z \frac{d}{\partial z} - u_z \right) C + \\ & \text{water quality processes} + \\ & \text{waste loads} \qquad (1) \end{aligned}$$

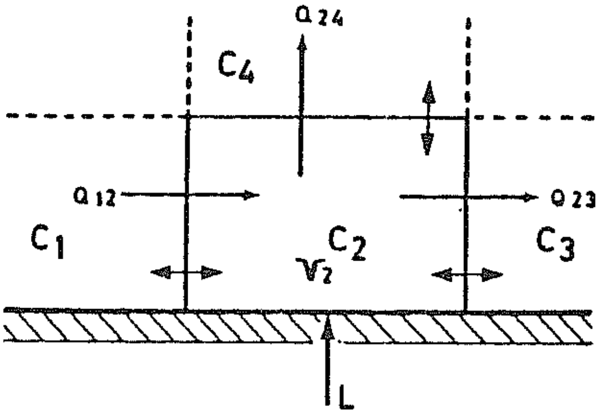
where:

$C$ - concentration of a water quality constituent ($g/m^3$)
$u_x$, $u_y$, $u_z$ - velocity components in the three spatial directions (m/s)
$D_x$, $D_y$, $D_z$ - dispersion coefficients in the three spatial directions ($m^2/s$)

In many cases the equation can be simplified. In situations without vertical stratification a two-dimensional vertically averaged model is often appropriate, because the water column is vertically homogeneous. In stratified systems the lateral gradients are often much weaker than the vertical or longitudinal gradients, allowing the application of a two-dimensional laterally average schematisation. Other simplifications can be made, especially with respect to the dispersion coefficient.

In most cases the dispersion coefficient is not known a priori. It has to be estimated by the use of a calibration procedure.
The dispersion coefficient accounts for a number of effects. Not only does it comprise the molecular and turbulent diffusion, it also comprises the effect of the schematisation of the model area. Details of the flow field that are smaller than the grid size can not be included in the description of the advective transport. Neither can the velocity profile be incorporated directly in the case of a vertically integrated model. Instead, analogous to turbulent mixing, the effects are modelled as a dispersive component of the total transport.

The numerical approximation of Equation 1 is derived as follows. First the model area is divided into segments. Second, Equation 1 is integrated over each of these segments and the resulting volume integrals are estimated. This is done by assuming that the concentration is constant within the segments, it only differs between segments. Then the volume integrals of the transport terms are converted into surface integrals by the use of Gauss's theorem. For a simple two-dimensional situation the resulting equation is given here (see also figure below):



$$\frac{d}{dt} ( V_2 C_2 ) = Q_{12} C_1 - Q_{23} C_2 - Q_{24} C_2 +$$

$$(\frac{DA}{\Delta x})_{12} ( C_1 - C_2 ) + (\frac{DA}{\Delta x})_{23} ( C_3 - C_2 ) +$$

$$(\frac{DA}{Dx})_{24} ( C_4 - C_2 ) + L_2 +$$

$$V_2 \text{ ( water quality processes )} \qquad (2)$$

Here:

$A_{ij}$ - area of the interface between the adjoining segments i and j
$C_i$ - concentration in segment i
$L_i$ - waste load in segment i
$Q_{ij}$ - flow rate over the interface between segments i and j
$V_i$ - volume of segment i
$\Delta x_{ij}$ - distance between the centers of segments i and j

In equation 2 the so-called upstream differences for the estimation of the transport terms are used. There are other methods for estimating the transport terms(12). They differ in accuracy and other characteristics, but each method has it's own advantages and disadvantages. The differences arise from the treatment of the advective transport terms.

The equations for the different constituents within one segment can be linked to one another by the water quality processes. The equations for the different segments are linked by the transport processes. In the model an explicit method is used to integrate all these equations. The terms that appear on the right-hand side are evaluated at time level t to give an estimate of the time derivative and therefore:

$$V^{t+\Delta t}\,C^{t+\Delta t} = V^{t}\,C^{t} + \Delta t\,\left[\,\frac{d}{dt}\,(\,V\,C\,)\,\right]^{t} \qquad (3)$$

This method is generally applicable and accurate, but the timestep Δt should not be too large, because then the method becomes unstable.

The transport processes are in general not specific for a constituent, but there is a notable exception. Particulate matter can sink to the lower regions of the water column, whereas dissolved matter can not. This aspect of the transport processes is dealt with separately, that is to say, it is treated as a water quality process (see next chapter).

## 2.2 Physical Characteristics of the Bay

The findings of four-year observations reveal that the Bay of Izmit, as being a part of the Marmara Sea, is influenced to a large extent by the water exchanges taking place between the Black Sea and Aegean Sea(4-6). Although the Bay dictates a permanent two-layer stratification throughout the year, the degree of stratification and the characteristics of water masses show considerable inter annual variations, particularly in the upper layer(4-6). In order to see the temporal variations of temperature(T) and salinity(S) in the surface along the Bay, the average values measured at one meter depth were depicted in Fig. 2. The spatial variations are generally ∓0.5 ppt and ∓ 0.3 °C for salinity and temperature, respectively. As can be seen from the figure, the summer season corresponds to relatively higher temperature( 20-24 °C ) and lower salinity (22-24 ppt), which is caused by the brakish waters originating from the Black Sea. It can be noted that, particularly during the summer period, there is a opposite correlation between temperature and salinity in the surface waters within the Bay. It is the results of strong northeasterly wind, vertical

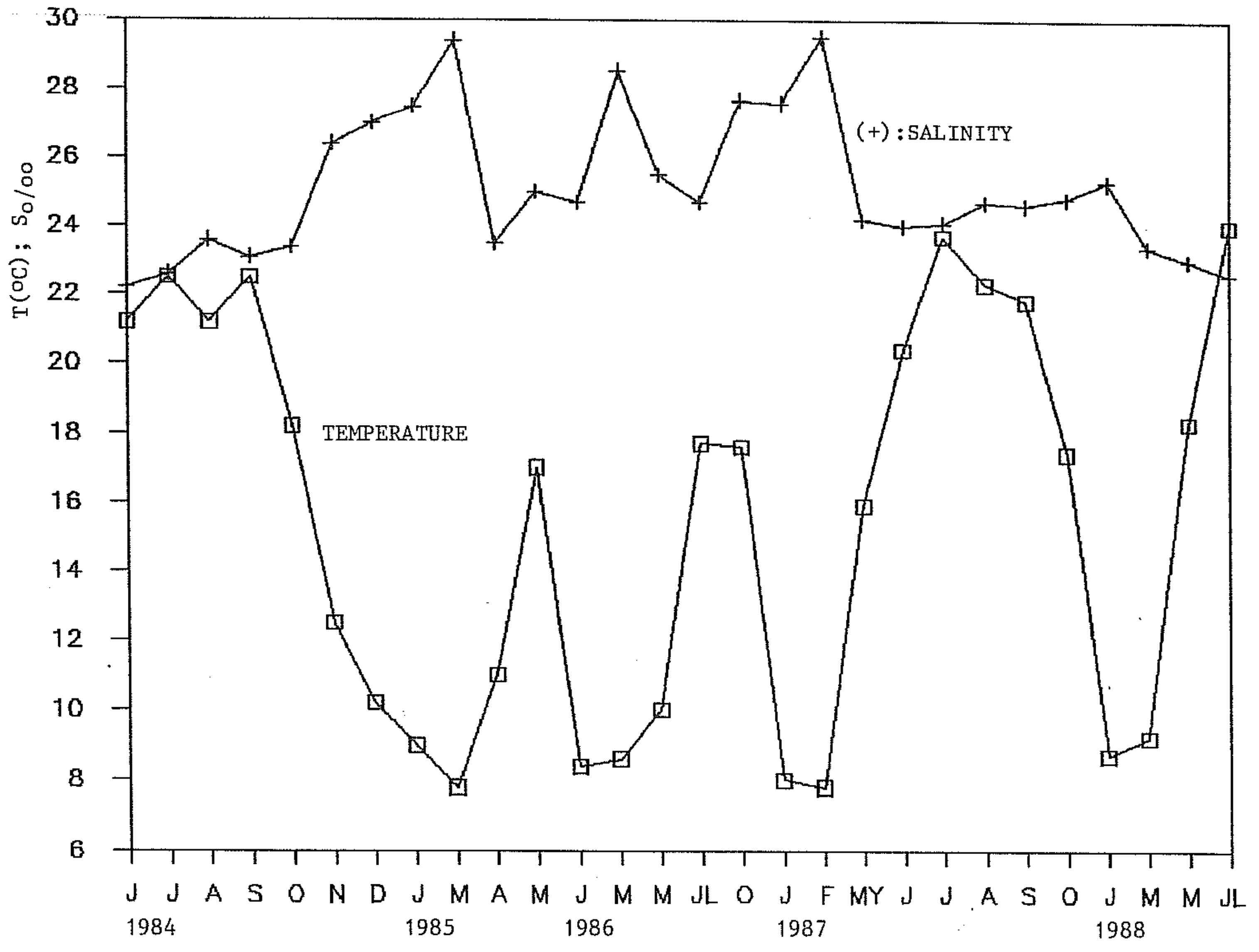


Figure 2. Monthly variations of mean temperature and salinity in the surface waters(1m) of the Bay.

mixing, and thus low horizontal water exchange with the open waters of the Marmara Sea. As the surface waters cool through vertical mixing, the surface salinity increases as a consequence of upward movement of high saline waters with relatively low temperature.

The spatial and temporal variations of salinity and temperature in the lower layers of the Bay(below 30 m) are not as drastic as those observed in the surface waters(see Fig. 3). The bottom waters influencing the Bay show little change in its character with 38-38.5 ppt salinity and 14.5-15.0 °C temperature values throughout the year. More details about the longitidunal variations of salinity-temperature can be seen in the technical reports(4-6).

In general terms, as discussed above, the known feature of the Izmit bay is the presence of two-layer current system associated with the two-layer stratification. During the spring-summer period, less saline waters of the Black Sea origin flow into the Bay. A compensatory lateral westerly outflow takes place mainly in the surface layers(first 15 meters) and weakens in the intermediate waters(15-30 meters) of the Bay, particularly during the April-June period. After June depending upon the hydrological conditions of the Bay at that time and meteorological conditions high saline waters of the Marmara Sea flow into the bottom layers(below 30 meters) of the Bay. It, thus, results in measurable salinity and temperature increases at 15-35 meters in depth, as well as considerable changes in biochemical parameters. For example, the dissolved oxygen concentration in the Bay shows significant decreases at 20-30 meters.

During the late autumn and winter, high saline waters of the Marmara Sea(38.5 ppt) flow into the Bay under the interface. This situation persists until the spring. Then a measurable surface flow starts again. Superimposed on these seasonal circulation patterns the wind stress on the free surface associated with internal seiches and wind induced currents cause short-term motions of the interface and thus inflow or outflow of the surface waters depending on the wind direction with certain speed, respectively, which may contribute, to a certain extent, to the seasonal mean circulation, in other words, hydrographic feature of the Bay.

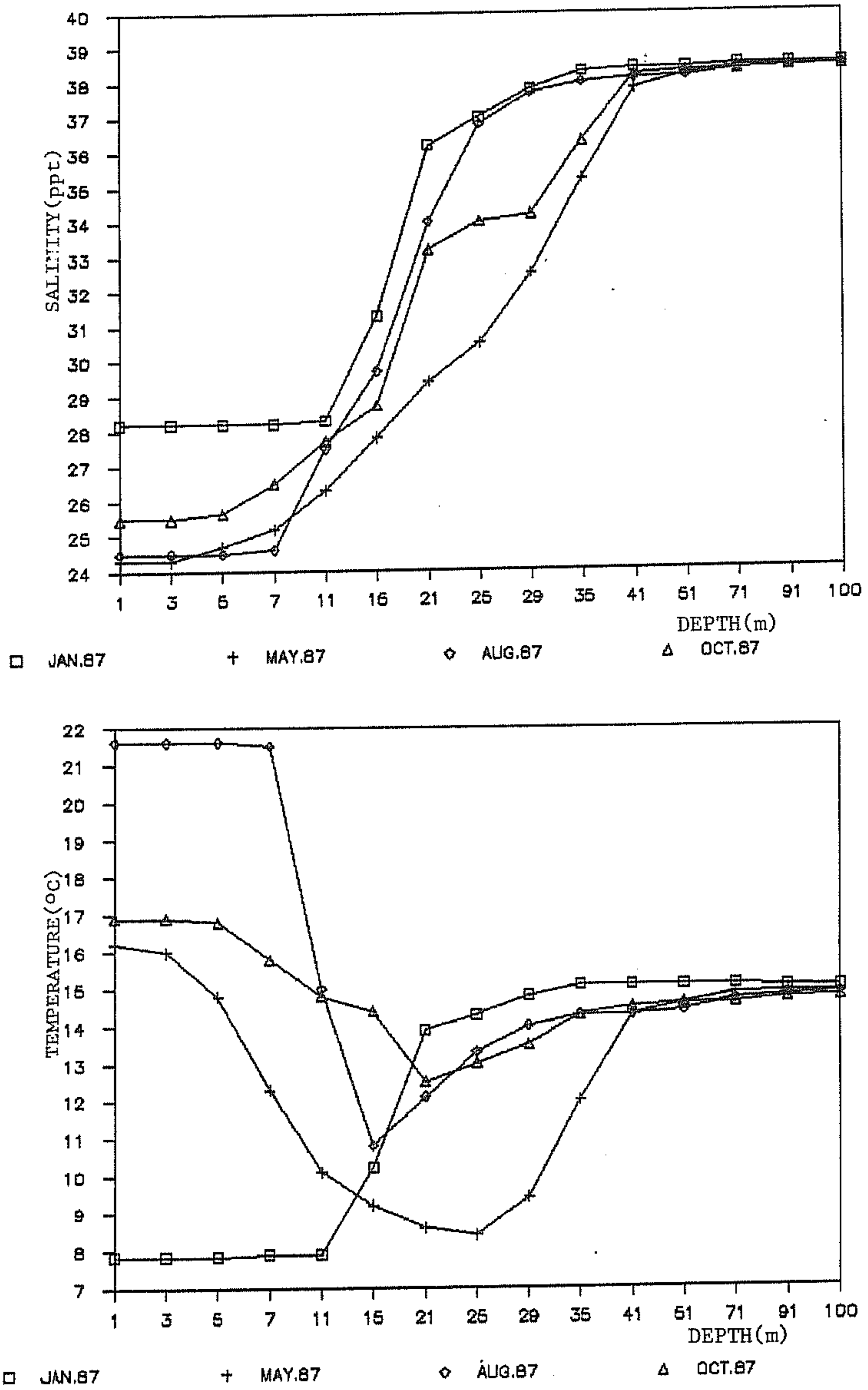


Figure 3. Salinity and Temperature profiles in the central part of the Bay.

## 2.3 Circulation Modelling Study

A numerical hydrodynamical model was developed for the Bay by the Marine Sciences Institute of METU so as to describe the seasonal and spatial distributions of flow fields and thereby to estimate the exchange rates of the water masses between various regions of the Bay(13). In the real world, though there is a multi-layer circulation within the Bay, a two-layer modelling approach is adopted in the study. Generally speaking, one of the essential repuirements in developing such a hydrodynamical model is to have reliable measurements and knowledge of observed dynamical features present in the region under consideration. This is important not only for the proper formulation of the dynamics in the model but also for prescribing the relevant input parameters as realistic as possible. The model can only then provide the results which may be consistent with the observed features to an acceptable degree of accuracy.

The circulation model of METU considers simultaneous solutions of the layer averaged continuity and horizontal momentum equations as well as the salt balance equations for the layers. It also takes into account the nonlinear convective terms, interfacial exchanges of mass and volumes, and bed, interfacial and wind stresses. Application of the model requires input of the following data: bottom topography, initial surface and interface elevations, observed salinities in the layers, specifications of the wind stress, coefficients of the bed and interfacial stresses and various constant parameters used in the model(13). The experiments performed can be categorized in four basic groups. The first group of experiments is related with the performance of the model and sensitivity studies. Various emprical constants and parametric settings were tested in the model to be able to achieve the optimum conditions. The second and third group experiments include simulation of observed winter and summer circulation patterns and associated water exchanges between the regions of the Bay as well as the layers. In the fourth group, the influence of typical observed winds on the seasonal circulations of the bay waters was investigated.

### 2.3.1 Summer Circulation

Numerous experiments were performed to obtain typical summer circulation patterns without taking into consideration wind effect in the model. A case study which results in approximately observed horizontal circulations within the

Bay is presented in Figure 4 (13). As can be seen from the figure, the surface waters flow into the Bay as the lower layer waters flow in the westerly direction and join finally to the open waters of the Marmara along the northwestern coast of the outer region. The water exchange rates computed from the simulation experiments, which generally represent upper rate limits under no wind effect, are also illustrated in Figure 5. However, the hydrographic results of 1984-1988 demonstrate that summer circulation evidently persists in the March-July period, later it almost ceases and wind induced currents dominate the water exchange and circulation in the surface layers of the Bay. According to the model, wind with 2-3 m/sec speed could not induce any appreciable change in the water circulation of deeper layers due to the hydrographic feature and boundary conditions at the entrance of the Bay.

### 2.3.2 Winter Circulation

Simulation of winter circulation was carried out by taking into account the current and hydrological data obtained in November-December months(13). The high saline waters of the Marmara Sea flowing from deep layer enter the Bay and return to the open sea from the upper layers by following the circulation patterns illustrated in Figure 6. Based on this simulation experiments, the water trasport rates between the segments of the Bay, as well as across the interfaces were also computed( see Figure 7).

### 2.3.3 Influence of Wind on the Circulation

The predominant wind regime of the area is the northwesterlies throughout the year(refer to Table 1). According to the model results, the relatively stronger daily easterly and northeasterly wind episodes over 5 m/sec may have short-term effects on the current systems if it prevails along the Bay more than one day. The wind induced circulation pattern given in Figure 8 shows significant differences as compared with the wind-free summer circulation depicted in Figure 4, whereas it accelarates the wind-free winter circulation. But, contrary to northeasterlies, the westerly wind episodes have a considerable effect on the winter circulation of the Bay and disturbs the winter hydrographic features. For example, in January 1988, the surface salinity value of the Bay was reduced to the typical summer salinity levels by the stronger westerly wind prevailing before the survey.

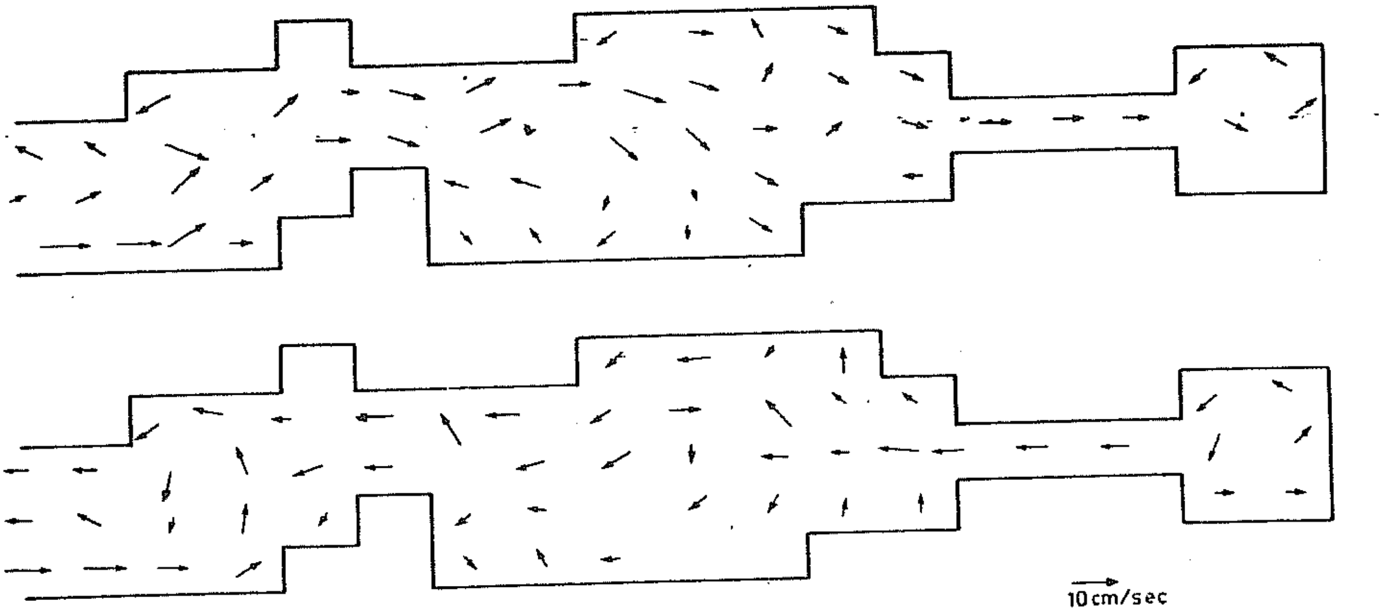


Figure 4. Upper and lower layer summer circulation patterns.

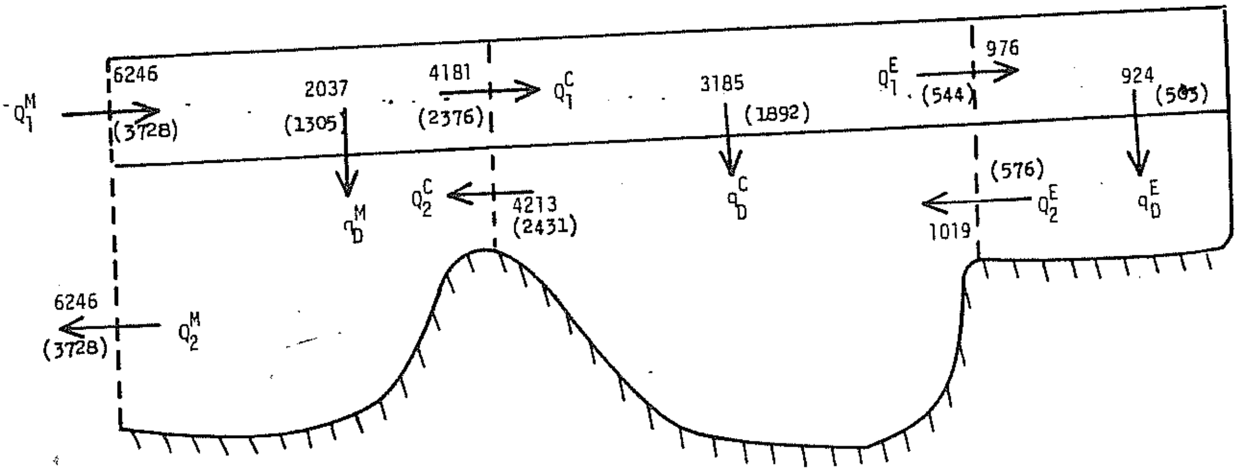


Figure 5. Computed flow rates for the summer circulation.

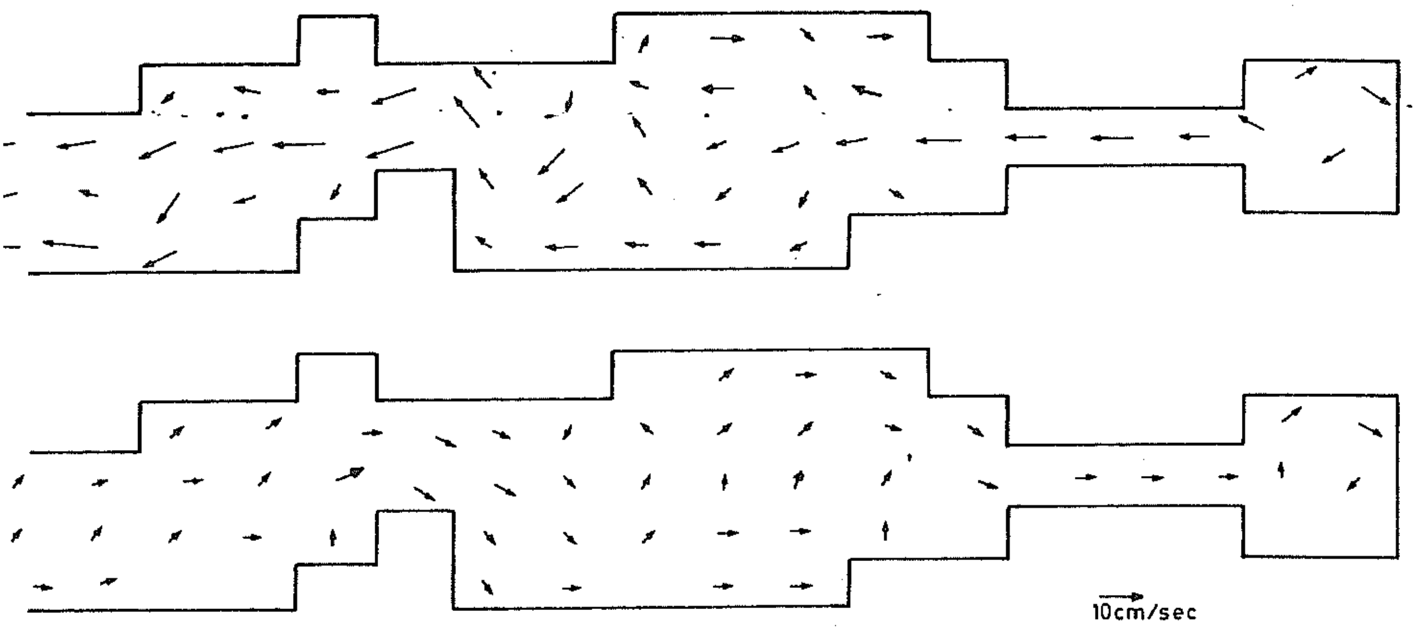


Figure 6. Upper and lower layer winter circulation patterns.

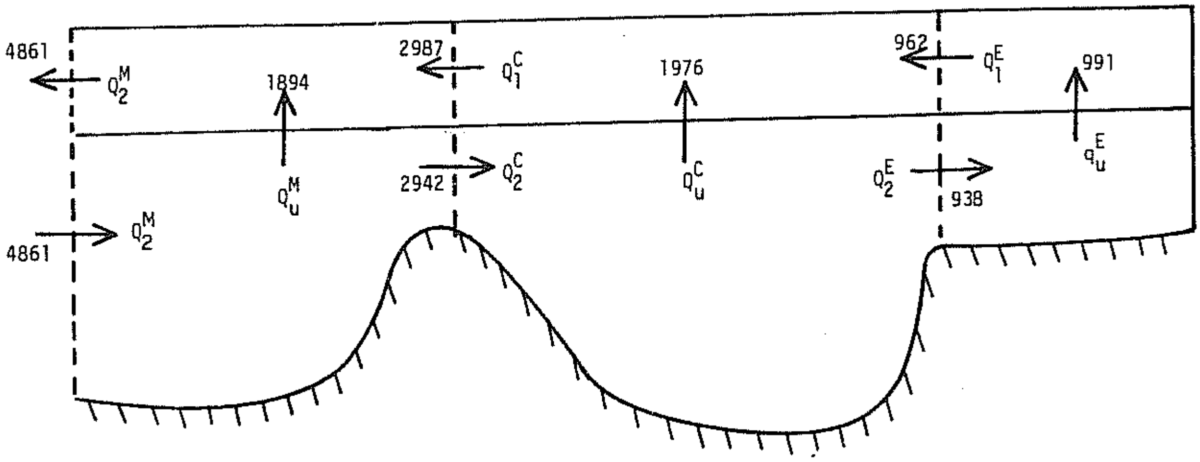


Figure 7. Computed flow rates for the winter circulation.

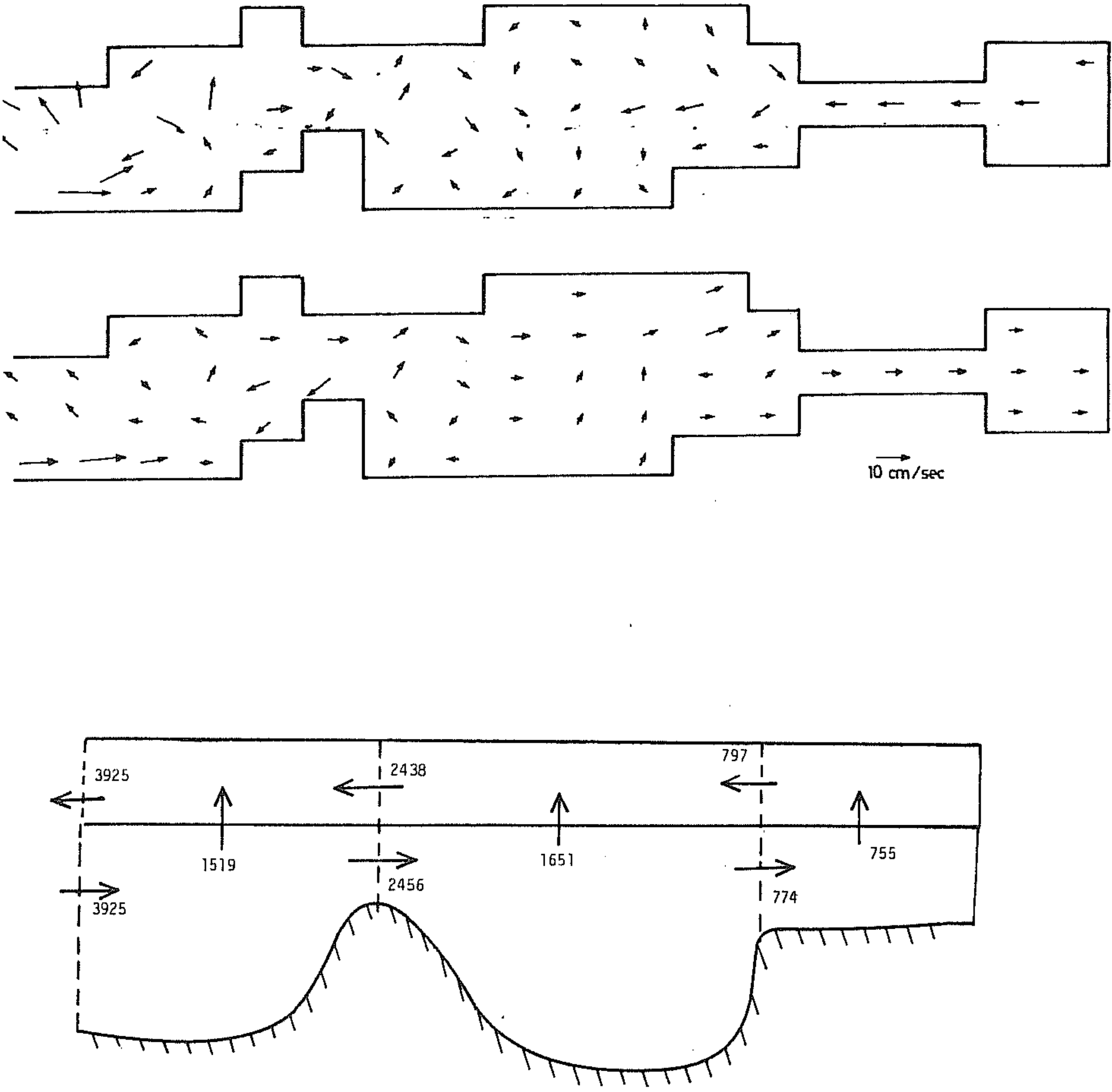


Figure 8. Upper and lower layer circulation patterns and computed flow rates for the northeasterly wind-induced summer circulation.

## 2.4 Transport Model of Delft Hydraulics

By taking into consideration the hydrographic characteristics of the Bay and the circulation model results of METU-MSI, a two-dimensional and multi-layer transport model used in the water quality study was developed and adapted to the Izmit Bay by Delft Hydraulics Laboratory to calculate conservative and nonconservative parameters of the model as a function of time. The concept of the transport model is given in part 2.1. From the results of METU-MSI it was determined that the exchange rate of water in the Bay with the Marmara is of the order of 2000-4000 $m^3$/sec (13). Since the total amount of water in the Bay is approximately 13 $km^3$, the residence time of water in the central and eastern parts of the Bay is estimated to be about 1-2 months. This estimate is illustrated by the fact that in March 1985 the surface salinity was 30 ppt in the whole bay, and one month later a value of 24 ppt was observed. The opposite trend was observed in October 1985. The simultaneous increase of dissolved oxygen concentration in the bottom waters from 0.2-0.5 to 1.0-2.0 ppm was a clear indication of the refreshment of the whole bottom waters below 30 meters from October to November 1985.The similar observations were also encountered in the surveys performed between 1986 and 1988. Thus, the observations led the decision to represent the Izmit Bay in the transport model by a laterally averaged discretisation (see Figure 1). Four horizontal parts are distinguished: the western section, which opens to the Marmara Sea, two central sections(centralwest and centraleast) and the eastern section, which is relatively shallow and receives the significant proportion of waste loads. This discretisation is in accordance with the oceanographic subdivision used in the first annual report(5). In order to account for the vertical stratification in the Bay, seven horizontal layers are distinguished. The first six layers are each 5 m thick and the seventh layer reaches to the bottom. The schematisation allows for enough detail within the Bay to approach the observed gradients.

### 2.4.1 Calibration of the Transport Model

Before simulating the biochemical processes related to water quality management of the Bay, the model adapted to the Bay of Izmit was first calibrated for the April-October period by using the results of salinity and temperature measurements. Because, in this period,particularly in September-October months as encountered in 1984, the anoxic conditions in the bottom waters of the Bay develop as a consequence of both the limited water exchange with the open sea and large amount of waste loads. The main objective of this first calibration was to see whether the salinity and temperature distributions that were observed could be approximated by the model. In this case, we could conclude that the transport processes are adequately described and used to simulate water quality processes within the Bay.

By using the results of 1987-1988 as boundary conditions and considering a residence time of approximately one month for the total surface waters of the Bay(first 10 meters), the model was first calibrated to determine reasonable vertical and horizontal dispersion coefficients which adequately approximated the simulated salinity and temperature results to the measurements within the Bay for the April-October period. The vertical dispersion coefficient, which is very small due to the buoyancy suppressing vertical turbulent mixing, was found to be about $(0.5\text{-}2.0)\times10^{-5}$ $m^2$/sec in the surface layers and $(0.1\text{-}1.0)\times10^{-6}$ $m^2$/sec below interface. These values reveal that the vertical flow in the Bay is very weak in comparison to the horizontal circulation. The values of horizontal dispersion coefficient range between 10-500 $m^2$/sec, depending on the surface area of interface between the segments and its location in the Bay. For the further calibration of the transport model we also made use of the dissolved oxygen data and the results of some biochemical parameters measured simultaneously with salinity and temperature in the Bay.

Typical salinity and temperature profiles, and their mothly variations in the first layer of the Bay,which were simulated by using adequate dispersion coefficients and boundary conditions derived from the measurements of 1987-1988, are compared with the measurements(see Figures 9-12). The figures show that the results of transport model are in a good agreement with the field data representing the real hydrological situations in the Bay. Although, in real world, the transport phenomenon within the Bay seems not to progress steadily, the transport model can be used to simulate water quality processes affecting the bay system with time.

### 2.4.2 Sensitivity Analysis

In order to find out acceptable dispersion coefficients that allow us to simulate the salinity and temperature variations along the Bay with time, the transport model was run with different values of coefficient by keeping horizontal or vertical coefficient at reasonable levels. Figure 13 demonstrates evidently that the vertical dispersion coefficient must range between $10^{-5}$-$10^{-6}$ $m^2$/sec. The values over $10^{-5}$ increase the residence time and salinity of surface waters within the Bay and water temperature of the intermediate layers in comparison with the measurements. When it is reduced to a value of less than $10^{-6}$ $m^2$/sec in the surface layers, heat transfer from surface layer to lower layers does not compensate for the increase in temperature in the intermediate waters observed throughout the Bay as a function of time.

Figures 14 and 15 depict the effect of horizontal dispersion coefficient on the water transport per unit time and thus on the distributions of physical and chemical parameters with time. Simulation with the larger dispersion values resulted in unreasonable salinity and temperature variations with time, with regard to the measurements. The computed salinity and temperature were found to be significantly less than the measured ones, particularly in the eastern part of the Izmit Bay, provided that a horizontal dispersion coefficient of 500 $m^2$/sec was used for the surface layers of the eastern region. In the surface waters, the salinity distribution simulated by the transport model with relatively low dispersion coefficients differed from the measurements due to increasing residence time of surface waters within the Bay . The concentration of dissolved oxygen in the bottom waters of the Bay(below 30 meters) is determined by the rate of horizontal water exchange as well as the biochemical reactions discussed extensively in the next chapter. The water transport rates used in the model also affect the distributions of biochemical parameters in the water quality processes modelled.

The mean wind speed and prevailing wind direction observed daily in the area are compiled in Table 1. A wind speed of 2 m/sec was used in the model to simulate the physical and biochemical parameters modelled, such as salinity, temperature, dissolved oxygen, phytoplankton concentration(biomass), degradable detritus, chll-a, (in)organic nutrients, particulate organic carbon, $BOD_5$ etc. However, to see the wind effect on salinity and water temperature in the surface layers through water transport, a wind speed of 4 m/sec, which is the upper limit of daily average in the area in question, was also used to calculate T and S variations with time. The results obtained with two different wind speeds are tabulated in Table 2. As seen from the table no significant change was observed in the values of salinity and temperature in the surface waters of the Bay. The solar radiation values used in the input file of the model were derived from the measurements given in Table 3.

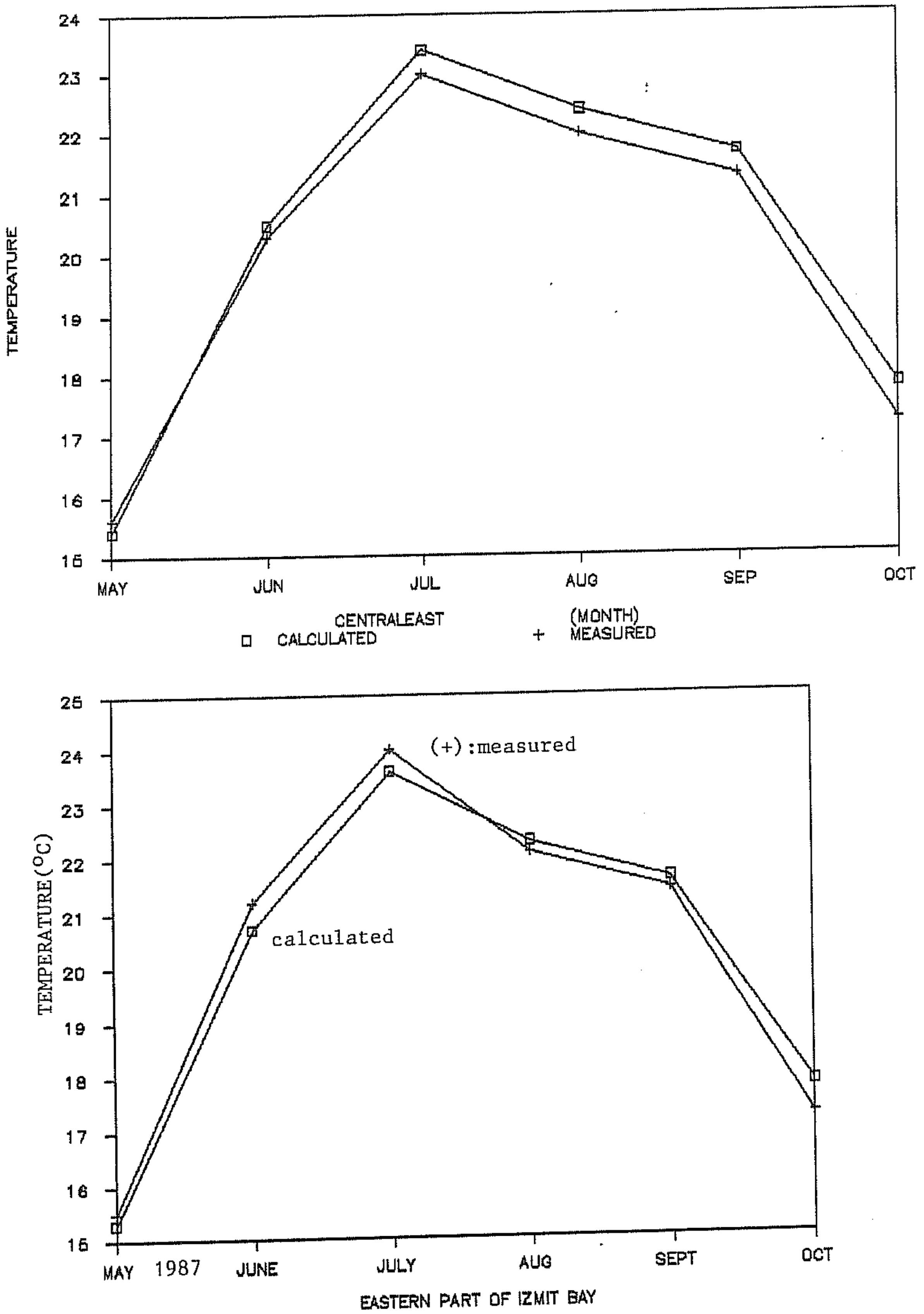


Figure 9. Comparison of measured and computed temperature in the surface water(0-5m).

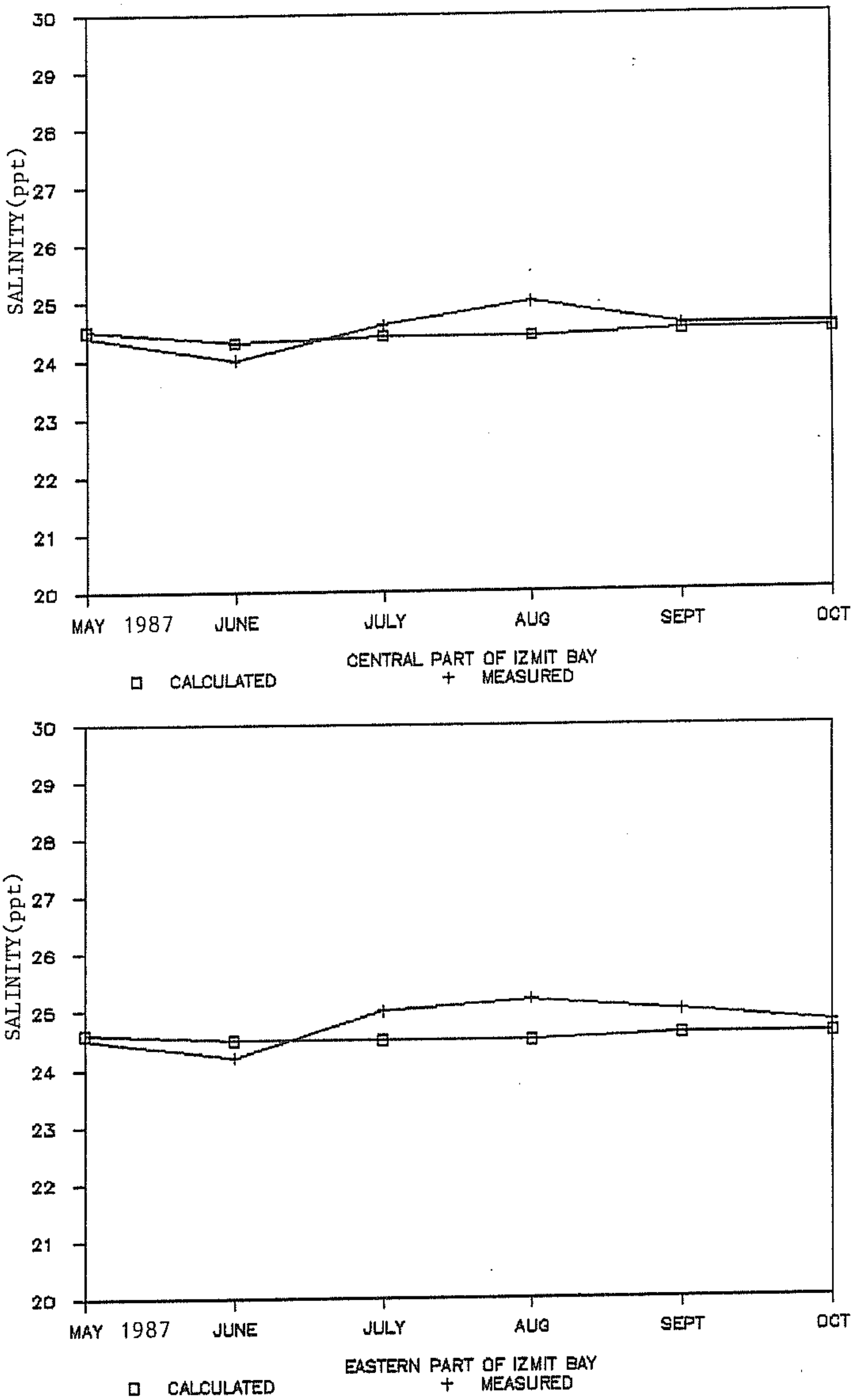


Figure 10. Comparison of measured and computed salinity in the surface waters(0-5 m).

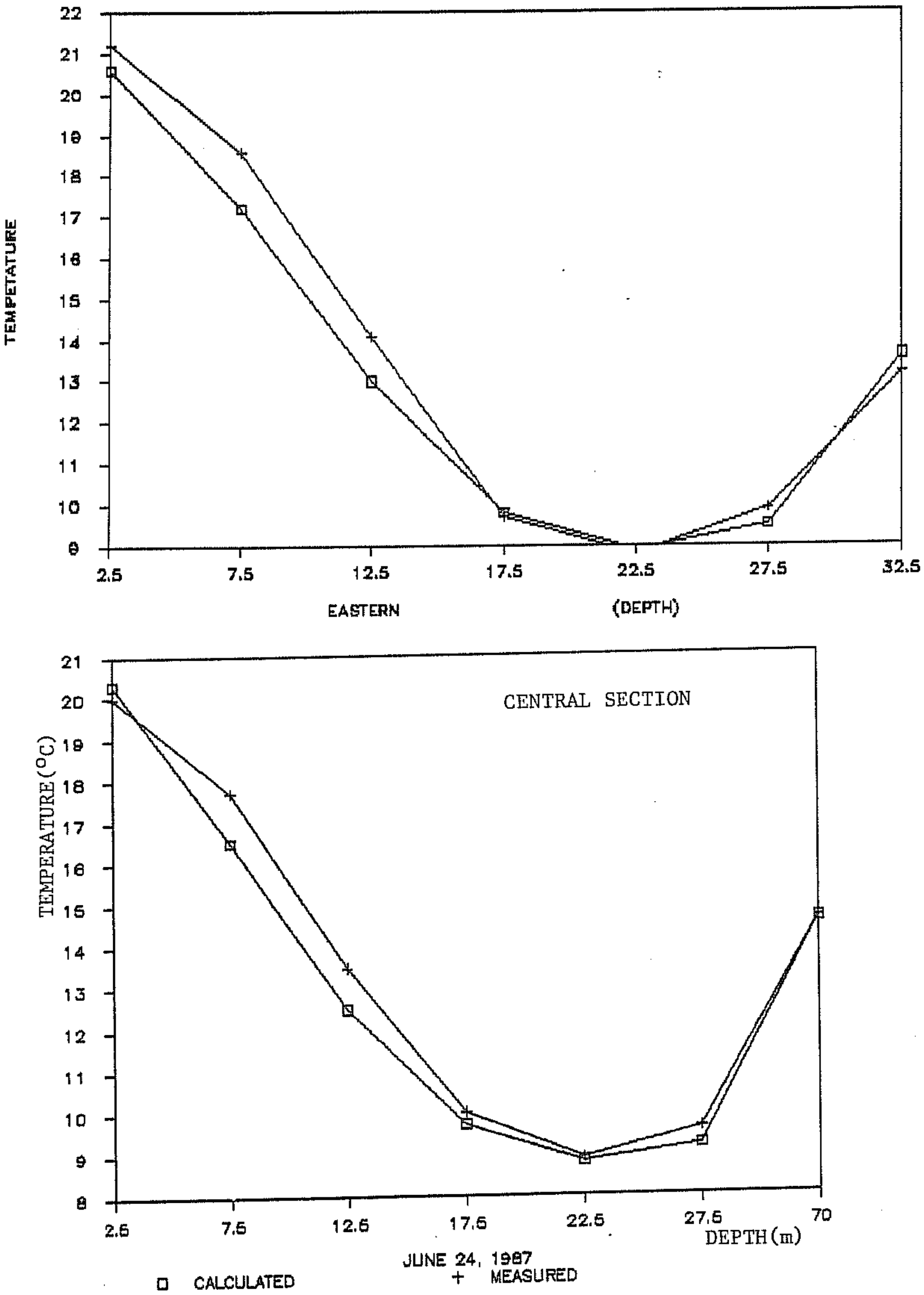


Figure 11. The calculated and measured temperature gradients in the central and eastern sections of the Bay.

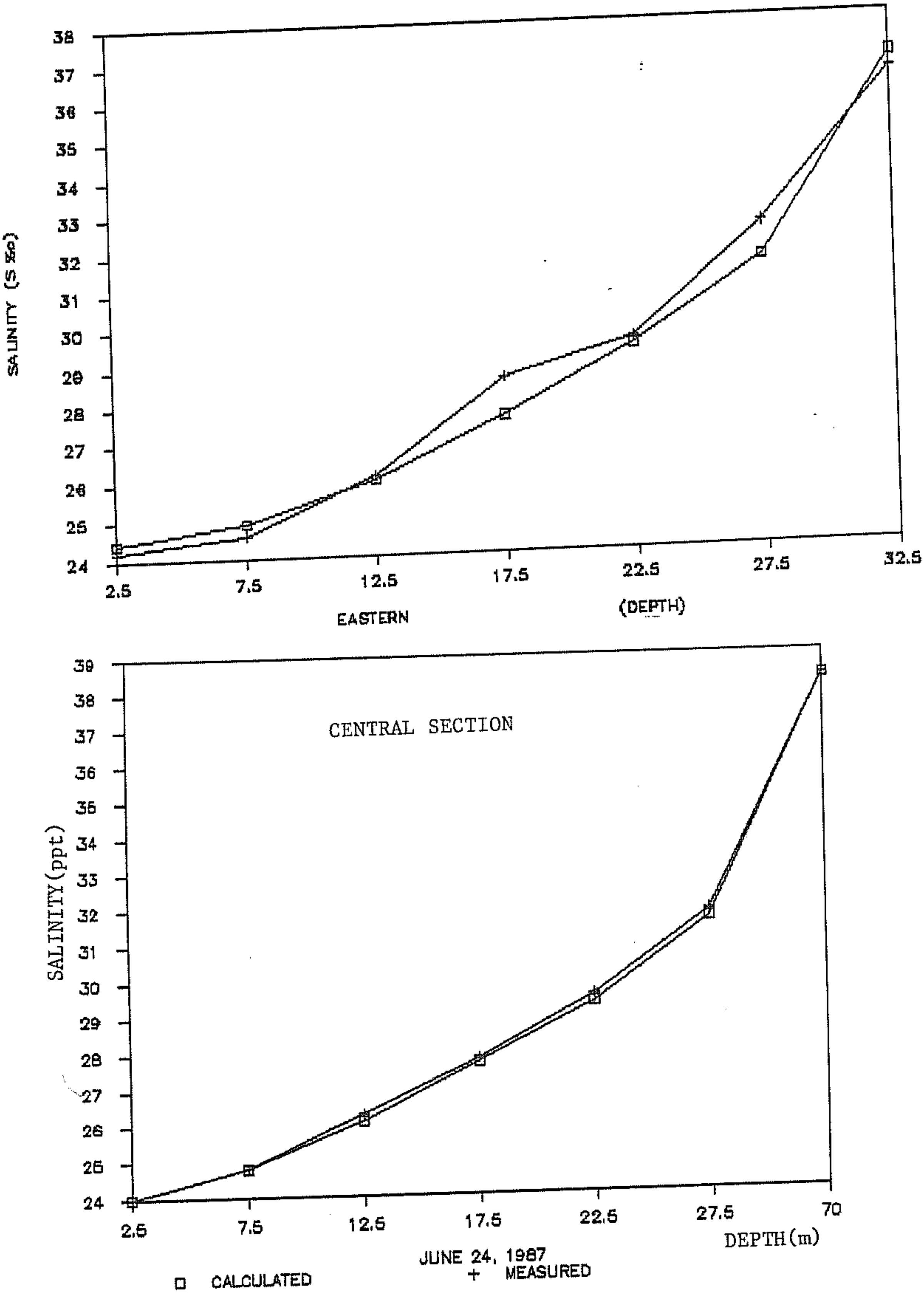


Figure 12. The calculated and measured salinity gradients in the central eastern sections of the Bay.

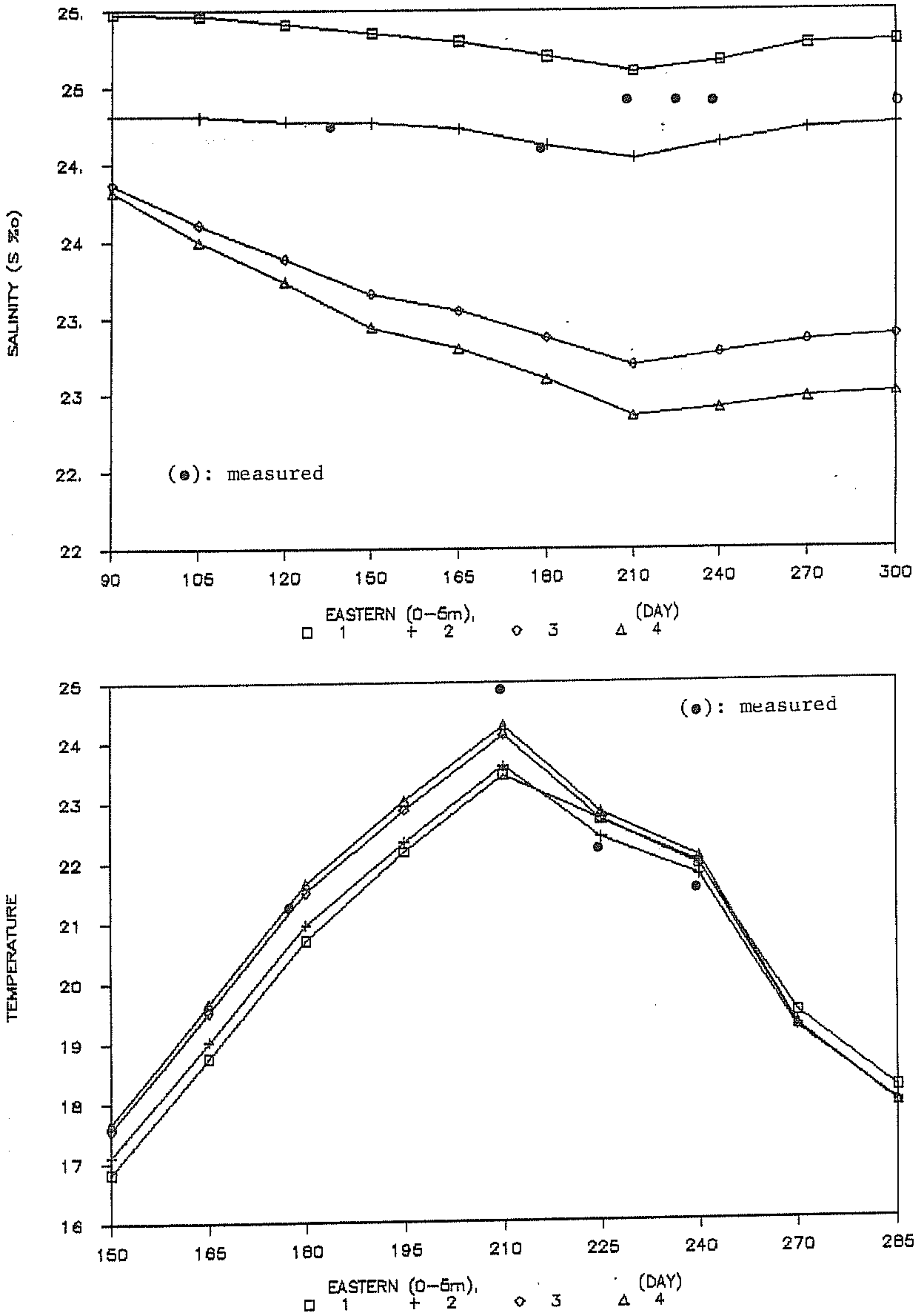


Figure 13a. Effect of vertical dispersion coefficient on salinity and temperature variations.
$1{:}2.5\text{x}10^{-4}$, $2{:}2.5\text{x}10^{-5}$, $3{:}2.5\text{x}10^{-6}$, $4{:}2.5\text{x}10^{-7}$ $m^2/s$.

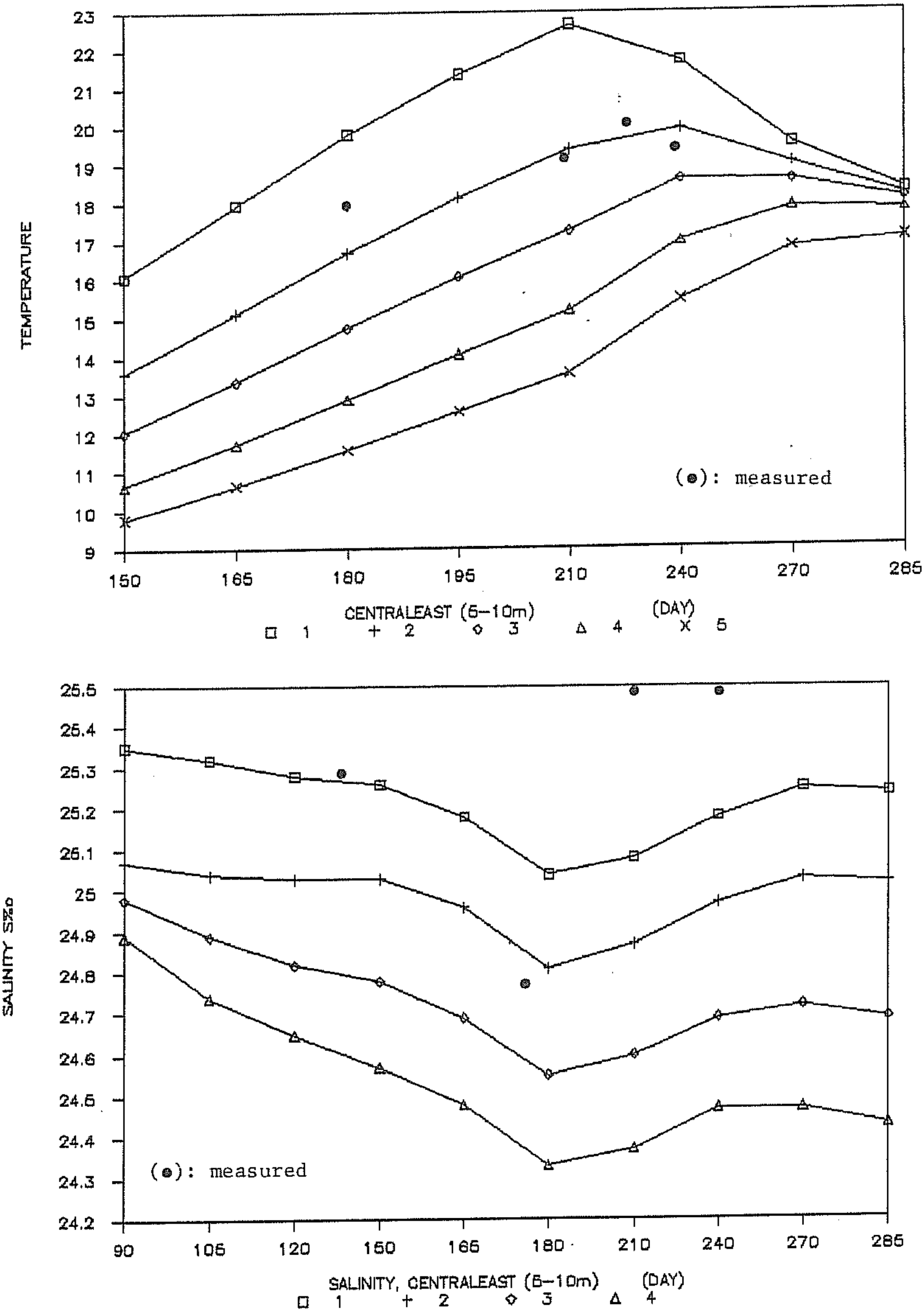


Figure 13b. Effect of vertical dispersion on temperature and salinity.
$1{:}0.8\times10^{-4}$, $2{:}0.8\times10^{-5}$, $3{:}0.4\times10^{-4}$, $4{:}0.8\times10^{-6}$, $5{:}0.8\times10^{-7} m^2/s$.

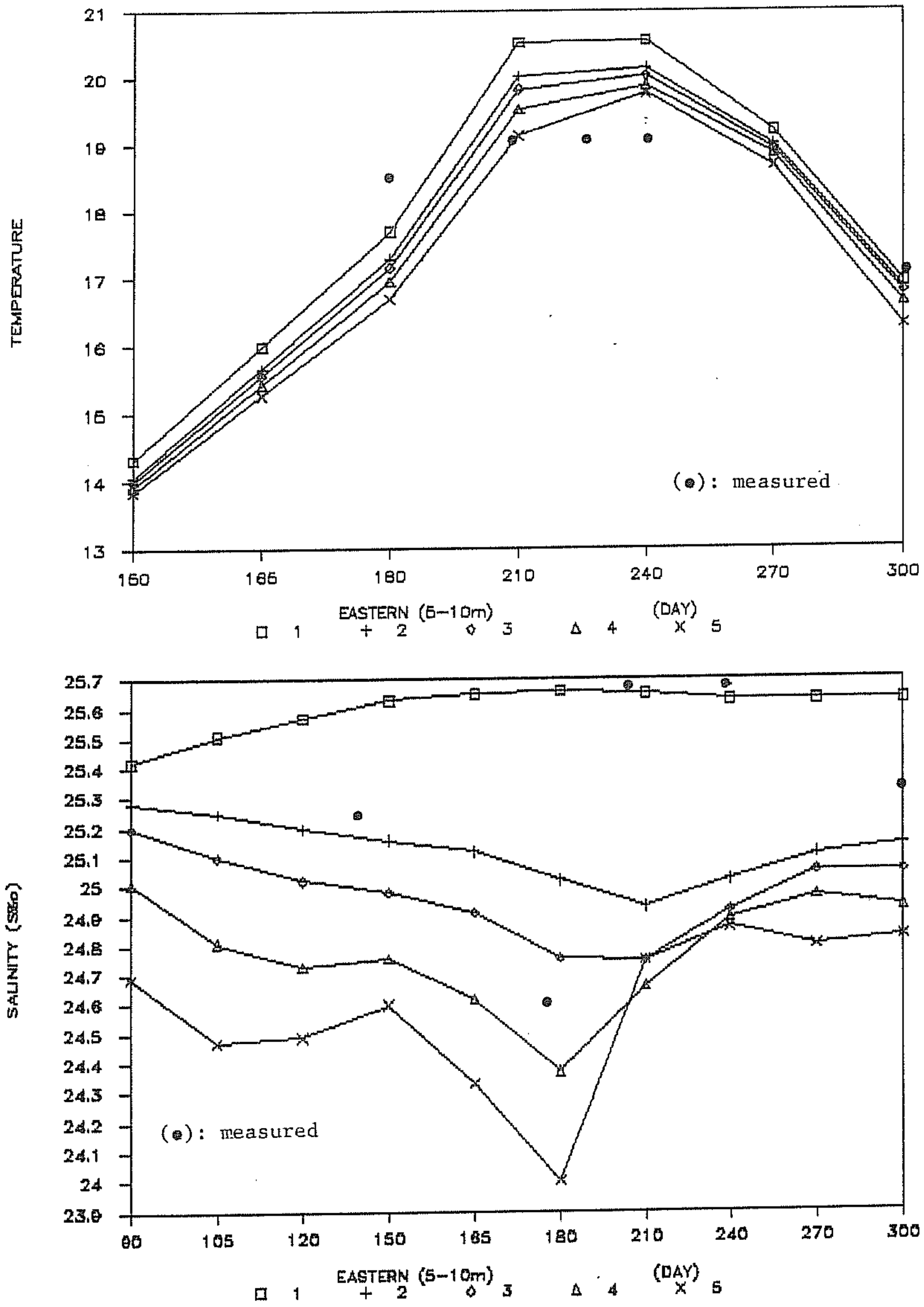


Figure 14. Effect of horizontal dispersion coefficient on temperature and salinity. 1:50, 2:180, 3:270, 4:500, 5:1000 $m^2/s$.

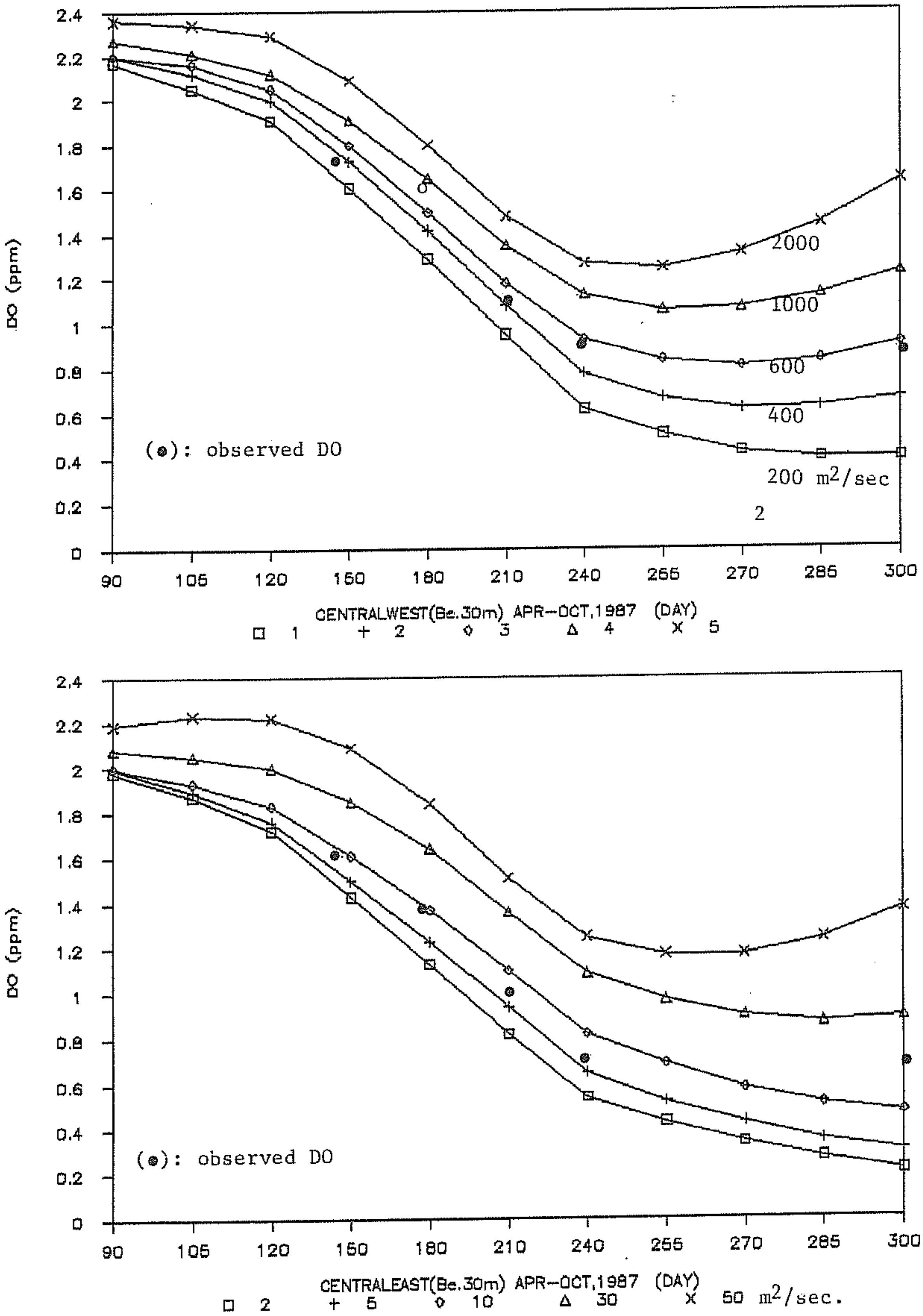


Figure 15. Effect of horizontal dispersion coefficient on the depletion rate of dissolved oxygen in the bottom waters of central region.

Table 2. Effect of wind speed on salinity and temperature variations in the Izmit Bay(0-5m).

| Region | Month | Wind Speed | | | |
|---|---|---|---|---|---|
| | | 2 m/sec | | 4 m/sec | |
| | | temperature/salinity | | temperature/salinity | |
| Central | May | 15.3 | 24.6 | 15.3 | 24.6 |
| " | June | 19.2 | 24.5 | 19.2 | 24.5 |
| " | July | 22.5 | 24.3 | 22.5 | 24.3 |
| " | August | 22.5 | 24.5 | 22.5 | 24.5 |
| " | Septem. | 20.6 | 24.6 | 20.6 | 24.6 |
| Eastern | May | 15.2 | 24.8 | 15.2 | 24.8 |
| " | June | 19.0 | 24.7 | 19.0 | 24.7 |
| " | July | 22.3 | 24.5 | 22.3 | 24.5 |
| " | August | 22.4 | 24.6 | 22.4 | 24.6 |
| " | Septem. | 20.6 | 24.7 | 20.6 | 24.7 |

Table 3. The measured solar radiation in the Izmit Bay area (cal/$m^2$-day).

| Month | 1987 1st 10 days | 1987 2nd 10 days | 1987 3rd 10 days | 1986 | 1985 |
|---|---|---|---|---|---|
| January | 85 | 165 | 81 | 125 | 98 |
| February | 116 | 219 | 190 | 173 | 165 |
| March | 235 | 306 | 330 | 226 | 252 |
| April | 335 | 250 | 280 | 450 | 347 |
| May | 390 | 574 | 510 | 531 | 478 |
| June | 530 | 520 | 550 | 567 | 513 |
| July | 520 | 563 | 633 | 575 | 525 |
| August | 560 | 455 | 425 | 507 | 456 |
| September | 434 | 427 | 370 | 378 | 358 |
| October | 280 | 200 | 266 | 234 | 228 |
| November | 145 | 113 | 134 | 156 | 156 |
| December | - | - | - | 92 | 116 |

# 3. DESCRIPTION OF WATER QUALITY PROCESSES

## 3.1. Simulated Constituents

In this chapter a description is given of water quality constituents and related processes as considered by the model. The selection of modelled processes was based on the perception of the actual situation in the Izmit Bay. The following points were considered:

- o Geographical characteristics of the Bay
- o Biological characteristics
- o Specific water quality problems
- o Availability of data sets for calibration

On the basis of these points it was first decided to focus the model development on the processes relevant to oxygen dynamics. The biological processes considered, are partly derived from an existing ecological model 'GREWAQ'(10). Due to specific goals for this study and general lack of field data for such parameters as particulate organic carbon, nutrients in organic form, degradable dissolved organic carbon and current levels of waste loads entering the Bay simplification were made and extensions were developed, especially with respect to oxygen dynamics. With the model two constituents are considered to describe the hydrophysics and irritations between nutrients(N, P, Si), phytoplankton, detritus(biodegradable organic carbon) and dissolved oxygen.

The model considers the following state variables:

| State variables | Symbol | Unit |
|---|---|---|
| Continuity | C | - |
| Salinity | S | $^{0}/oo$ |
| Temperature | T | $^{o}C$ |
| Dissolved oxygen | $C_o$ | $g\ O_2.m^{-3}$ |
| Other phytoplankton | $A_1$ | $g\ C.m^{-3}$ |
| Diatoms | $A_2$ | $g\ C.m^{-3}$ |
| Fast degradable detritus (particulate organic carbon) | $D_f$ | $g\ C,N,P,Si\ .m^{-3}$ |
| Slow degradable detritus (dissolved organic carbon) | $D_s$ | $g\ C,N,P,Si\ .m^{-3}$ |
| Dissolvednitrate | $N_2$ | $g\ NO_3-N.m^{-3}$ |

| | | |
|---|---|---|
| Dissolved ammonia | N1 | g NH4-N.m-3 |
| Dissolved phosphate | P | g PO4-P.m-3 |
| Dissolved silicon | Si | g SiO-Si.m-3 |
| | | |
| Benthic complex detritus | Db | g C,N,P,Si .m-2 |

The model conception doesn't include separate bottom layers. Benthic processes are modelled in a zero-dimensional layer where no dissolved pools are specified. These processes are expressed only as fluxes which immediately are reallocated to pools in the adjacent water segments. This bottom 'layer' is called the benthic complex.

## 3.2 Simulated processes

The modelled processes can be divided into the following groups:

1. Calculation of relevant physical processes.
2. Calculation of processes related to phytoplankton kinetics.
3. Calculation of (an)aerobic mineralisation and (de)nitrification in the water segments.
4. Calculation of benthic complex nutrient dynamics.
5. Calculation of related oxygen production and consumption.

The schematisation used in the model causes each of the named processes to be quantified for each water segment. Fluxes generated in the benthic complex ('the complex') are added according to the relative bottom area under each segment. The following figure shows the modelled processes and their interactions.

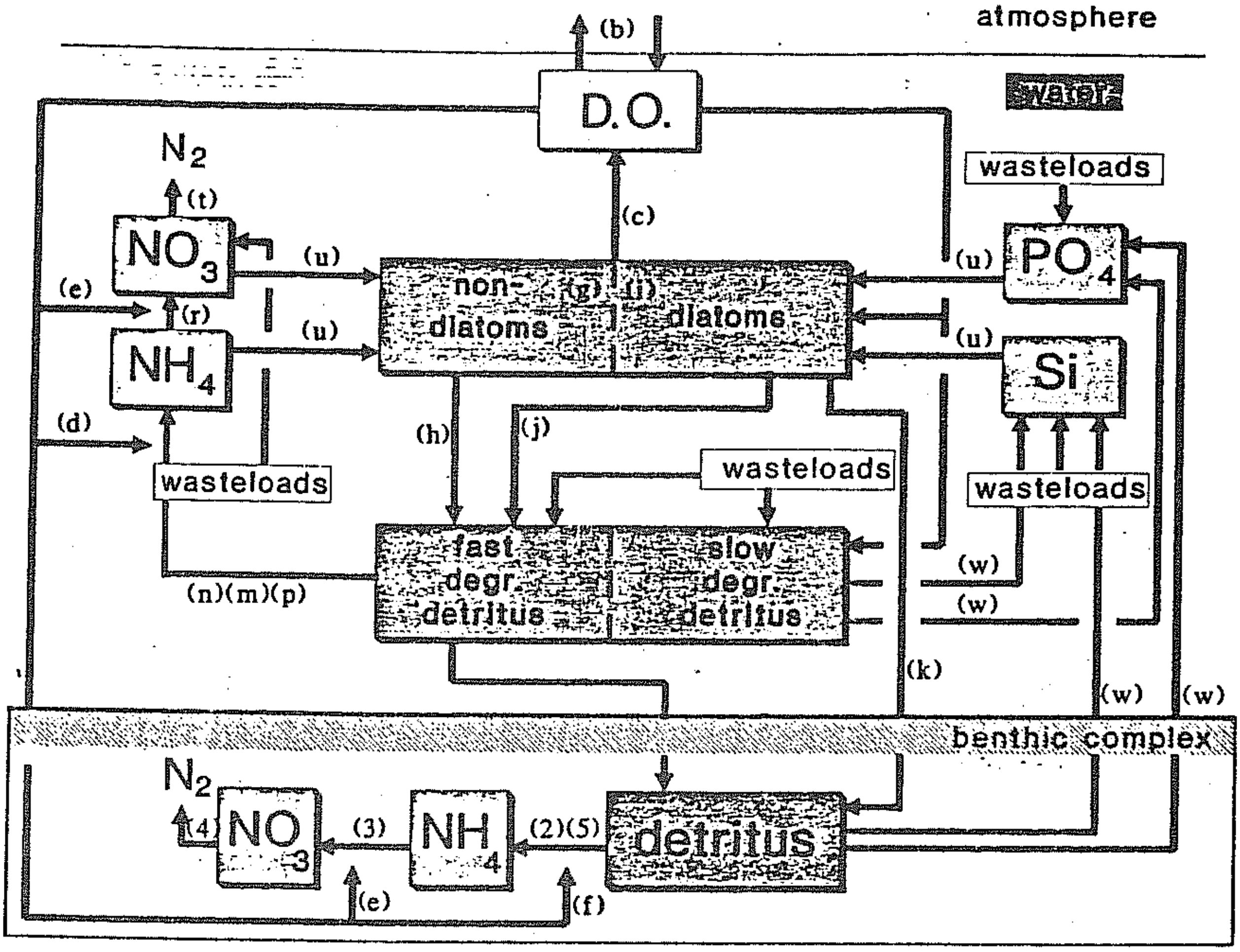


Figure 16. Modelled processes in the Izmit Bay model

When the model is used one should keep in mind the fundamental difference between processes dynamics in water segments and in the complex. The dynamics of the latter are based on instantaneous allocation of fluxes without the existence of complex nutrient pools, while the first is based on process-rates in combination with dissolved nutrient pools (see 3.4: Complex dynamics).

In this paragraph all processes that are included in the model are described. In the next paragraph the mathematical formulations will be given.
(See Figure 16 for information about interrelations.)

Kinetics related to oxygen budget

Water/atmosphere oxygen exchange (b)
Oxygen production by phytoplankton growth (c)
Oxygen consumption by mineralisation of suspended detritus (d)
Oxygen consumption by benthic mineralisation flux (f)

Oxygen consumption by nitrification (e)
Production of direct demand for oxygen (= negative oxygen concentration) by anaerobic mineralisation of
detritus (n)

Kinetics related to phytoplankton and detritus dynamics

Net production of algal biomasses (g) (i)
Mortality of phytoplankton (z) (j)
Settling of diatoms (k)
Mineralisation of suspended detritus (m) (p)
Anaerobic mineralisation of fast degradable detritus (n)
Settling of detritus (o) (q)

Kinetics related to dissolved nutrient budgets

Release of nutrients by mineralisation of detritus (w)
Excretion of nutrients by phytoplankton
Uptake of nutrients by phytoplankton (u)
Release of nitrate by nitrification of ammonia in water (z)
Consumption of nitrate by denitrification in water (t)

Kinetics related to benthic complex dynamics

(An)aerobic mineralisation of benthic detritus (2) (5)
Release of nitrate by nitrification of ammonia (3)
Consumption of nitrate by denitrification (4)

## 3.3 Mathematical description of modelled kinetics

In this paragraph all processes included in the model are described in the same order as the described constituents (state variable) to which they applied.
For each constituent the complete differential equation is given together with a description of processes as considered by the model.
Input parameters, functions and constants are indicated separately by INP-P, F and C respectively.

1. Continuity (C)

(no water quality processes, only transport)

2 Salinity (S)

(no water quality processes, only transport)

3. Temperature (T)

$$\frac{dT}{dt} = \underbrace{\frac{k_H}{d_s}(T_s - T)}_{(a)}$$

(a) **heat exchange** with (measured) near-surface water temperature ($^oC$)

$T_s$ = surface temperature INP-F
$k_H$ = heat exchange coefficient INP-C
$d_s$ = surface layer thickness INP-P

4. Dissolved oxygen ($C_o$)

$$\frac{dC_o}{dt} = \underbrace{\frac{k_\ell}{d_s}(C_s - C)}_{(b)} + \underbrace{\alpha_o(\mu_1 A_1 + \mu_2 A_2)}_{(c)} +$$

$$- \underbrace{\alpha_o\ (k_f D_f + k_s D_s + k_a D_f)}_{(d)} +$$

$$- \underbrace{\beta_o\ k_1 N_1}_{(e)}$$

$$- \underbrace{\varphi_o\ r_b}_{(f)}$$

(b) **atmospheric reaeration**

$k_\ell$ = reaeration coefficient (m/d)
$d_s$ = depth (thickness) of surface layer (m) INP-P
$C_s$ = oxygen saturation concentration
$k_\ell = 0.15 + 0.03\ W_{10}^2 * 1.016^{(T-20)}$

$W_{10}$ = wind at 10 m above water surface (m/s) INP-F

T = temperature of surface water layer

$$C_s = \frac{(0.680-6.10^{-4}T) * (755.4-0.032\ T^2)}{T + 35} * (1 - 6{,}2.10^{-3}\ (\rho_w-1000))$$

$\rho_w$ = density of water in surface layer ($kg/m^3$).

$\rho_w = 1000 + 0.8\ S - 0.0065\ (T-4 + 0.22\ S)^2$

S = salinity ($^o$/oo)

(c) **net production of oxygen by algae**

$\alpha_o$ = stochiometric constant for carbon-oxygen (g $O_2$/gC) INP-C

$(\mu_1 A_1 + \mu_2 A_2)$ = net production of phytoplankton (see 5 and 6)

(d) **oxygen consumption by mineralisation of detritus**
(including decay of waste-BOD)

$k_f D_f + k_s D_s + k_a D_f)$ = mineralisation of carbon detritus (see 7 and 11)

(e) **oxygen consumption for nitrification**

$\beta_o$ = stochiometric constant for nitrogen-oxygen (g $O_2$/g N) INP-C

$k_1 N_1$ = nitrification of ammonia (see 16)

(f) **benthic oxygen demand**

$\varphi_o$ = benthic oxygen consumption (g $O_2/m^2$/day)
(see bottom detritus)

$r_b$ = ratio of bottom surface to water volume INP-P

## 5. 'other' phytoplankton ($A_1$)

Phytoplankton kinetics

The calculation of phytoplankton dynamics is dependent on the following basic parameters.

1. Temperature
2. Irradiation
3. Extinction in the water column
4. Nutrient concentrations
5. Respiration and excretion

Irradiation levels are calculated using a forcing function or an input data file. The light level is influenced by daylength. Calculation of an actual light level includes an extinction formula. The total extinction in a water segment is dependent on a background extinction and actual POC-concentrations. Ambient nutrient concentrations (total-nitrogen, phosphate and silicon) influence maximum production rates using Monod-kinetics. Each named process is expressed in a coefficient and influences the maximum production rate. Finally, a respiration and excretion rate is subtracted from the calculated production rate. The following formulations are used.

$$\frac{dA_1}{dt} = \underset{(g)}{\mu_1 A_1} - \underset{(h)}{\delta A_1}$$

**(g) net primary production by other phytoplankton**

$\mu$ = net production rate ($\text{day}^{-1}$)

$$\mu_1 = \mu_1^{max} . \min(f(N), f(P)) - \rho_r$$

$\mu_1^{max}$ = maximum gross (daily-averaged) production rate without nutrient limitation
f(N) = function for nitrogen limitation
f(P) = function for phosphorus limitation
$\rho_r$ = respiration rate

$$\mu_1^{max} = \mu_1^o \cdot e^{\gamma(T-20)} * f_1 * \frac{I}{I_{s_1}} e^{(1- I/I_{s_1})}$$

$\mu_1^o$ = maximum daily production rate (20°C) for other phytoplankton ($day^{-1}$) INP-C

$\gamma$ = temperature coefficient algae processes ($C^o$-1) INP-C

$f_1$ = reduction factor for effective daily production period

$I$ = light intensity ($W/m^2$)

$I_{s_1}$ = light saturation value for other phytoplankton ($W/m^2$) INP-C

$$I = I_o \, e^{-\int k_e \, dz}$$

$I_o$ = light intensity just below water surface ($W/m^2$)

$k_e$ = extinction coefficient (1/m)

$$I_o = \frac{I_{rad}}{f_{day}} (1 - 0.1) * 0.5 * \frac{10000}{86400}$$

reflection 50% of light available for algae

$f_{day}$ = day length fraction INP-F

$I_{rad}$ = solar i.e. radiation ($J/cm^2/day$) (daily average) INP-F

$$k_e = \varepsilon_o + \varepsilon_{s_1} A_1 + \varepsilon_{s_2} A_2 + \varepsilon_{s_d} D_f$$

$\varepsilon_o$ = background extinction ($m^{-1}$) INP-C

$\varepsilon_{s_1}$ = specific extinction non-diatoms INP-C

$\varepsilon_{s_2}$ = specific extinction diatoms INP-C

$\varepsilon_{s_d}$ = specific extinction fast detritus INP-C

$$f_1 = \min\left(1, \frac{f_{day}}{\frac{ta_1}{24}}\right)$$

$ta_1$ = maximum daily production period for non-diatoms (hr) INP-C

$$f(N) = \frac{N_1 + N_2}{K_N + N_1 + N_2}$$

$N_1$ = ammonia ($gN/m^3$)
$N_2$ = nitrate ($gN/m^3$)
$K_N$ = monod parameter, nitrogen ($gN/m^3$) INP-C

$$f(P) = \frac{P}{K_p + P}$$

$P$ = phospate ($gP/m^3$)
$K_p$ = monod parameter, phpsphorus ($gP/m^3$) INP-C

$$\rho_r = \rho_o \; e^{\gamma(T-20)}$$

$\rho_o$ = respiration rate of algae at 20°C ($day^{-1}$) INP-C

(h) **mortality of 'other' phytoplankton**
$\delta$ = death rate
$\delta = \delta_o \; e^{\gamma(T-20)}$
$\delta_o$ = death rate of algae at 20°C INP-C

6. Diatoms ($A_2$)

$$\frac{dA_2}{dt} = \mu_2 A_2 - dA_2 - v_{a_2} \frac{dA_2}{dz} \cdot g(Si)$$

(i) (j) (k)

(i) **net primary production of diatoms**
similar formulations as for 'other' phytoplankton (see 5 g)

$$\mu_2 = \mu_2^{max} \max(f(N), f(P), f(Si)) - \rho_r$$

f(Si) = function for silica limitation

$$f(Si) = \frac{Si}{KSi + Si}$$

KSi = monod parameter, silica ($g\ Si/m^3$) INP-C

$Si$ = silica (see 18)

other input data related to diatoms:

$\mu_2^o$ = maximum daily production rate 20°C for diatom ($day^{-1}$) INP-C

$I_{S_2}$ = light saturation value for diatoms ($W/m^2$) INP-C

$ta_1$ = maximum daily production period for non diatom (hr) INP-C

(j) **mortality of diatoms**

same as for other phytoplankton (see 5 h)

(k) **settling of diatoms**

$v_{a_2}$ = settling rate (m/s)

$z$ = depth

$g(Si)$ = function for active settling during silica limitation

$$g(Si) = \frac{K_{Si}}{Si + K_{Si}}$$

$K_{Si}$ = monod parameter for settling of diatom during silica limitation ($gSi/m^3$) INP-C

7. Fast degradable detritus ($D_f$)

$$\frac{dD_f}{dt} = + \underbrace{d(A_1\alpha_1 + A_2\alpha_2)}_{(l)} - \underbrace{k_f\, D_f}_{(m)} - \underbrace{k_a\, D_f}_{(n)} - \underbrace{v_f\, \frac{dD_f}{dz}}_{(o)}$$

(l) **detritus production due to algae mortality**

(see 5h and 6j)

$\alpha_1$ = stochiometric constant (= 1 for carbon)

$\alpha_2$ = stochiometric constant (= 1 for carbon)

(m) **mineralisation (aerobic) of fast detritus**

$k_f$ = mineralisation rate

$$k_f = k_f^o \cdot \theta^{(T-20)} \cdot \frac{C_o}{KC_o + C_o} \cdot \frac{D_f^N/D_f}{D_f^N/D_f + K_{NC}}$$

$k_f^o$ = maximum mineralisation rate at 20°C ($\text{day}^{-1}$) INP-C

$\theta$ = temperature correction parameter INP-C

$C_o$ = dissolved oxygen (see 4)

$KC_o$ = monod parameter for mineralisation of organic matter with low nitrogen contents (gN/gC) INP-C

(n) **anaerobic decay of fast detritus**

$k_a$ = anaerobic mineralisation rate

$$k_a = k_a^o \cdot \theta^{(T-20)} \cdot \frac{KC_a}{C_o + KC_a} \cdot \frac{D_f^N/D_f}{D_f^N/D_f + K_{NC}}$$

$KC_a$ = monod parameter for abaerobic mineralisation in poor oxygen conditions

(o) **settling of fast detritus**

$v_f$ = settling rate for fast detritus (m/day)

$v_f = v_f^u$ above pycnocline

$v_f = v_f^b$ below pycnocline

$v_f^u$ = settling rate upper layer (m/day) INP-C

$v_f^b$ = settling rate lower layer (m/day) INP-C

## 8. Fast degrable detritus, nitrogen ($D_f^N$)

(see 7)

$\alpha_1 = \alpha_1^N$ = stochiometric constant nitrogen-carbon for other phytoplankton (gN/gC) INP-C

$\alpha_2 = \alpha_2^N$ = stochiometric constant nitrogen-carbon for other diatoms (gN/gC) INP-C

## 9. Fast degrable detritus, phosphorus ($D_f^P$)

(see 7)

$\alpha_1 = \alpha_1^P$ = stochiometric constant phosphorus-carbon for other phytoplankton (gP/gC) INP-C

$\alpha_2 = \alpha_2^P$ = stochiometric constant phosphorus-carbon for other diatoms (gP/gC) INP-C

## 10. Fast degradable detritus, silica ($D_f^S$)

(see 7)

$\alpha_1 = \alpha_1^S$ = stochiometric constant silica-carbon for other phytoplankton (gSi/gC) INP-C

$\alpha_2 = \alpha_2^S$ = stochiometric constant silica-carbon for other diatoms (gSi/gC) INP-C

## 11. Slow degradable detritus ($D_s$)

$$\frac{dD_s}{dt} = \underset{(p)}{- k_s D_s} \underset{(q)}{- v_s \frac{dD_s}{dz}}$$

(p) **mineralisation of slow detritus**

$k_s$ = mineralisation rate (similar as for fast detritus, see 7 m)

$k_s^o$ = maximum mineralisation rate at 20°C ($day^{-1}$) for slow detritus INP-C

(q) **settling of slow detritus**

(similar as for fast detritus, see 7)

$v_s^u$ = settling rate in upper layer INP-C

$v_s^b$ = settling rate in lower layer INP-C

### 12. Slow degradable detritus, nitrogen ($D_s^N$)

(similar as fast detritus, see 8)

### 13. Slow degradable detritus, phosphorus ($D_s^P$)

(similar as fast detritus, see 9)

### 14. Slow degradable detritus, silica ($D_s^S$)

(similar as fast detritus, see 10)

### 15. Nitrate ($N_2$)

$$\frac{dN_2}{dt} = + \underbrace{k_1 N_1}_{(r)} + \underbrace{\varphi_n . r_b}_{(s)} - \underbrace{k_d N_2}_{(t)} - \underbrace{(1-f_{N_1})(\mu_1 A_1 \alpha_1^N + \mu_2 A_2 \alpha_1^N)}_{(u)}$$

**(r) nitrification from ammonia to nitrate**

(see ammonia 16)

$N_1$ = ammonia ($gN/m^3$)

**(s) nitrate release/consumption by benthic processes**

(see processes at the bottom)

$\varphi_n$ = benthic nitrate flux ($gN/m^2$/day)

$r_b$ = ratio of bottom surface to water volume

(same as for oxygen, see 4 f)

**(t) denitrification during oxygen poor conditions**

$k_d$ = denitrification rate ($day^{-1}$)

$$k_d = k_d^o \, . \, \theta^{(T-20)} \, (1 - \frac{C_o}{K_{DN} + C_o})$$

$k_d^o$ = maximum denitrification rate at 20°C ($day^{-1}$) INP-C

$K_{DN}$ = monod parameter for denitrification
(see also ammonia 16)

(u) **uptake of nitrate by primary production**

$f_{N_1}$ = fraction of ammonia uptake from total nitrogen uptake by algae
for primary production (see also 5 and 6)

$$f_{N_1} = \frac{N_1}{N_1 + N_2}$$

$N_1$ = ammonia (see 16)

## 16. Ammonia ($N_1$)

$$\frac{dN_1}{dt} = \underbrace{- k_N N_1}_{(v)} + \underbrace{(k_d D_f^N + k_{d_s} D_s^N + k_a D_f^N)}_{(w)} + \underbrace{\varphi_N r_b}_{(x)} - \underbrace{f_{N_1}(\mu_1 A_1 + \mu_2 A_2)\,\alpha^N}_{(y)}$$

(v) **nitrification**

This process includes both 1st and 2nd step nitrification from ammonia to nitrate (intermediate product nitrite is not considered)

$k_N$ = nitrification rate

$$k_N = k_N^o \cdot \theta^{(T-20)} \cdot \frac{C_o}{K_{DN} + C_o}$$

$k_N^o$ = maximum nitrification rate ($day^{-1}$)

$C_o$ = dissolved oxygen ($g/m^3$) (see 4)

$K_{DN}$ = monod parameter for denitrification ($g\ O_2/m^3$) INP-C

(w) **ammonia release during mineralisation of fast and slow detritus**

see formulations of mineralisation of fast and slow detritus (7, 8, 11, 12)

(x) **ammonia release from benthic mineralisation**

$\varphi_N$ = benthic ammonia flux ($gN/m^2/day$)
(see benthic detritus)
$r_b$ = bottom surface to water volume ratio

**(y) ammonia uptake by primary production**
see for primary production 5 and 6

## 17. Phosphorus (P)

$$\frac{dP}{dt} = (k_{d_f} D_f^P + k_{d_s} D_s^P + k_a D_f^P) + \varphi_p r_b - \alpha^P(\mu_1 A_1 + \mu_2 A_2)$$

(z) (aa) (ab)

**(z) release of phosphorus by mineralisation of fast and slow detritus**

**(aa) phosphorus release from benthic mineralisation**

**(ab) phosphorus uptake for primary production**
similar processes as for ammonia (17)

## 18. Silica (Si)

$$\frac{dSi}{dt} = (k_{d_f} D_f^S + k_{d_s} D_s^S + k_a D_f^S) + \varphi_s r_b - \alpha^S(\mu_1 A_1 + \mu_2 A_2)$$

(ac) (ad) (ae)

similar processes as for phosphorus (Si)

## 3.4. Benthic Complex Dynamics

### 3.4.1. General Description and Assumptions

The bottom (or complex) is considered to be a very thin layer. Detritus settles on the bottom and is then mineralised. The fraction that is not mineralised accumulates on the bottom. Besides mineralisation there is nitrification, denitrification and anaerobic mineralisation. The actual rates of the processes are determined by the maximum rate possible and the availability of oxygen. Since it is assumed that the reaction products are not stored in the complex, but are directly released to the water, the nitrification and denitrification processes in the model are related to fluxes at the water-bottom interface.

The structure of the benthic complex module is based on quantification of mineralisation and (de)nitrification fluxes in relation to the oxygen situation. These fluxes are based on the existence of the only pool in the benthic complex, e.g. detritus. The other important parameter is the incoming oxygen flux based on a diffusion process.

Two stages can be distinguished in the calculation of the fluxes. First a potential maximum flux is calculated. This potential flux is recalculated in oxygen units and compared with available oxygen flux. When a surplus oxygen is calculated potential fluxes become realisable fluxes. This surplus of oxygen is used for the calculation of efficiency of denitrification. When a shortage of available oxygen is calculated the realisable fluxes will be less then potential fluxes. Denitrification efficiency is then at its maximum (1.0), causing nearly all nitrate to be consumed by this process. The same effect is assumed for the anaerobic mineralisation process. This process uses sulfate to create sulfides, which are recalculated in oxygen terms. The result can expressed as a potential oxygen demand. Another reaction product is ammonia that is added to the total ammonia flux from the complex.

When all realisable fluxes are known, the total balance is calculated. This means that ammonia, which is produced in various processes, is totaled. In the same way phosphate and silicon fluxes are calculated. The nitrate flux is corrected for denitrification, and the total ammonia flux is corrected for nitrification. Remaining total fluxes are added to pools in the water segments.

### 3.4.2. Formulation of the Processes

Fluxes in and out of the complex:

1. maximum oxygen flux $\varphi_o^*$ into the complex (by diffusion):

$$\varphi_o^* = D_o C_o / L_d$$

where: $D_o$ = diffusion coefficient of oxygen in water
$C_o$ = oxygen concentration in water
$L_d$ = diffusion length

2. potential flux $\varphi_m^{*c}$ out of the bottom due to mineralisation:

$$\varphi_m^{*c} + k_{mc} \{\frac{D_c^N/D_c^c}{D_c^N/D_c^c + K_{Nc}} \cdot \Theta^{(T-20)}\} D_c^c$$

where: $k_{mc}$ = maximum mineralisation rate at 20°C in the complex
$D_c^c$ = concentration of carbon in the complex
$D_c^N$ = concentration of nitrogen in the complex
$\Theta$ = temperature coefficient for microbial processes
$K_{Nc}$ = monod value describing the limitation of mineralisation due to low nitrogen content

the formulation is analogous to detritus in the water

3. potential flux $\varphi_n^*$ due to nitrification of available ammonia:

$$\varphi_n^* = f_{nm} \cdot \frac{\varphi_o}{K_{o1} + \varphi_o} \cdot \varphi_m^{*N}$$

where $f_{nm}$ = the maximum fraction of the ammonia flux that can be nitrified
$k_{o1}$ = monod parameter describing the limitation of the process due to the lack of oxygen

If there is enough oxygen for the demand of both processes, then the realisable fluxes $\varphi_m$ and $\varphi_n$ are the same as the potential fluxes $\varphi_m^*$ and $\varphi_n^*$. Otherwise the available oxygen is distributed proportionally and the fluxes are adjusted accordingly. The amount of oxygen flux $\delta_o$ that is left over determines the rates of denitrification and anaerobic mineralisation. The rest ($\varphi_o$) is subtracted from the water.

4. flux $\varphi_d$ due to the denitrification of nitrate that is available because of the nitrate flux:

$$\varphi_d = f_{dn} \cdot \frac{K_{o1}}{K_{o1} + \delta_o}$$

where: $f_{dn}$ = the maximum fraction of the nitrate flux that can be denitrified

$K_{o1}$ = monod parameter, same as above

5. flux $\varphi_a^c$ due to anaerobic mineralisation:

$$\varphi_a^c = k_{ac} \cdot \frac{K_{o2}}{K_{o2} + \delta_o} \cdot D_c^c \cdot \theta^{(T-20)}$$

where: $k_{ac}$ = the maximum rate of anaerobic mineralisation at 20°C

$K_{o2}$ = monod parameter for the limitation of the process due to oxygen availability

## 3.5. Output Parameters

In order to facilitate the comparison with the measurements an estimate is provided for the following water quality parameters:

1. chlorophyll-a
2. biological oxygen demand
3. particulate organic carbon
4. total organic carbon.

In the model these parameters are only needed for output.

ad 1.

The concentration of chlorophyll-a is estimated as: 1/50 $(A_1 + A_2)$; the factor of 1/50 represents the amount of chlorophyll-a in both phytoplankton species. It is a rather crude estimate.

ad 2.

The biological oxygen demand in five days is calculated by solving a number of differential equations. First of all the amount of phytoplankton is involved:

$$\frac{dA_i}{dt} = - \varphi_r A_i - \delta A_i \qquad (i=1,2)$$

It is assumed that there is no production of algae. By mortality detritus is formed. The detritus that was present in the beginning will also decay:

$$\frac{dD_f}{dt} = - k_f D_f + \delta((A_1 + A_2)$$

Furthermore the slowly degrading detritus will also decay:

$$\frac{dD_s}{dt} = - k_s D_s$$

Both decay processes will cause an oxygen demand, as will the respiration of algae. So the mass balance for oxygen is:

$$\frac{dC_o}{dt} = - 2.67\ (k_s D_s + k_f D_f + \rho_r (A_1 + A_2))$$

By solving these equations and substituting a period of five days an estimate of BOD is obtained from the concentrations of algae and rapidly and slowly grading detritus.

ad 3, 4.

Particulate organic carbon is supposed to be the sum of three fractions: the concentrations of normal phytoplankton and diatoms and the concentrations of fast detritus. Dissolved organic carbon is derived from slowly degrading detritus, whereas total organic carbon equals the sum of particulate and dissolved.

# 4. APPLICATION OF THE WATER QUALITY MODEL

The complex processes that determine the water quality in the Bay of Izmit are characterized by a number of constants. Most of these constants ranges can be found in the literature(10,13). Others are not known, because they are specefic for the area considered. For example the coefficient for background extinction depends on the amount of particulate matter among others but no reliable relationship can be given, because it depends on particle size etc. Another constant that needs calibration is the settling velocity of dead organic matter, because it is not only determined by the rate of fall of individual particles but also by the turbulent mixing in the water.

Therefore the model needs to be calibrated based upon a thorough comparison between calculated and observed concentrations. Unfortunately, only for dissolved oxygen, total and particulate organic carbon, inorganic nutrients, $BOD_5$ and chll-a measurements were available at mothly or seasonal intervals. Organic forms of nutrients, biodegradable dissolved organic carbon, oxygen utilization rate of benthic comlex were not measured in the course of the project study. The values of these parameters were estimated through the model calibration so as to use them as the boundary conditions of the model and input data of waste loads. Nevertheless, the calculations were carried out to see if the model could predict adequately the present situation and demonstrate the effect of the present waste loads estimated on the bay system.

## 4.1. Waste Loads and Boundary Conditions

For salinity, temperature, dissolved oxygen and inorganic nutrients, the variations of the boundary values over the simulation period were derived from the measurements of 1987. For the other parameters, the values were estimated from the measurements of 1986-88. For example, particulate organic carbon data are only available for the August 1987-July 1988 period. The level of dissolved organic carbon that can decay in the surface layers of the Bay was estimated considering the relationship between $BOD_5$, chll-a, TOC and POC that were measured simultaneously in the Bay.

The pollutional loads of domestic and industrial waste waters from different locations around the Izmit Bay were estimated in the previous studies(14). The figures given in Table 4 represent merely the gross pollutional loads of

Table 4. Estimated pollutional loads of domestic and industrial waste waters originating from different locations around the Izmit Bay (tons/day).

| Locations and sources | $BOD_5$ | TSS | T-N* | T-P |
|---|---|---|---|---|
| NORTHERN PART | | | | |
| Industrial | 83 | 70 | 10.9 | 0.61 |
| Domestic | 24 | 36 | 4.8 | 1.2 |
| EASTERN PART | | | | |
| Industrial | 21.7 | 5.6 | 2.2 | 0.19 |
| Domestic | 1.4 | 2.1 | 0.29 | 0.07 |
| SOUTHERN PART | | | | |
| Industrial | 0.78 | 1.26 | - | - |
| Domestic | 6.1 | 9.2 | 1.23 | 0.31 |
| Industrial total | 105.5 | 76.9 | 13.1 | 0.80 |
| Domestic total | 31.5 | 47.3 | 6.3 | 1.58 |
| OVERALL TOTAL | 137.0 | 124.2 | 19.4 | 2.38 |

* T-N : Total Kjeldahl nitrogen (organic - N + $NH_3$)

the whole sources measured by 1982. But most of the measurements are the results of one or two samplings in the industries and subsequent analysis(14). The domestic waste loads were estimated from the present population of the area, daily water consumption per head and average concentrations of pollutants in domestic waters(14). Moreover, it is difficult to determine what percentage of the present loads reaches the open waters of the Bay. In Table 4, the load of biodegradable organic matter is given in terms of $BOD_5$ values. By assuming a decay rate of 0.07/day, 137 tons of $BOD_5$ are equal to about 170 tons of biodegradable organic carbon per day in the waste waters. All of the waste waters originating from different sources are still discharged to the coastal zones of the Izmit Bay. Therefore, significant proportion of them is unlikely to be transported to the open waters of the Bay before they are decayed partly by microorganisms in the waters of coastal zones.Also, majority of inorganic nutrients in the waste waters are used up through photosynthetic reactions in these zones. Thus the waste loads used in the model were estimated by increasing the amounts of wastes and adding one more waste parameter to the model step by step. Moreover, it was assumed that all nutrients in the waste waters were converted to organic matter through photosynthesis and then enter the bay system in organic forms. Ultimately, by considering the transport model was calibrated well, the calculated results of the biochemical parameters were approximated to the measurements of BOD5, dissolved oxygen, inorganic nutrients, particulate organic carbon and chll-a performed simultaneously in the surface and lower layers of the Bay by changing the waste loads added to the eastern and central regions. The estimated waste loads for the model are tabulated in Table 5. However, we know that these values are not precise estimates and do not enter the surface waters of the Bay uniformly due to wind effect and subsequent variable current system in the surface layers. In order to estimate the present real values of waste loads reaching the bay, it is necessary to measure the waste loads systematicaly at discharge points and basic biochemical parameters must be monitored simultaneously in the receiving waters at short intervals, e.g. weekly or bimonthly. The distinction of organic matter into rapidly decaying and slowly decaying fractions is based on the character of the industries. It is clear that the values of particulate and dissolved organic carbon given in Table 5 can only be rough estimates derived from the model calibration. The optimized input file of the model for the present situation is given in the appendix.

Table 5. Waste loads used in the model (tons/day).

| Parameter | Centralwest | Centraleast | Eastern | Total |
|---|---|---|---|---|
| Particulate organic carbon | 5.0 | 15.0 | 20.0 | 40.0 |
| Particulate organic nitrogen | 0.3 | 1.5 | 0.6 | 2.4 |
| Particulate organic phosphorus | 0.05 | 0.3 | 0.1 | 0.45 |
| Particulate organic silicate$^+$ | 0.5 | 0.5 | 0.5 | 1.5 |
| Dissolved organic carbon | 10.0 | 20.0 | 20.0 | 50.0 |
| Dissolved organic nitrogen | 0.6 | 2.0 | 1.2 | 3.8 |
| Dissolved organic phosphorus | 0.1 | 0.3 | 0.2 | 0.6 |
| Dissolved organic silicate$^+$ | 0.5 | 0.5 | 0.5 | 1.5 |

+: the unit of silicate is ton- Si/day.

Table 6. Extinction coefficient measured in the Izmit Bay waters(1/m).

| Date | Western region | Centralwest reg. | Centraleast reg. |
|---|---|---|---|
| 27.4.1987 | 0.35 | - | - |
| May 1987 | 0.25 - 0.38 | - | - |
| 24.6.1987 | 0.28 - 0.40 | 0.42 | 0.55 |
| 28.7.1987 | 0.24 | - | 0.42 |
| 15.8.1987 | 0.27 | 0.28 | 0.32 |
| 20.8.1987 | 0.21 | - | - |
| 31.8.1987 | 0.27 | 0.28 | 0.58 |
| 24.9.1987 | 0.35 | - | - |
| 29.9.1987 | 0.39 | - | - |
| 12.10.987 | 0.22 | 0.32 | 0.45 |
| March 988 | 0.24 | 0.54 | 0.56 |
| May, 1988 | 0.29 | 0.36 | 0.54 |

Three scenarios can be derived from the present situation of the Bay. First of all, the present situation can be simulated with the estimated waste loads given in Table 5. Then, by reducing all waste loads to zero in the model, the natural situation of the Bay in the past can be approximated. And third, alternative locations for the wastes are the bottom layers of the central and eastern regions of the Bay.

## 4.2. Simulation of the Present Situation and Different Scenarios

The water quality model was first used to simulate the present situation of the Bay. One of the parameters of interest is the dissolved oxygen concentration(DO). During the summer period DO is almost at saturated level in the first 10 meters of the bay waters except for the eastern part of the Bay. Below interface the concentration drops from 2 ppm in April to 1 ppm in July (see Figures 17-18). DO decreases steadily below 0.5 ppm in the bottom waters by September. The actual DO levels depend partly on the situation at the entrance of the Bay as well as on the consumption of oxygen for decay of organic matter in the lower layers.

The calculated DO results for the present situation with the estimated waste loads given in Table 5 are depicted in Figure 19, together with the measured

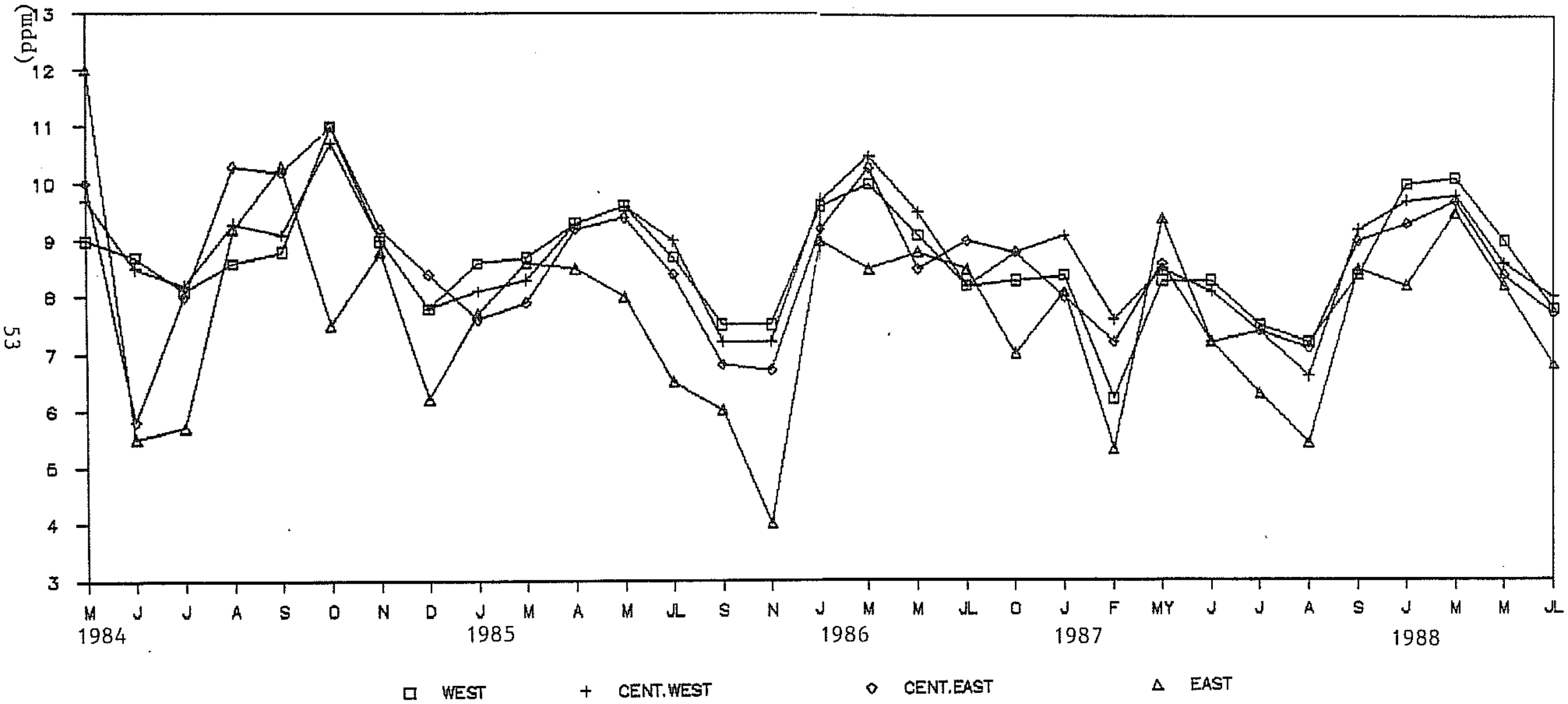


Figure 17. Dissolved oxygen variation in the surface waters(0-10m) of the Izmit Bay.

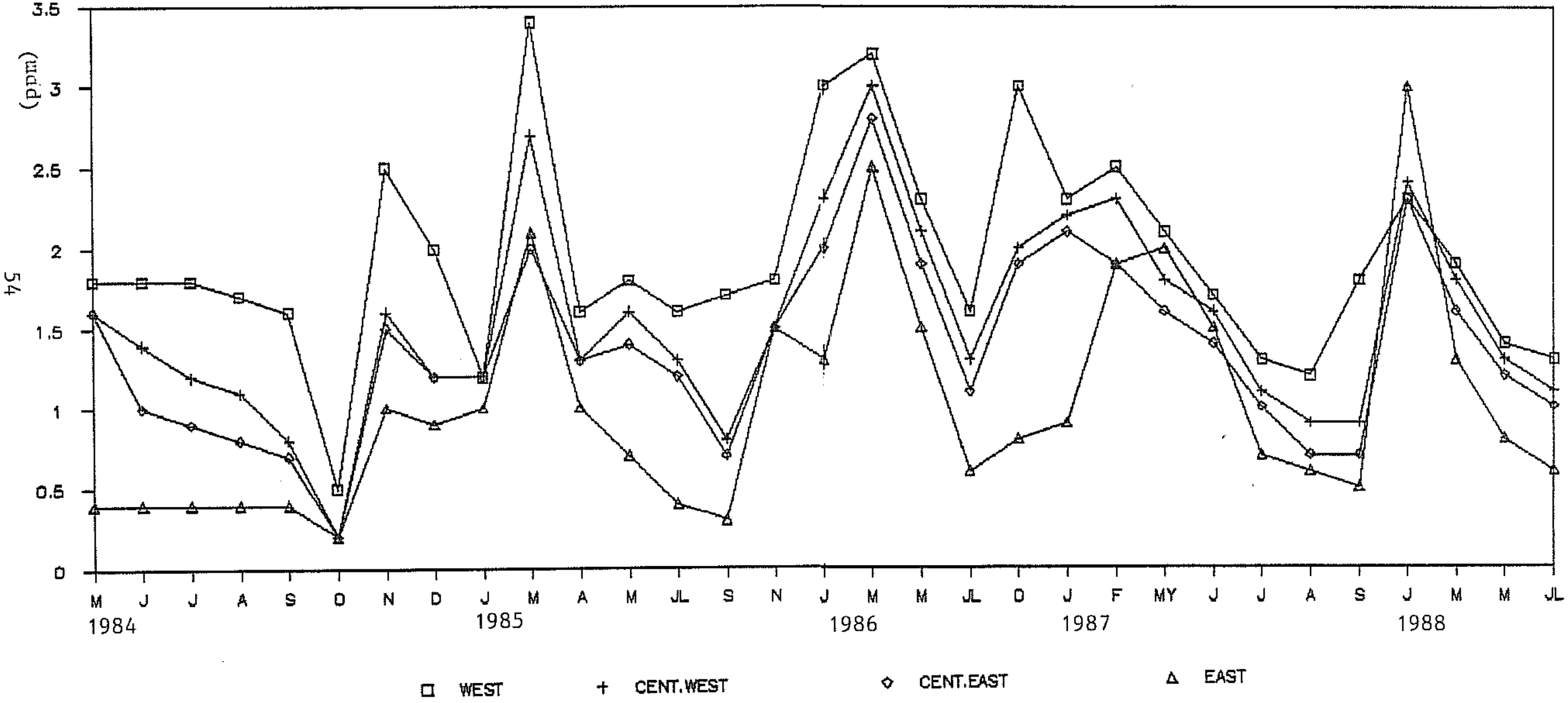


Figure 18. Dissolved oxyged variation in the bottom waters(below 30m) of the Bay.

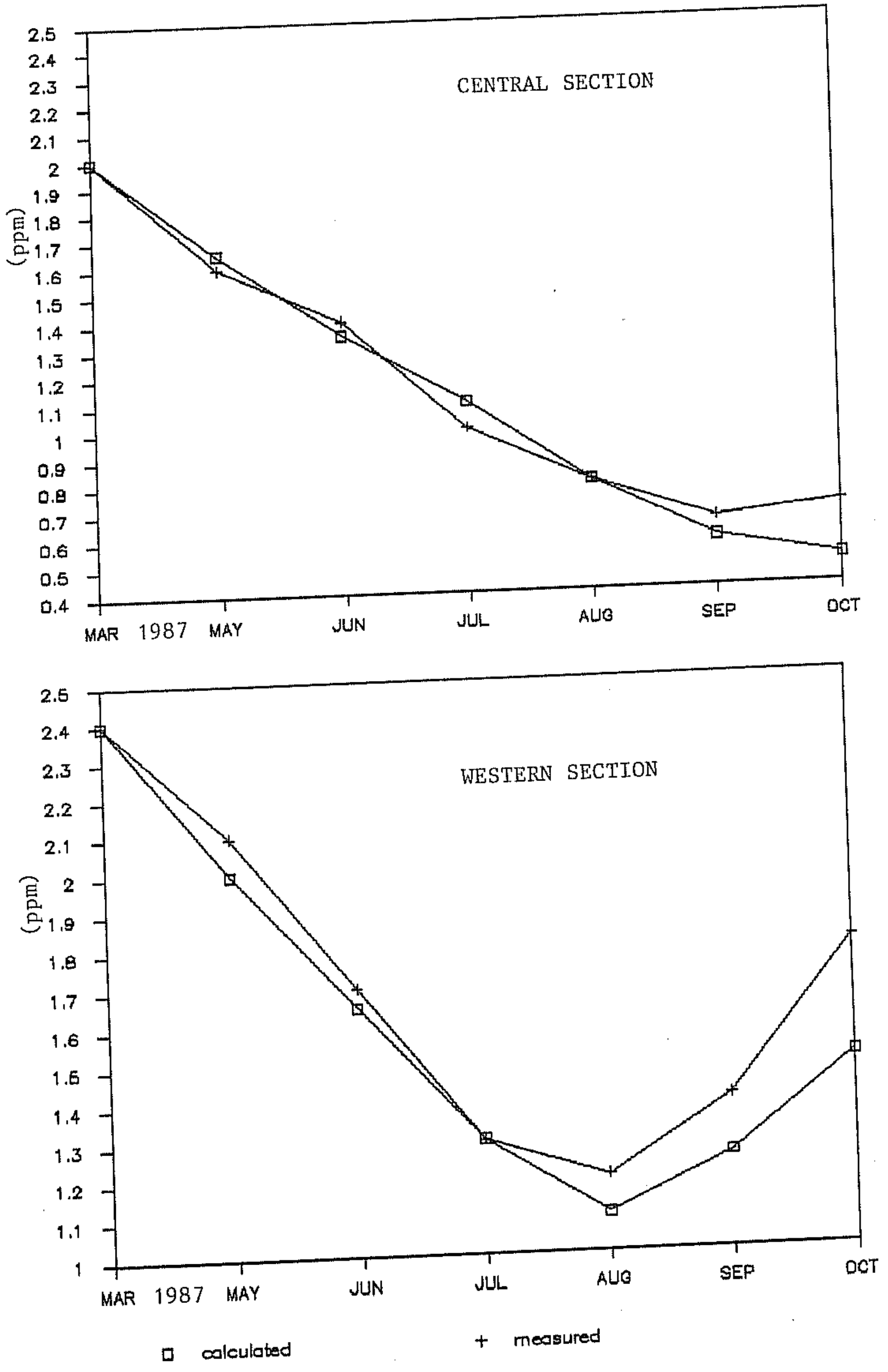
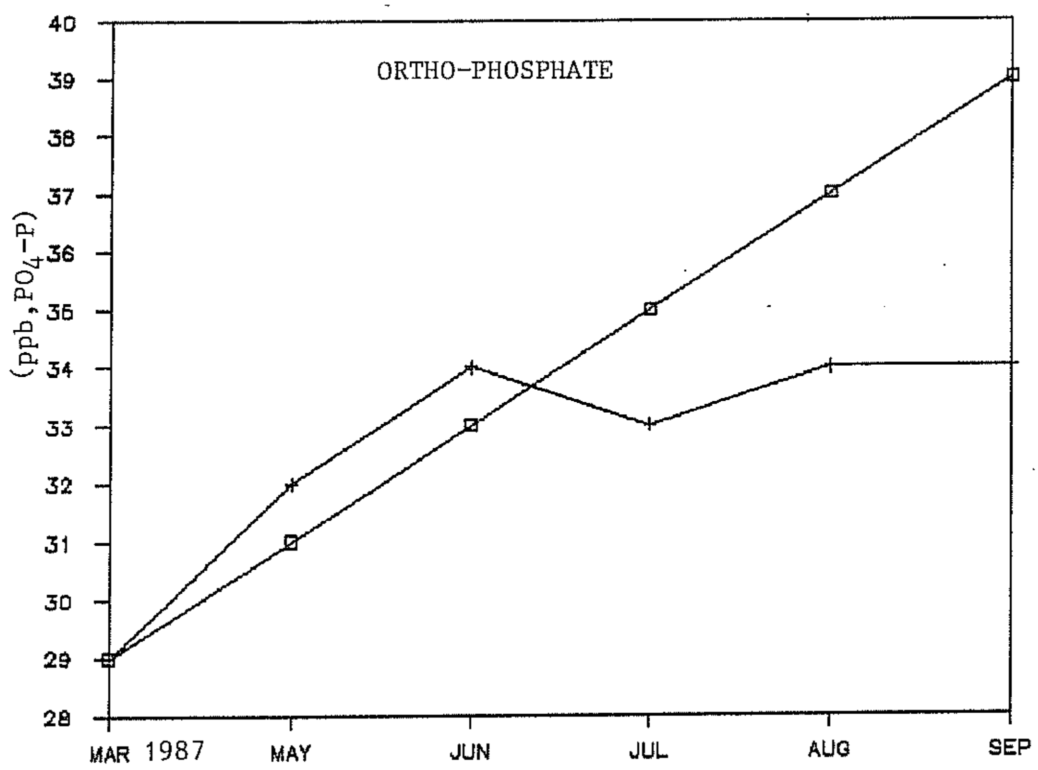


Figure 19. The calculated and measured dissolved oxygen concentrations in the bottom waters(below 30m) of the Bay.

concentrations in the bottom waters of the central and western sections of the Bay. Both the measured and calculated results predict that the DO depletion rate is about 0.2 ppm per month in the central region, but the rate is higher in the spring and early summer months due to the higher primary production and subsequent settling of particulate detritus to lower layers, and then decreases with decreasing decay rate of detritus and DO in the lower layers.

For the nutrient elements, the model results correspond quite well to the measurements (see Figure 20). However, because of uncertainties in the flux of nutrients from the waste waters, and subsequent high production in the surface layer of the eastern region, inorganic nutrients pile up in the intermadiate waters of the region as the decay products of organic matters settling from the productive surface layers. Probably, a significant proportion of inorganic nutrients in this region is consumed by benthic algae in the shallower parts that was not involved in the model. But they are very widespread in the coastal zones of the region and some species, e.g. seaweed, are collected in the eastern part of the bay and then exported to developed countries in which they are used in some industries. Moreover, some proportion of organic matter produced in the productive surface layers by photosynthetic reaction are excreted in dissolved form and accumulates in the surface layers and subsequently decays partly there before they are transported to the open waters of the bay or adsorbed on particulate matter in the water column(16,17). This process is not involved separately in the model. Excretion term is considered within the respiration term used in the model.

The results of some physical and biochemical parameters calculated in the surface layer(0-5m) by the model together with the measurements are compiled in Table 7. As can be seen from the table the simulated results practically agree with the measurements. However, $BOD_5$ results from the model were mostly found to be lower than those of measurements. It indicates that the surface waters of the Bay receive more nonsinking biodegradable organic matter with low nutrient constituents than the figures used in the model. Moreover, it is well known that a measurable proportion of planktonic organic carbon is excreted as dissolved organic matter, which stays in the surface waters until used up by microorganisms within the food chain in the bay water. Since, as depicted in Figure 21, the variations of Chll-a, TOC, POC and $BOD_5$ mostly show similar increasing or decreasing trends with time in the productive surface waters of the Bay, depending upon primary production and related phytoplankton biomass.



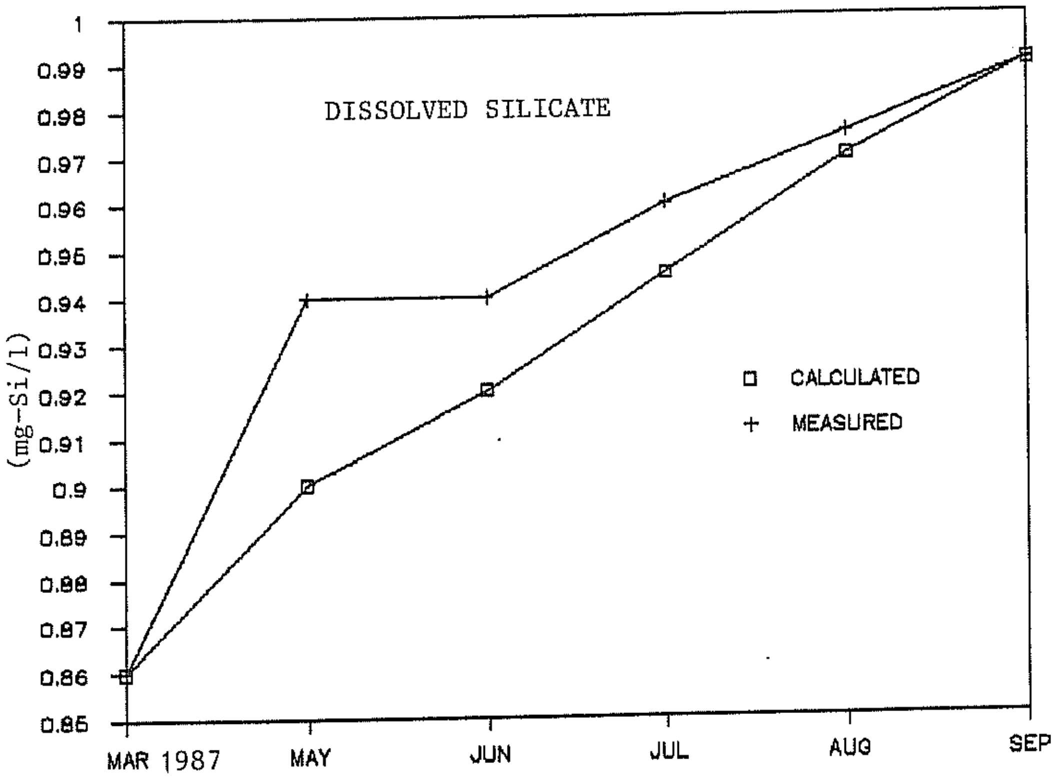


Figure 20. The calculated and measured concentrations of ortho-phosphate and dissolved silicate in the bottom layer(below 30m) of the central section of the Bay.

Table 7. The calculated and measured results of basic parameters in the surface layer (0-5 m) of the Bay on August 31, 1987.

| Parameter | Central Region | | Eastern region | |
|---|---|---|---|---|
| | Measured | Calculated | Measured | Calculated |
| Salinity(ppt) | 24.8 | 24.5 | 25.0 | 24.7 |
| Temperature(°C) | 21.6 | 21.8 | 21.7 | 21.7 |
| Nitrate+nitrite(ppb) | 6.0 | 4.3 | 8.0 | 3.4 |
| Ammonia(ppb) | 10.0 | 6.5 | 10.0 | 6.0 |
| o-phosphate(ppb) | 3.0 | 6.1 | 7.0 | 5.8 |
| Silicate (ppb) | 40.0 | 55.0 | 65.0 | 45.0 |
| Chll-a (ppb) | 0.6 | 0.9 | 1.1 | 1.3 |
| POC (mg-C/l) | 0.4 | 0.35 | 0.7 | 0.65 |
| $BOD_5$ (mg-$O_2$/l) | 1.2 | 0.9 | 1.5 | 1.3 |
| DO (mg-$O_2$/l) | 6.7 | 6.9 | 5.5 | 6.5 |

Table 8. Literature values of some constants used in the Izmit Bay water quality model.

| Parameter | | Literature Values(14,18) |
|---|---|---|
| Maximum growth rate- Total phytopl. | | 1.3-2.5 /day, at 20 °C |
| - Diatoms | | 1.8-2.5 /day, " " " |
| Non-predatory mortality rate | | 0.01- 0.17/day |
| Phytoplankton settling velocity | | 0.01-0.5 m/day |
| Algal respiration rate | | 0.05-0.15 /day, at 20 °C |
| Decay rate of detritus(POC---$CO_2$) | | 0.02-0.10 /day |
| Nitrification rate in water | | 0.02-0.30 /day |
| Denitrification rate in water | | 0.002-0.1$^x$/day |
| Nutrient/Carbon ratio in algal cell | | |
| | N:C | 0.17-0.25(mean:0.18) |
| | P:C | 0.003-0.14(mean:0.024) |
| | Si:C | 0.06-0.77(mean:0.6) |

x: This rate is multiplied by an oxygen limitation factor, $K_1/(K_1+O_2)$, where $K_1$:0.1 mg$O_2$/liter, $O_2$:dissolved oxygen concentration.

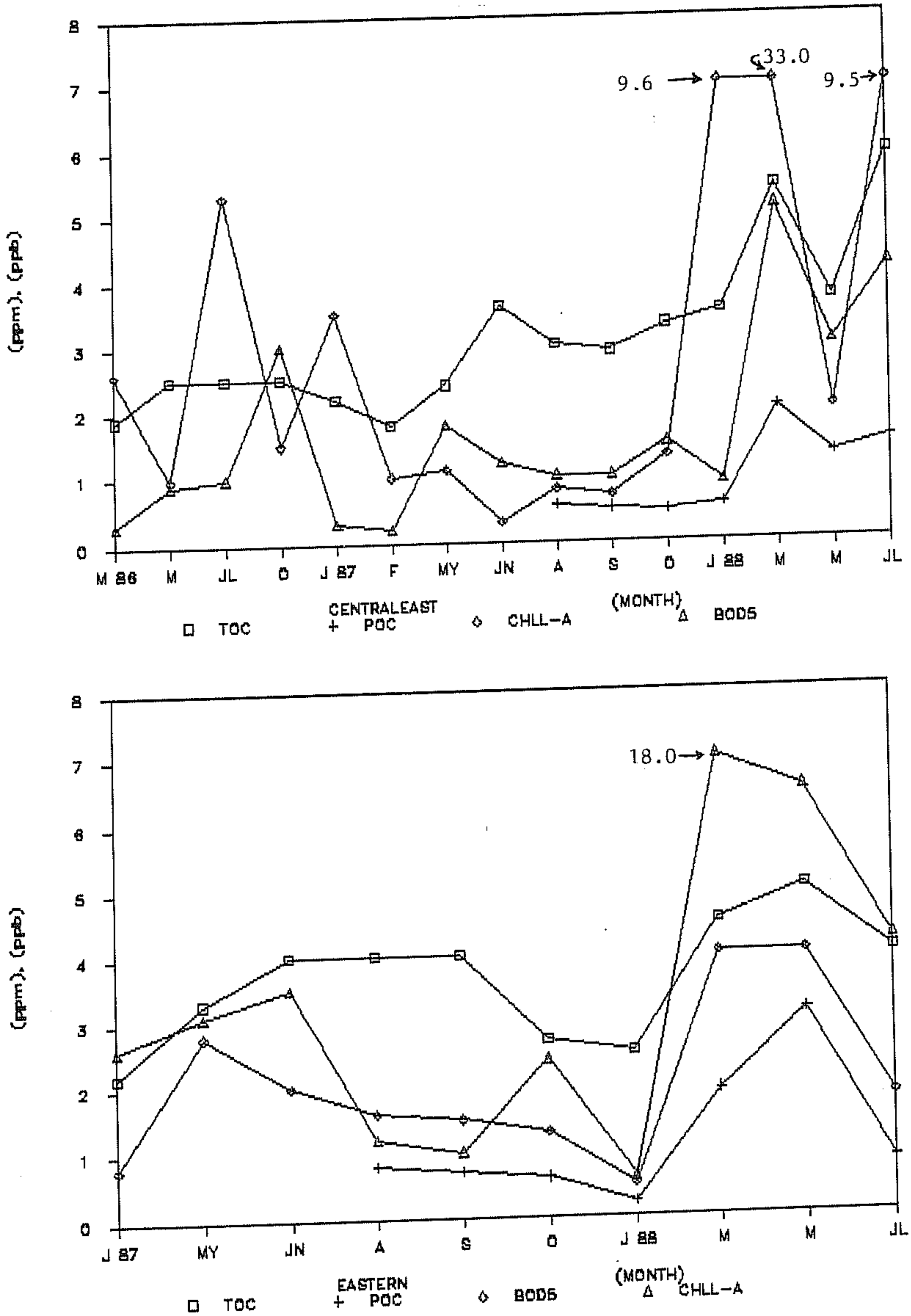


Figure 21. Measured TOC, POC, $BOD_5$(ppm) and chll-a(ppb) at 1 meter of the bay waters.

In order to estimate the reasonable ranges of constant parameters being used in the modelled processes calibration studies were performed for the constants. The variations of modelled biochemical parameters with the related constants are depicted in Figures 22-27. The results from the sensitivity analyses for such model constants as settling rate of particulate detritus, maximum production rate of phytoplankton, maximum rate of mortality, background extinction, nitrification rate in water, and mineralization rate of benthic detritus were evaluated by comparing with the measurements.

When the settling rate of biodegradable detritus above pycnocline used in the model exceeds 1 m/day the concentration of particulate organic carbon accumulating in the lower layers shows an increasing trend with regard to the measured ones as well as a significant decrease in the calculated POC concentrations of the upper layer in comparison with the measurements. Below pycnocline(25 m) any settling rate between 1.5-3.0 m/day does not change considerably the oxygen depletion rate in the bottom water layers of the Bay. However, it highly influences the benthic oxygen utilization rate and the POC concentration in the bottom layer (see Figure 22).

The variations of inorganic nutrient concentrations with the maximum production rate of diatoms used in the model are depicted in Figure 23. As the rate is increased the concentrations of dissolved inorganic nutrients in the productive surface waters decrease significantly and one of the nutrient elements is used up completely . The field measurements only showed nitrate deficiency occasionally that is a concentration below the detection limit of the method followed, 1 ppb nitrate-nitrogen. The inorganic nutrient results obtained with a rate over 2.0/day were never observed in the studied area. Thus, a production rate ranging between 1.8-2.0 was found to be reasonable for the model.

The rate of mortality used in the model, first of all, changes the concentration of phytoplankton and related chll-a concentration, and particulate organic carbon values in the surface and intermediate waters of the Bay. The variations of chll-a and POC concentrations with the mortality rate of algae together with the measured ones are illustrated in Figure 24. Since C/chll-a ratio was not measured in the Bay of Izmit a ratio of 50 was used in the model to calculate chll-a concentration from the model. This ratio, depending on the oceanographic characteristics of the marine environments, mostly ranges from 50 to 100. The literature values of some constants used in the Izmit water quality model are compiled in Table 8.

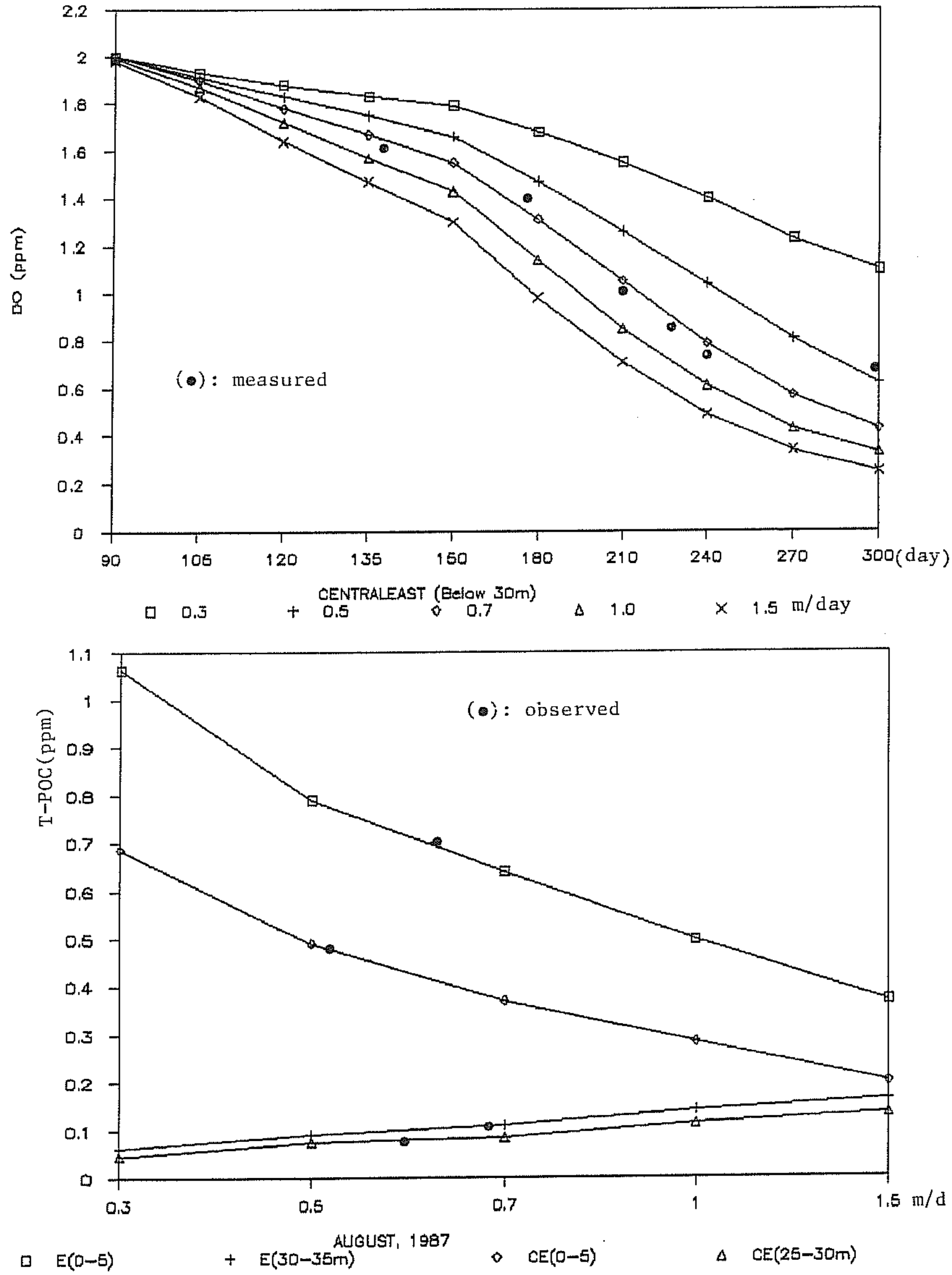


Figure 22. Variations of POC and dissolved oxygen with settling rate of detritus(m/day) above pycoline in different layers of the eastern(E) and centraleast(CE) regions of İzmit Bay.

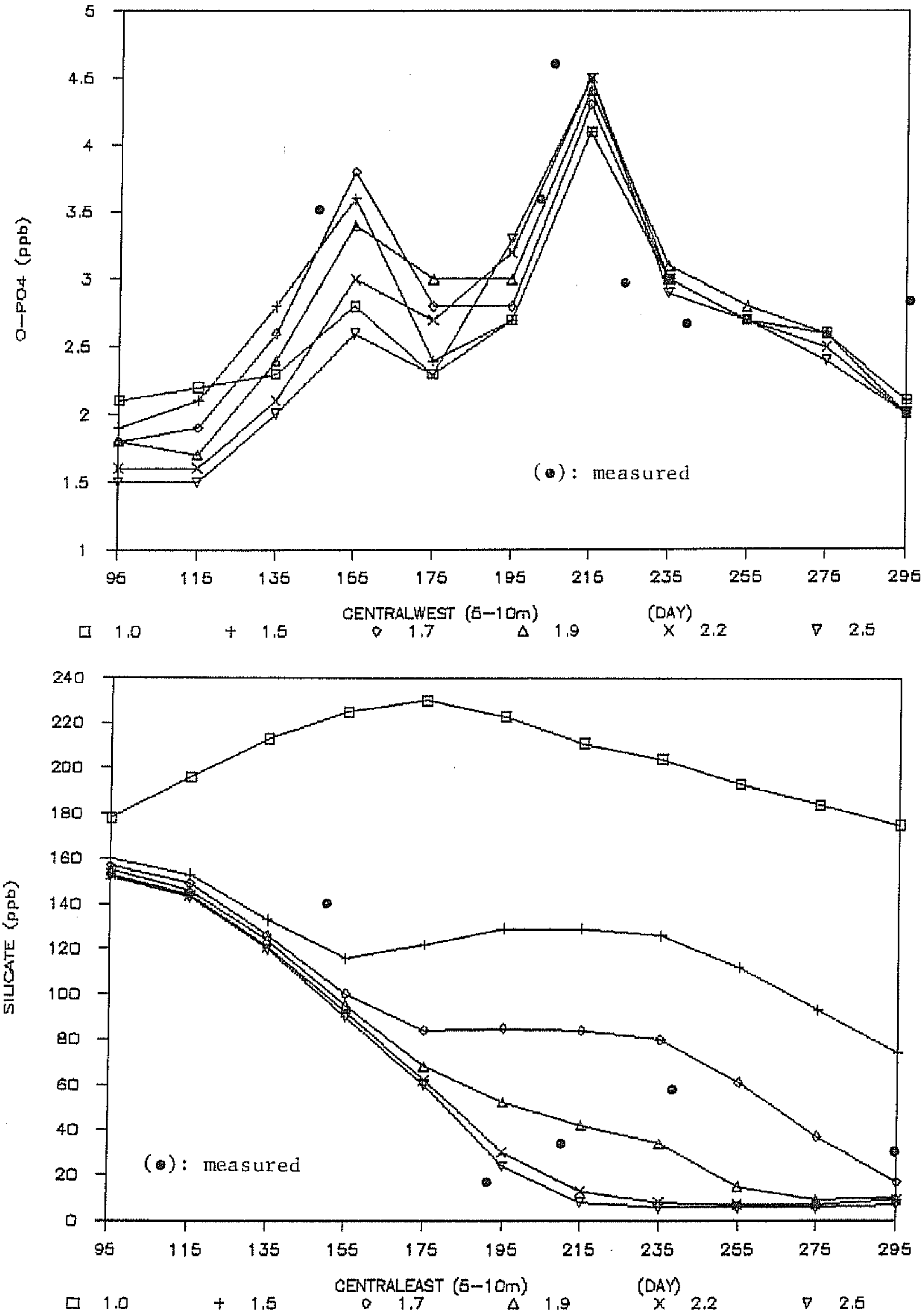


Figure 23. Variations of o-phosphate and silicate concentrations with maximum production rate of diatoms(1/day), whereas max. production rate of other phytoplankton: 1.9/day.

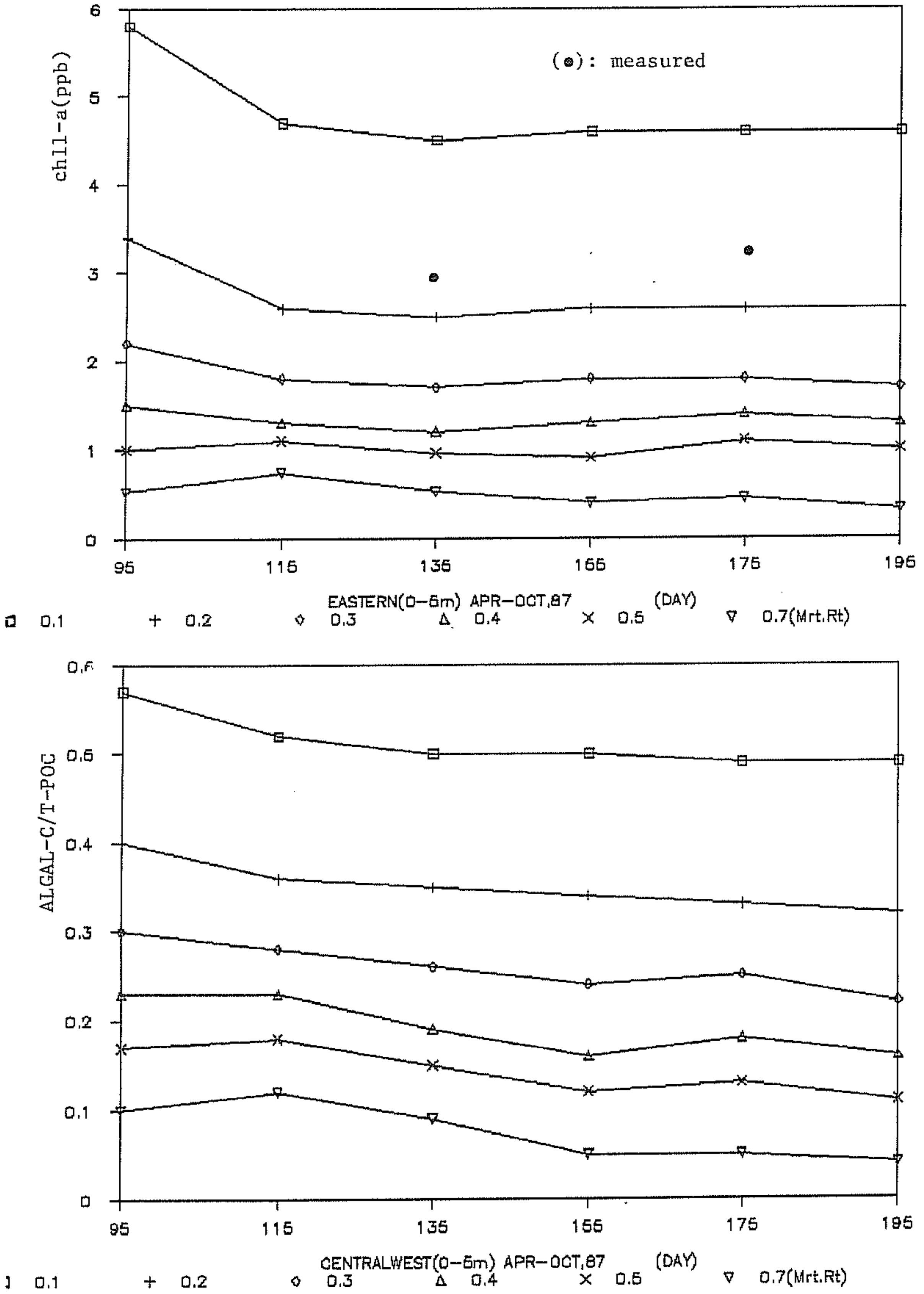
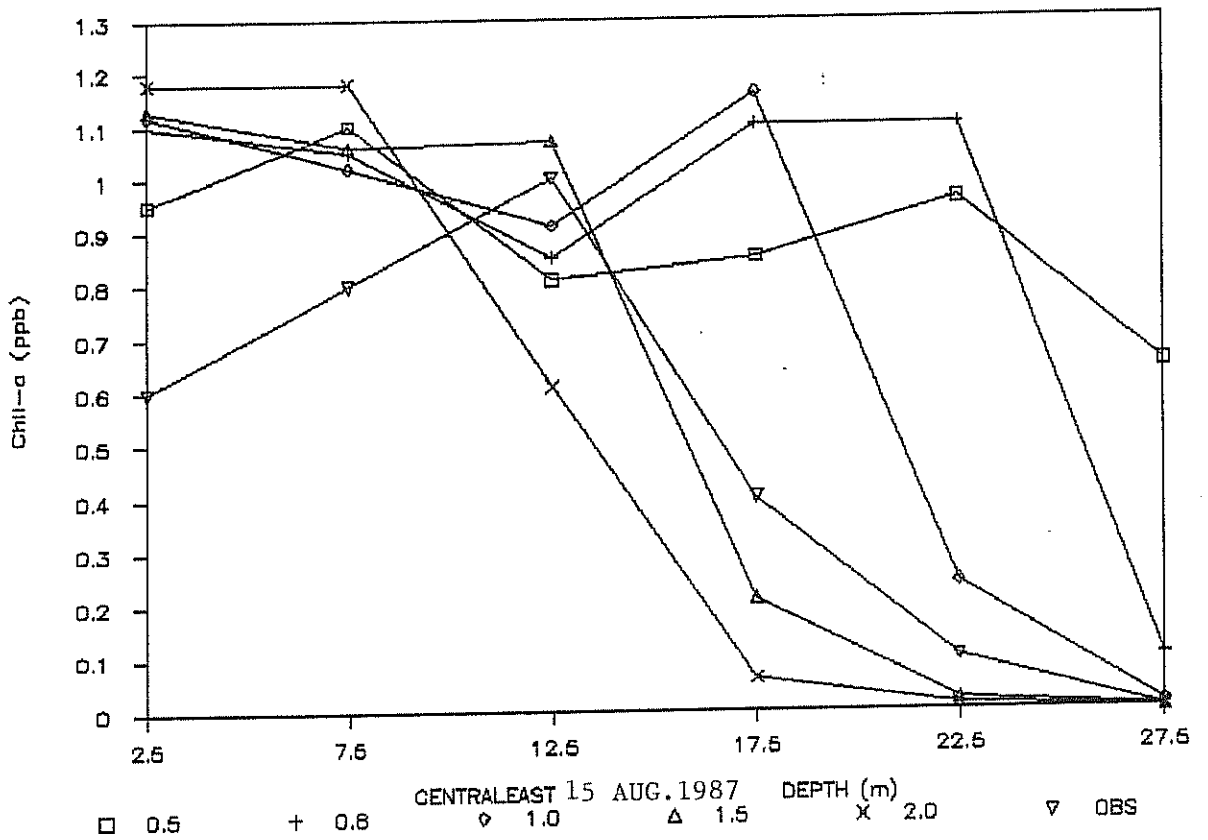


Figure 24. Variations of chll-a(assuming algal C/chll-a ratio:50) and algal C/T-POC ratio with mortality rate(1/day).

The extinction of light in water, which is determined by the characteristics of aquatic environments, such as particulate and dissolved organic matter concentrations and dissolved minerals in waters, may effect remarkable changes in the levels of algal production profiles with time(thus, phytoplankton biomass and related chll-a concentrations with depth) if light is transmitted enough to the lower layers of aquatic environments. Since, the nutrient elements are first exhausted in the surface waters unless continuous input from natural or anthropogenic sources exists, the production of algae increases with depth at which light intensity is sufficient for photosynthetic reaction and inorganic nutrients are available for algal production. The total extinction coefficient used in the model involves background term and specific extinction from particulate organic matter, which are constant and variable with time respectively. From the measurements of light intensity performed in the bay the range of total extinction coefficient was estimated(see Table 6). Thus the background term was calibrated by comparing the results of chll-a and nutrients measured with the ones calculated by using different background extinction coefficient values(Figure 25). The optimum value for the present situation was found to be about 0.1/m.

The nitrification rate affects the dissolved ammonia concentration in deep waters of the eastern region. When a rate, less than 0.1/day is used in the model the ammonia concentration increases significantly. Such values were not observed in the studied area in 1987. In July 1988, an ammonia concentration of 50 ppb was detected in the bottom waters of the eastern region. The high values measured demonstrate that algal production was relatively high in the summer of 1988 and the residence time of water in bottom layers of the region was expected to be longer in 1988 relative to that in the summer months of 1987. The variation of dissolved ammonia concentration with the nitrification rate in water is illustrated in Figure 26.

The mineralization rate of benthic detritus affects significantly both the levels of dissolved inorganic nutrients and dissolved oxygen in the bottom waters of any shallow semi-enclosed seas as in the Bay of Izmit, due to sedimentation of large amounts of degradable detritus from the surface waters, relatively small volume and long residence time of bottom waters in the stratified systems. The variations of DO and inorganic nutrients with different mineralization rates of benthic detritus are depicted in Figure 27. As the rate exceeds 0.1/day drastic changes are observed in the computed results of both DO and inorganic nutrients in the bottom waters of the inner Bay, particularly in the eastern part.



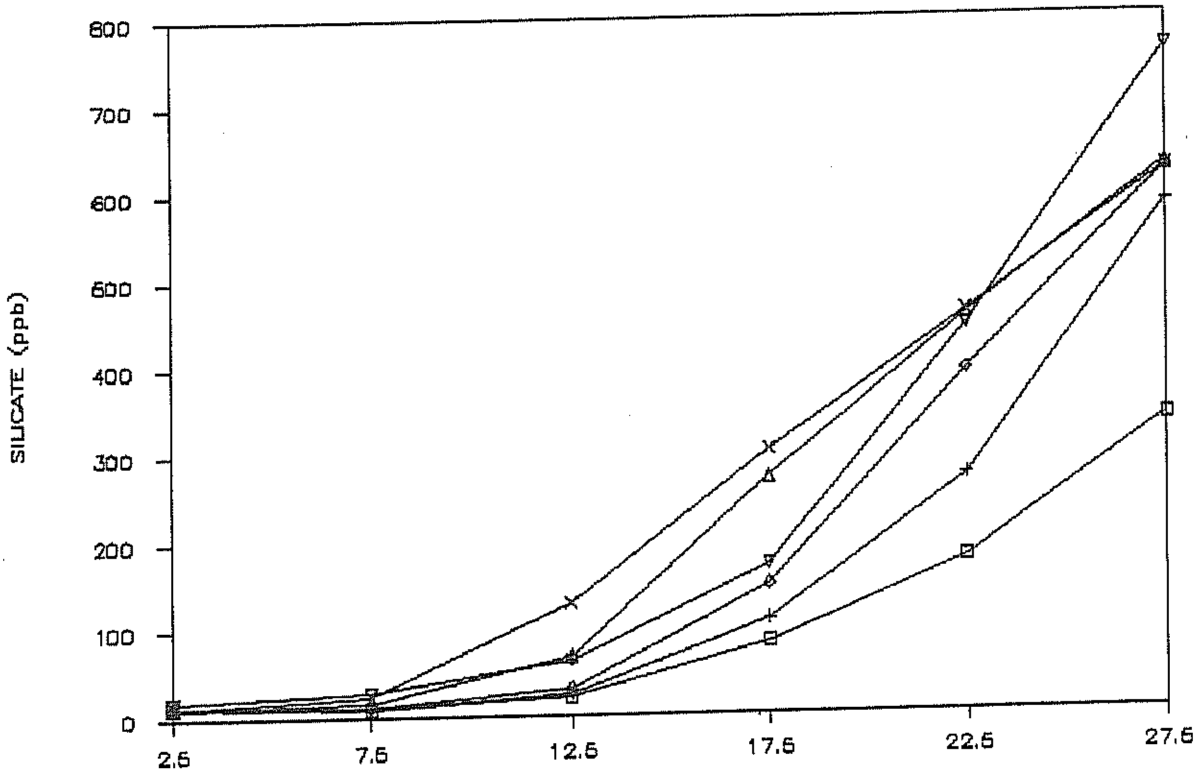


Figure 25. Variations of chll-a and silicate gradients with background extinction coefficient(1/m).

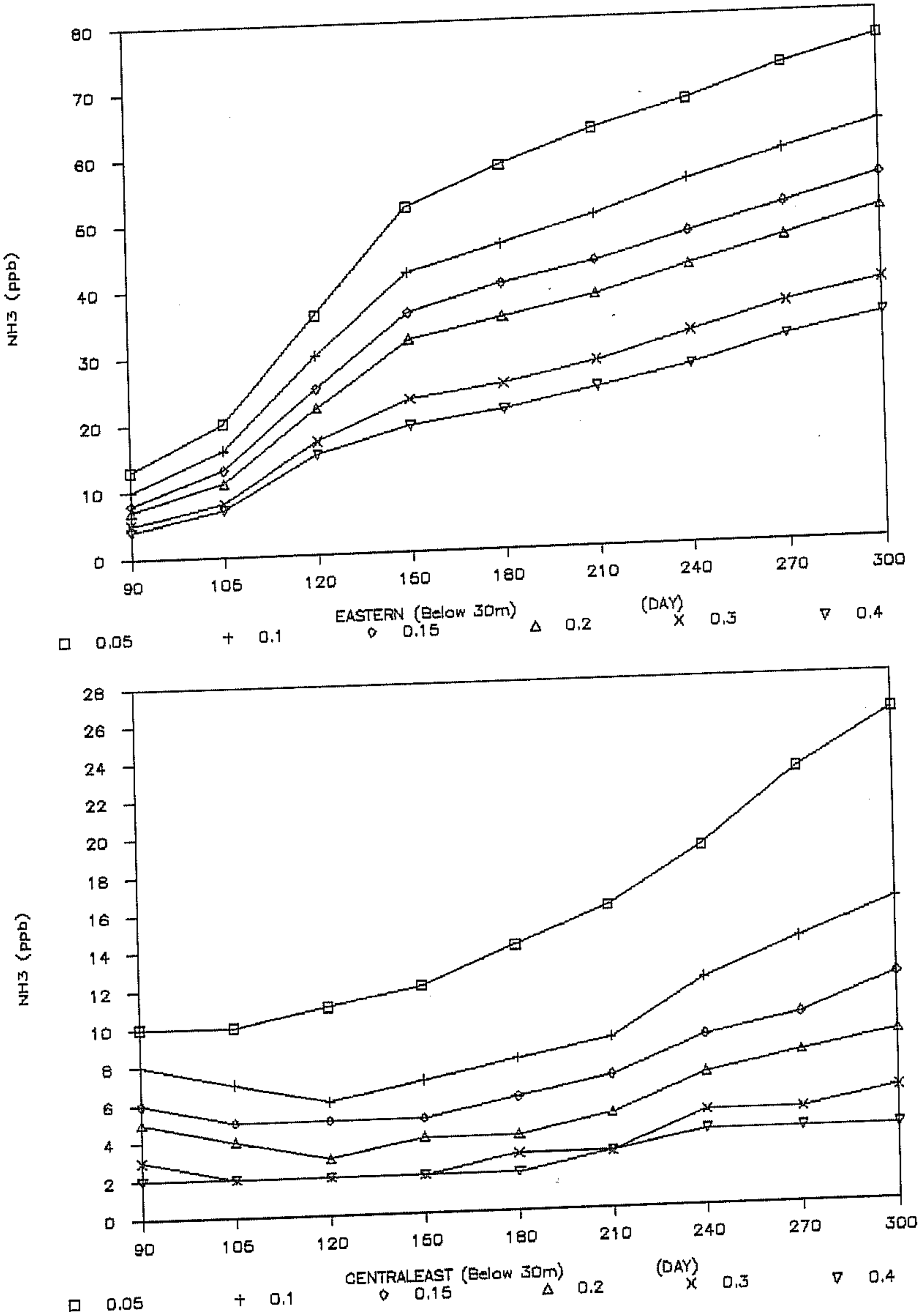
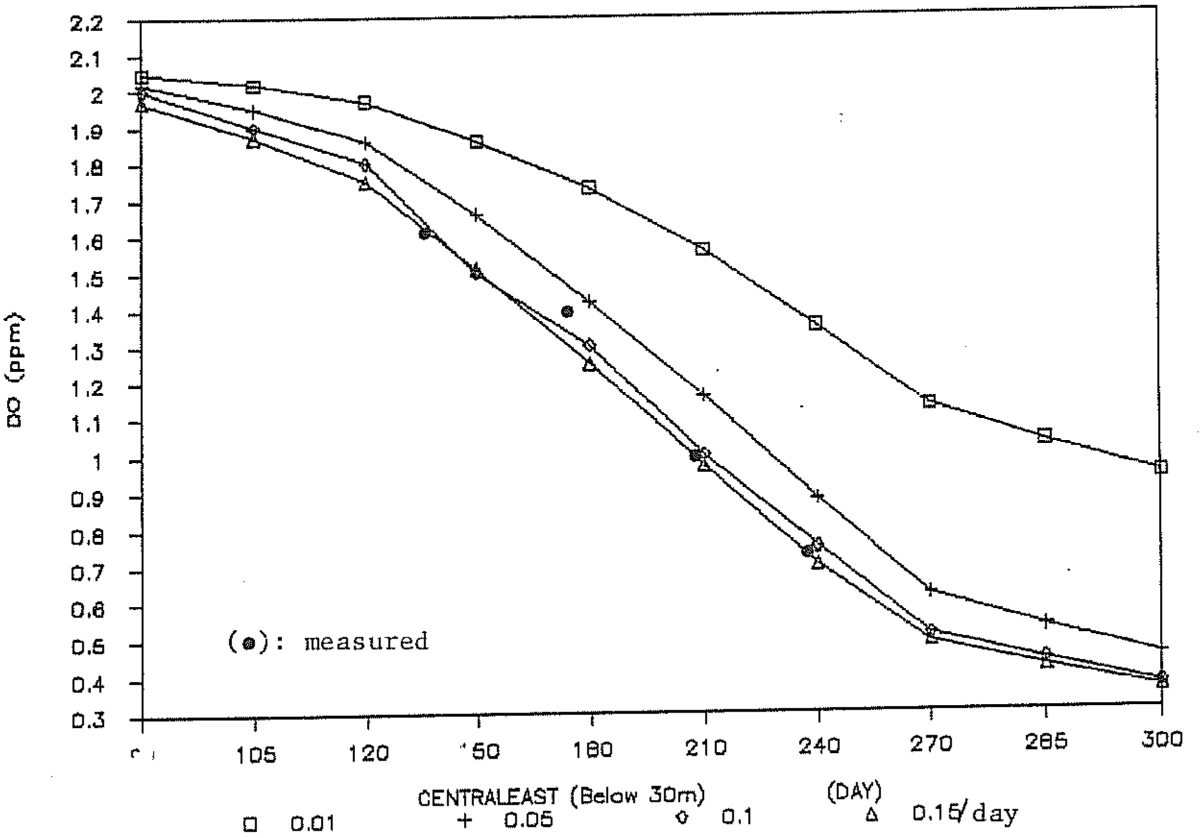


Figure 26. Variation of dissolved ammonia with nitrification rate(1/day) in the water.



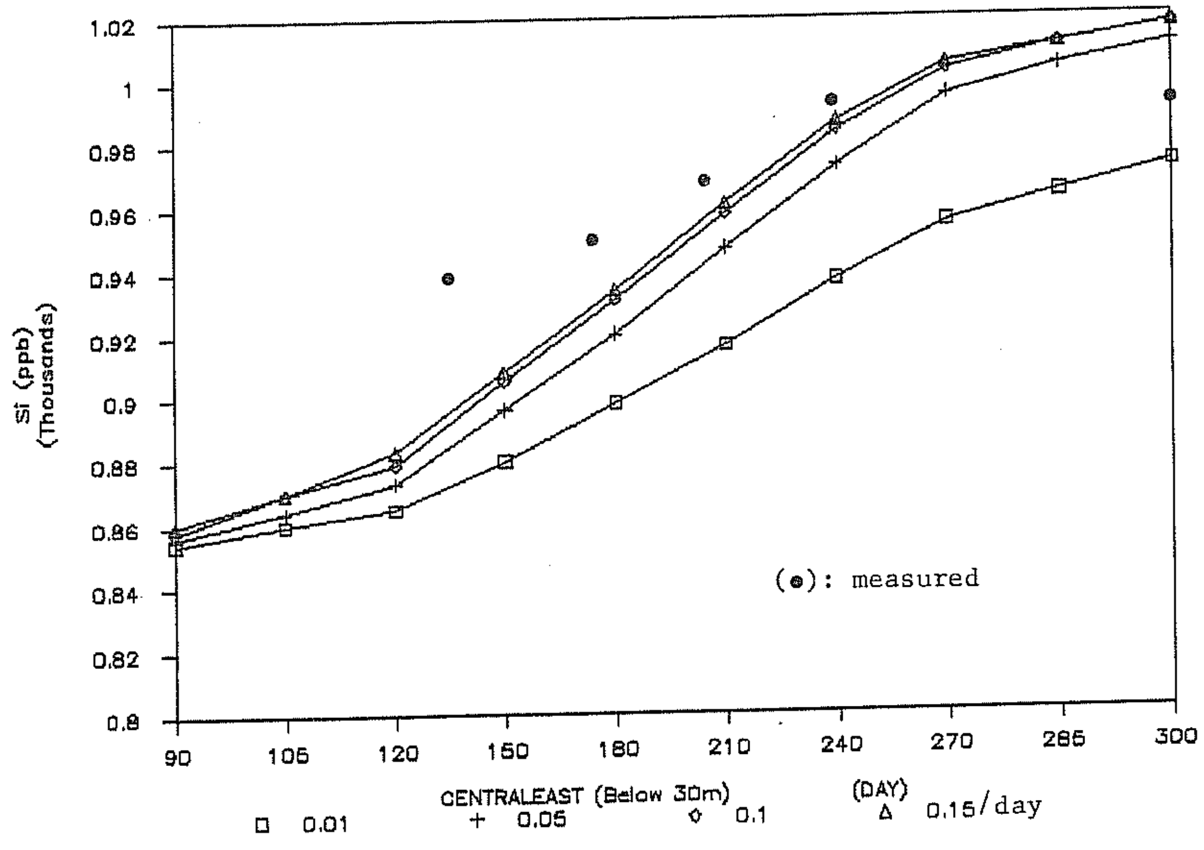


Figure 27. Variations of the dissolved oxygen and silicate concentrations in the bottom waters with the mineralization rate of benthic detritus.

We know that a master plan has been prepared for sewerage and outfall systems for the disposal of partly treated waste waters to deep waters of the Izmit Bay, particularly to the eastern and central sections of the Bay. The construction of the systems is probably completed in ten years. A deep-sea outfall system, that is planned at semi-enclosed receiving water environments with little water movements, should aim at:
a) lowering photosynthetic production and simultaneously resulting in clearer surfacial waters by reducing the amounts of inorganic nutrients, particulate matters and detritus entering the surface waters,
b) entrapping patogenic microorganisms at these larger depths and far from the surface by using advantage of variations in the density of water (and stratified flow) especially in the summer months,
c) increasing the dissolved oxygen level of intermediate and surface waters without changing DO concentration significantly in the lower layers of receiving water environments.

This approach could be applied when water movement is sufficient to rapidly renew the waters, but not in any receiving water environment where water movement (i.e. exchange rates between the segments and adjacent waters) is poor. Under unfavorable circumstances, the following detrimental consequences could result in:
a) The dissolved oxygen concentrations will decrease rapidly in deep waters, since the only sources for oxygen at these depths are the DO in small quantity of infowing waters from adjacent seas and diffusion from upper layers through weak vertical mixing.
b) In disposal areas, there will be an over accumulating polluted sludge on the sea bottom, which will be a continuous source of contamination in narrow, semi-enclosed receiving water environments.
c) Rising of polluted deep waters to the surface at certain period, which could occur from natural water movements, results in undesirable water quality as a consequence of high photosynthetic reaction under suitable environmental conditions ( e.g. red-tide events).

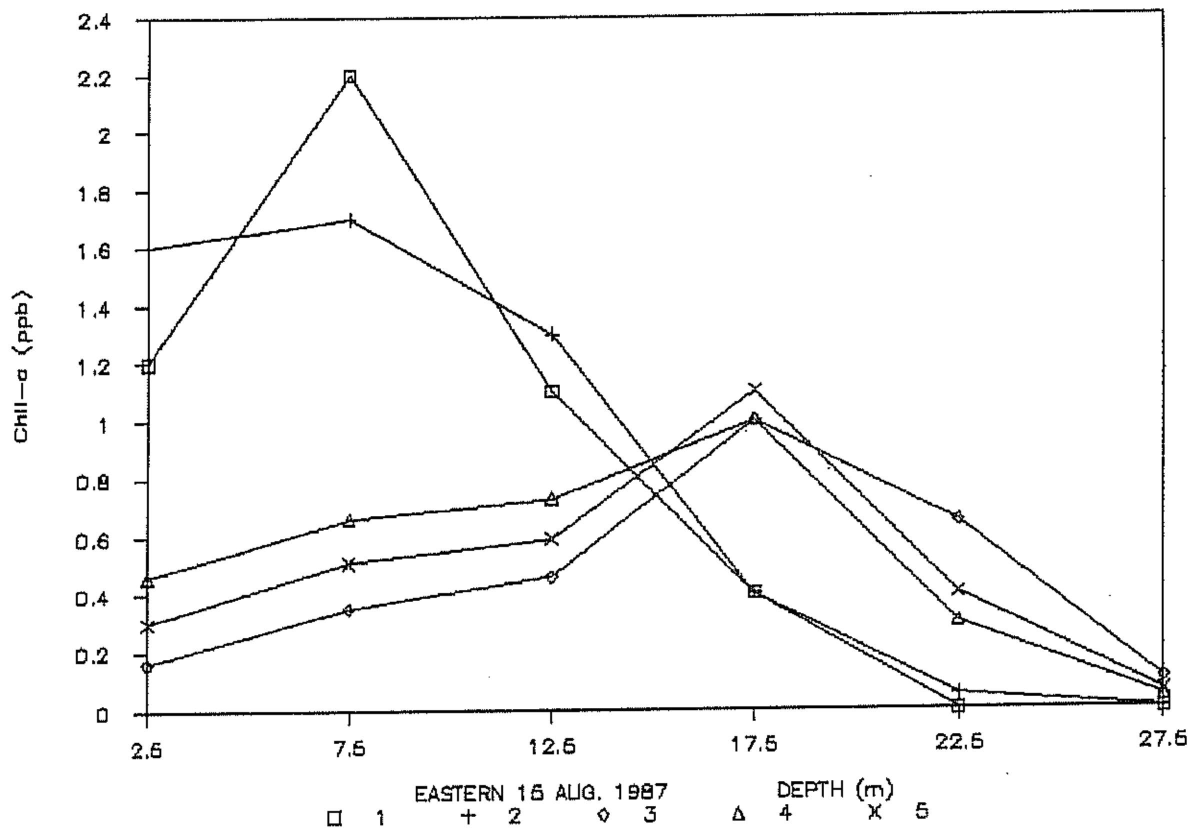
By taking into consideration the ultimate aim of the outfall systems scientifically and the points stated above, the water quality model, that was adopted and calibrated for the Izmit Bay, has been used to assess the effects of waste loads on the receiving waters by the use of three scenarios. The scenarios are thus characterized as follows:

1. (approximation of) present situation,
2. no waste loads at all (natural situation),
3. various amounts of waste loads are injected into the first or seventh layers(below 30 meters) of the eastern and central sections of the Bay.

In order to obtain reliable results from a water quality model, it must represent the present situation of the receiving water environments very well, approximate the measurements in reasonable ranges, and finally allow the users to simulate different alternatives for waste disposal. The present model used in the Izmit Bay study makes this goal possible.

First of all, the effect of waste loads on production in the Bay has been examined. The chll-a concentrations for different situations estimated from the algae concentration by the model are illustrated in Figure 28. Due to waste loads large amounts of nutrients are added to the system and this results in the chll-a concentrations of about 6-8 times the simulated 'natural' levels in the surface waters (0-5m) of the eastern region.

The effect of waste loads is further illustrated by the development of the dissolved oxygen concentration near the bottom (see Figure 29). In the absence of waste loads the DO concentration above the bottom in the eastern section is about 2 ppm in the summer and then drops to a value of 1.5 ppm in September. The present waste loads with the values in Table 5 affect the oxygen situation significantly in the bottom water of the eastern section of the Bay, even 20% of the present loads are discharged uniformly into the bottom or surface waters of the region (see Figure 30). As the loads are reduced only to 5 % of the tabulated values the water quality of the region is expected to approach the simulated natural situation. Since, the volume of water layers is very limited and the residence time of waters in the bottom layers is not short enough to prevent drastic oxygen depletion. In addition, the natural level of DO in the deep waters of the Marmara Sea is too low to compensate for the oxygen utilization within the Bay. For example, the bottom waters of the western region of the Bay has about 2-3 ppm of dissolved oxygen in the relatively oxygen-rich winter months.However, the waste loads discharged directly into the bottom waters of the central region of the Bay do not cause significant changes in dissolved oxygen relative to the simulated natural situation of the region if the amounts of loads are reduced to 10% of the present loads.



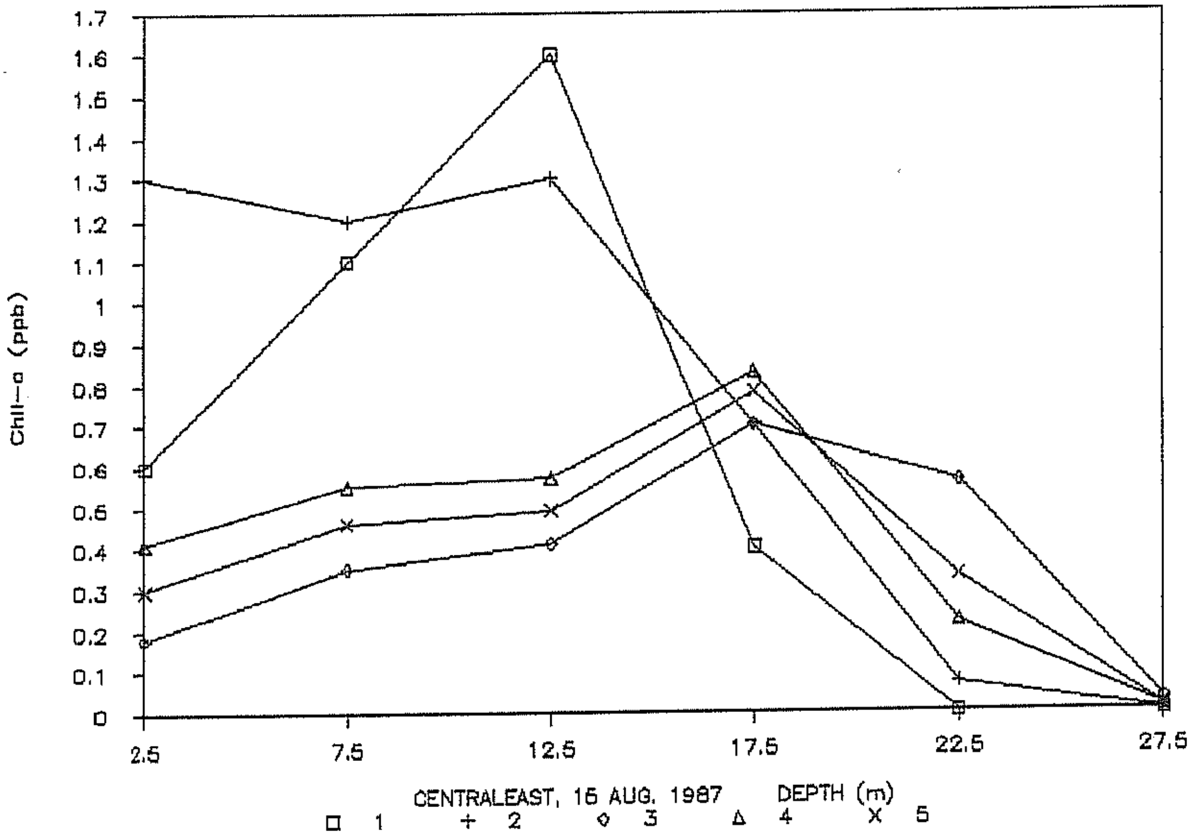


Figure 28. Calculated and measured chll-a gradients, assuming algal C/chll-a:50. 1:measured, 2:present waste loads to surface layer(0-5m), 3:zero discharge, 4:1/5xpresent waste to surface, 5:1/10 x pres. waste to sur.

The effects of the estimated current waste loads on the distributions of nutrients, particulate organic carbon(POC) and dissolved oxygen in the bay waters were simulated by using three different waste loads; the present values, 50, 20, 10, 5 % of the present waste loads. The variations of biochemical parameters with waste loads are illustrated in Figures 29-33. A measurable increase in the DO concentration with decreases in the waste loads used in the model shows the importance of treatment system, particularly for the eastern region of the Bay, before discharging wastewaters into deep waters. The model results also indicate that a certain amount of waste loads with relatively low nutrients have to be given into the intermadiate waters of the eastern region of the Bay to keep the bottom waters oxic(oxygenated) during the summer period. The increase in the calculated o-phosphate concentration in the bottom waters of the central and eastern parts with regard to the measurements indicates that some proportion of dissolved phosphate might be removed from water to the bottom through chemical and/or adsorption reactions taking place in the water, which are not considered in the model.

As it is stated in the preceding paragraphs rising of the polluted deep waters to the surface layers in certain periods results in undesirable water quality in semi-enclosed water environments which have low water movements. Such a situation is likely encountered occasionally in the eastern part of the Izmit Bay as a consequence of strong easterly winds prevailing in the studied area, which highly determine the water circulation in the Bay as pointed out briefly in Part 2.3, and some proportion of nutrients with sea water can be carried to the surface layers of the eastern region in the spring and fall months due to weak stratification existing in these months. But it is very difficult to estimate the extent and duration of upward movement of deep waters in the eastern region. Therefore the variation of phtoplankton biomass as chll-a was simulated using different vertical flow rates and the results are depicted in Figure 34. In addition to significant increases in chll-a concentration, it is likely that one of the phytoplankton species becomes dominant in the surface waters for a while and the appearance of algal bloom may effect significant changes in the water resources of the area.

The variations of physical and biochemical parameters as a function of time, which were simulated for the present situation in different parts of the Izmit Bay, are depicted in Figures 35.a-35.m.

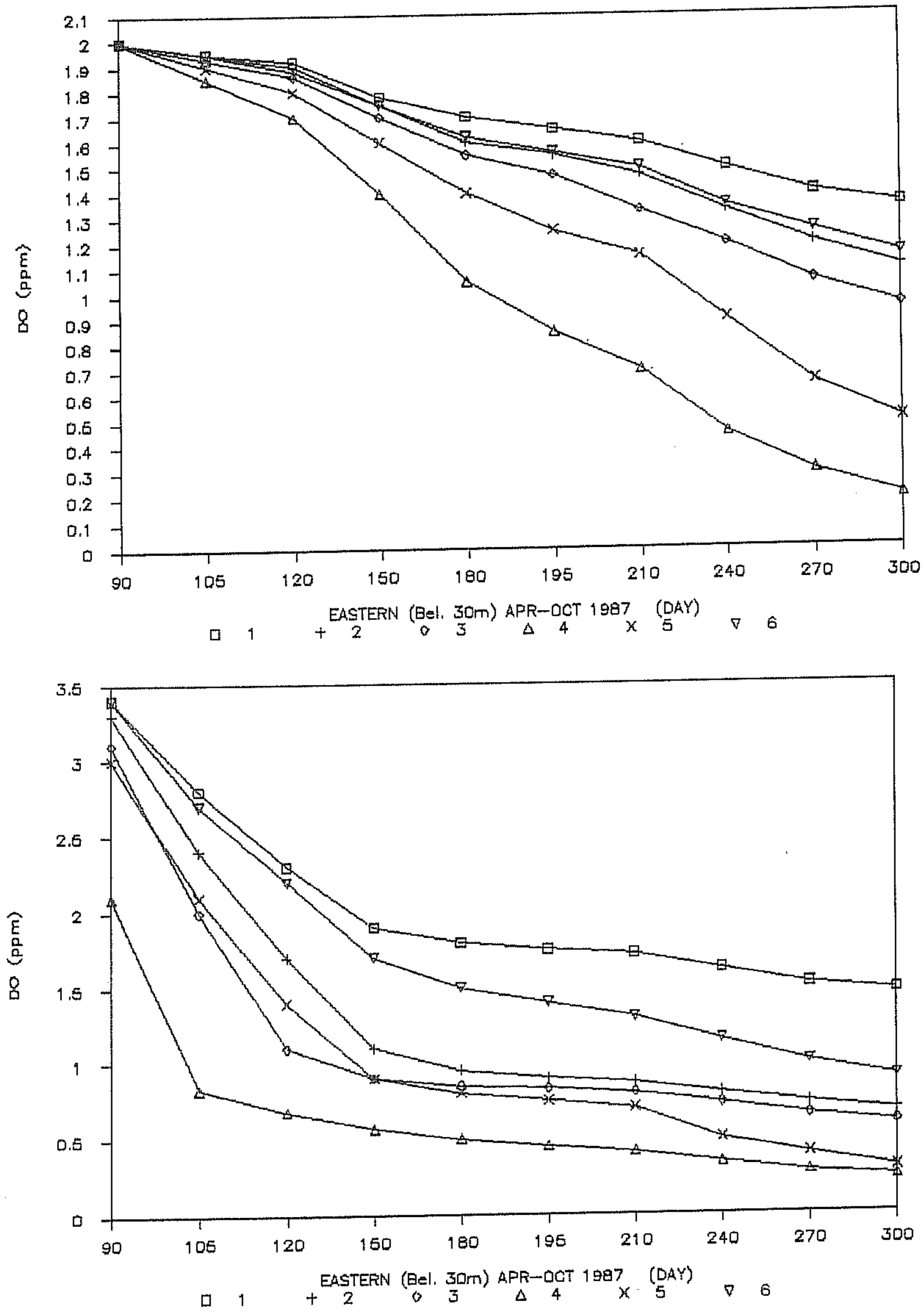


Figure 29. Effect of waste loads on the dissolved oxygen concentrations in the bottom waters of the bay(below 30 meters).

1: zero discharge, 2: 0.05x present waste loads to bottom(7th layer in the model), 3: 0.1 x " " " " "
4: 0.5x waste loads to bottom, 5:all waste to surf., 6: 0.2xwaste to surface.

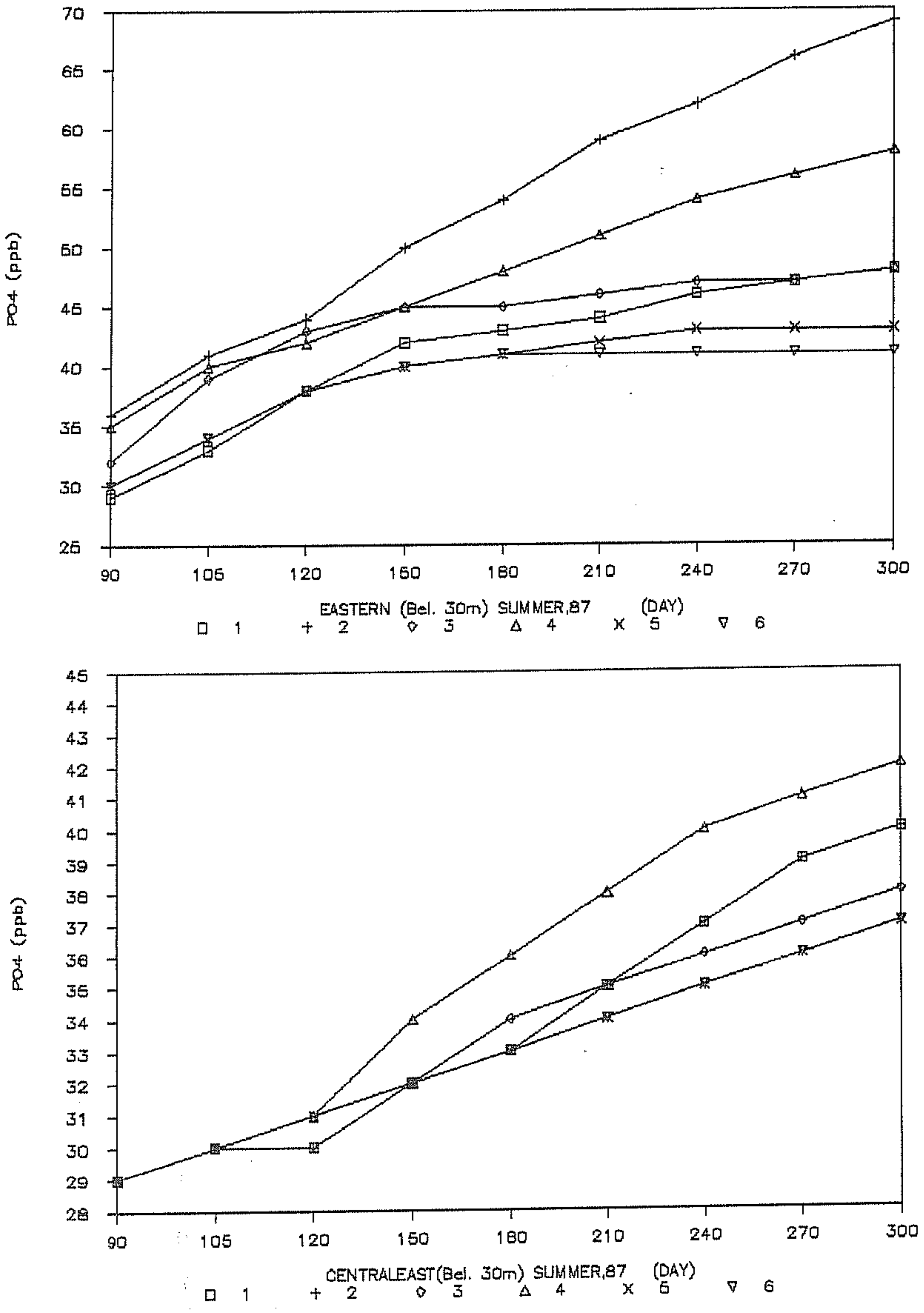


Figure 31. Variation of o-phosphate with waste loads injected into bottom and surface layers in the model.

1: waste to surface, 2: waste to bottom, 3: 0.1x waste to bottom, 4: 0.5x waste to bottom, 5: 0.2x waste to surface layer(0-5m), 6: zero discharge(estimated natural situation).

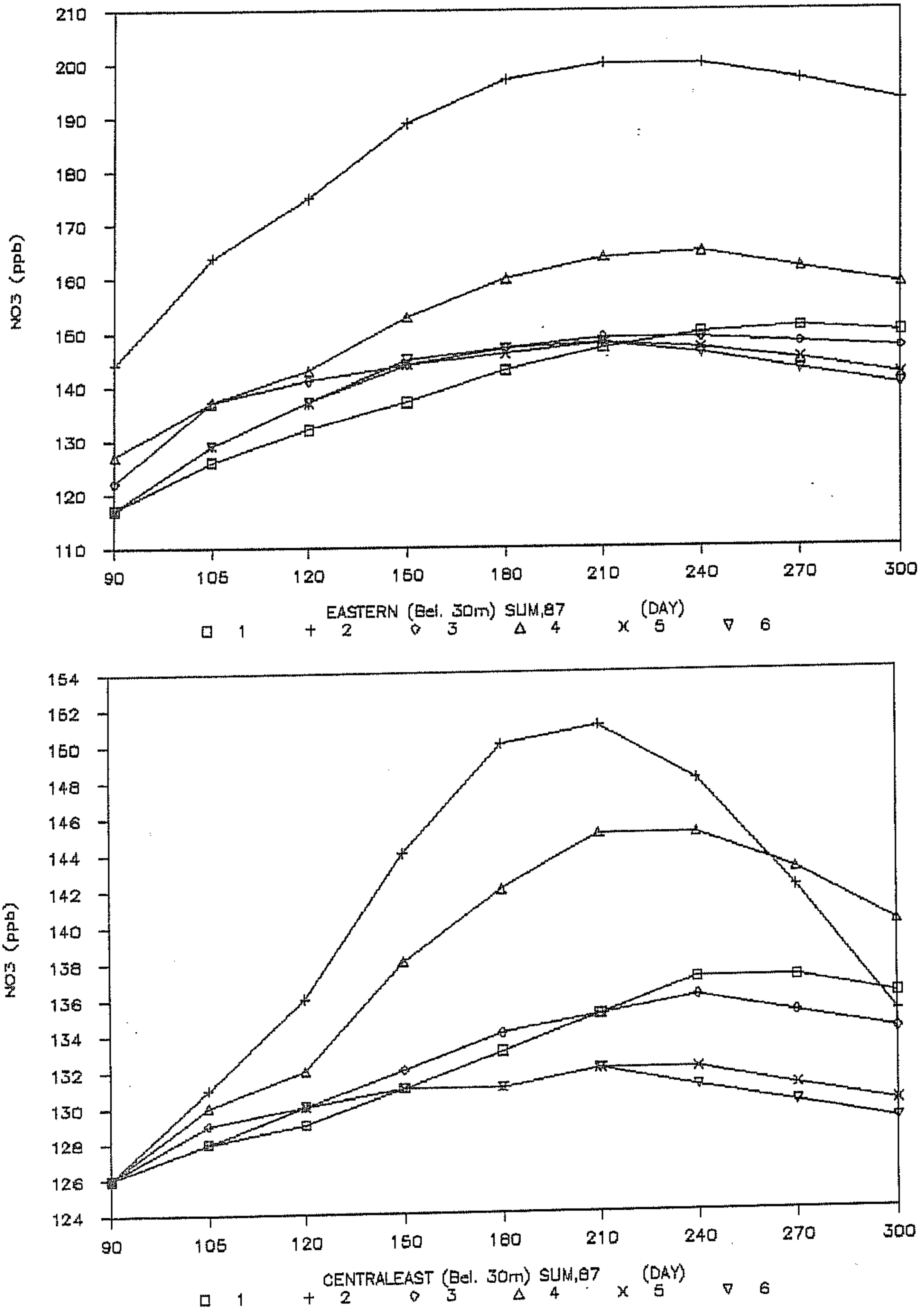


Figure 32. Variation of nitrate with waste loads injected to different layers.

1: present waste loads to surface layer(0-5m), 2: waste to bottom,
3: 0.1x waste to bottom layer, 4: 0.5x waste to bottom,
5: 0.5x waste to surface layer, 6: zero discharge.

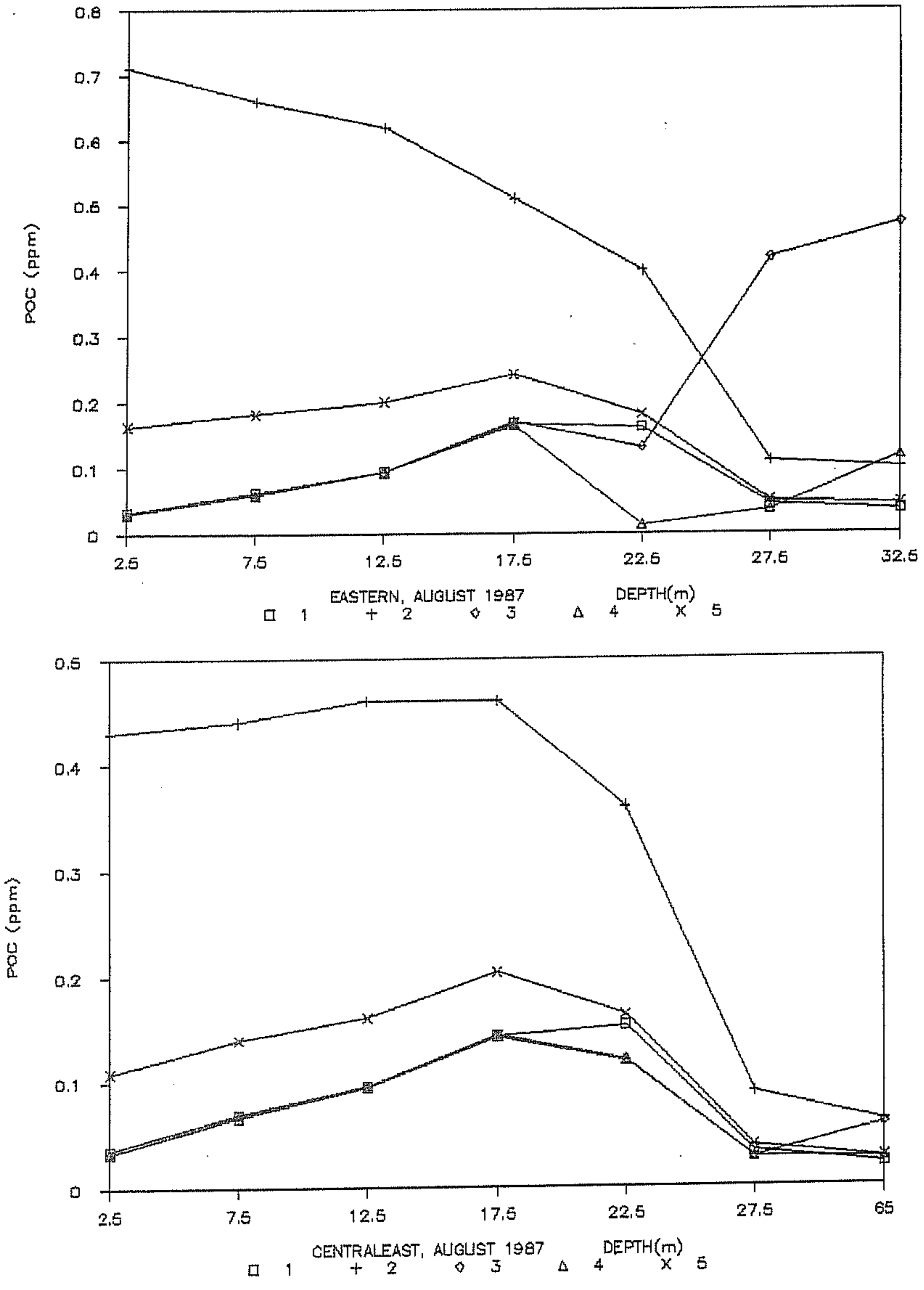


Figure 33. Total particulate organic carbon(POC) gradients simulated by using different waste loads.

1: zero discharge, 2: pre. waste to surface layer, 3: 0.5x pre. waste to bottom layer, 4: 0.1x waste to bottom, 5: 0.2x waste to surface layer(0-5m).

it is suggested to extend the model and survey towards the Marmara Sea. Thus, the effects of wastes from the Istanbul area on the Bay system can be estimated by the extended model.

The simulated results of physical and biochemical parameters indicate that the eastern part of the Bay has the limited self-purification capacity due to its low water volume and relatively long residence time of the bottom waters in the region with regard to the amounts of oxygen supply and organic matter sinking from the upper water layers into the bottom waters of the region per unit time. Since, according to the model results, the oxygen supply to the bottom waters of the region through vertical diffusion and horizontal water inflows and outflows taking place between the segments of the Bay and with the Marmara Sea is far from to compensate for the consumption rate of oxygen observed in the area. Therefore, from the results of the model, a load of 2.0 tons of degradable organic carbon can be given to the deep waters of the eastern part daily. In order to keep the bottom waters oxygenated and develop water quality in the Bay, particularly in the eastern, waste waters should be discharged from various water depths and points into the deep water layers to reach expected dilution and dispersion, since the water movements in the Bay is very weak during the summer.

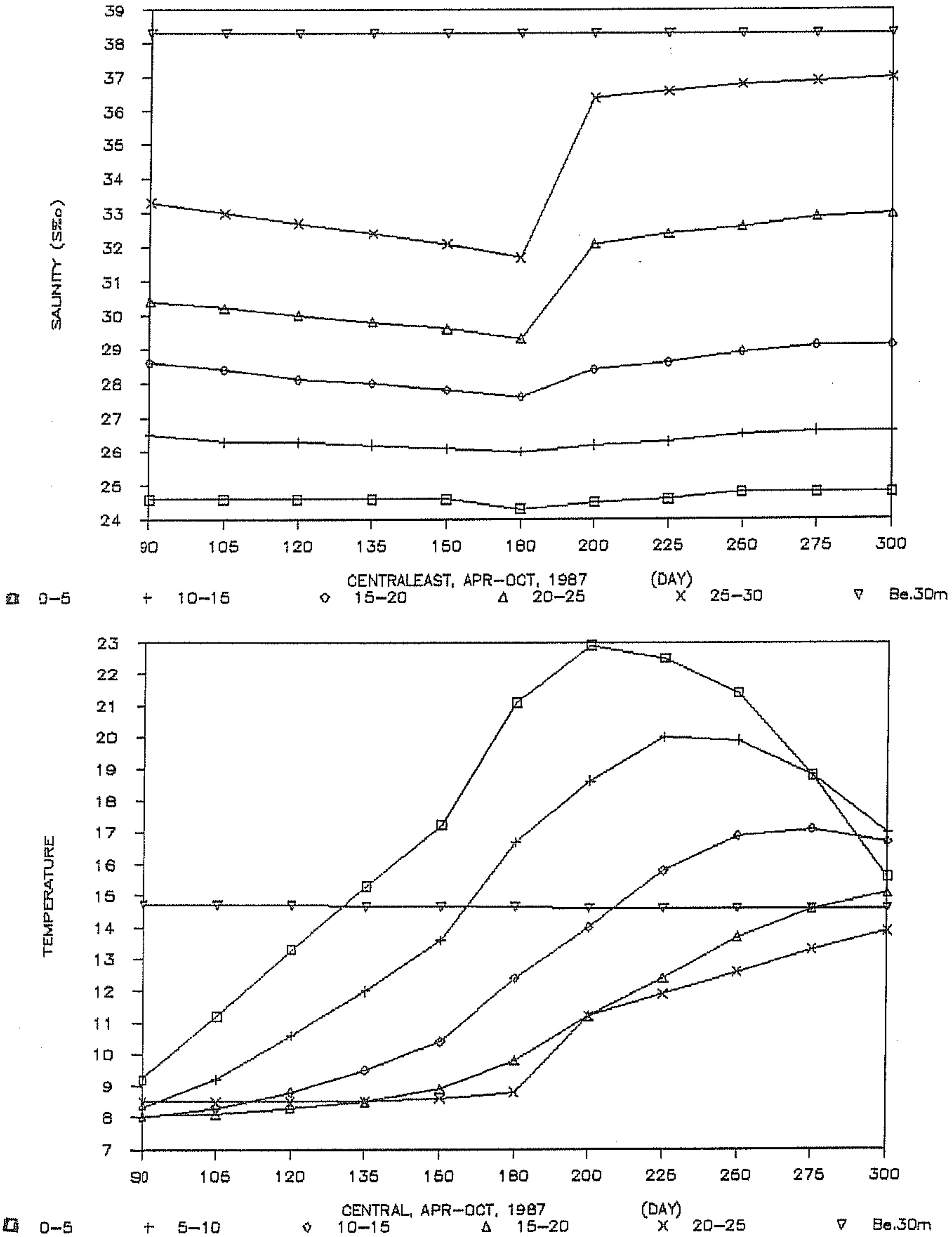


Figure 35a-b. Simulated salinity and temperature values in the layers of the central section of the bay.

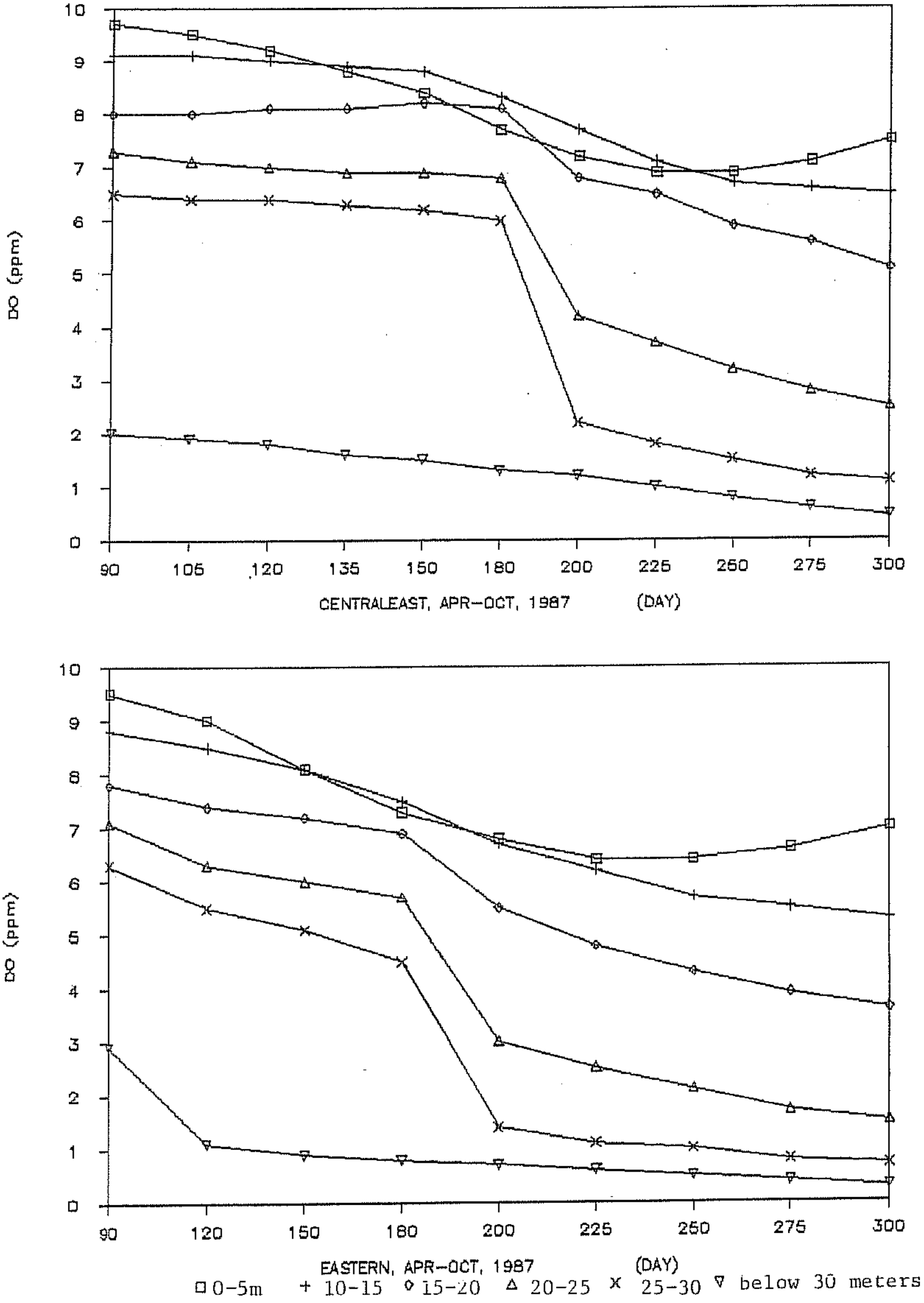


Figure 35c. The dissolved oxygen concentrations in different layers of the bay waters simulated for the present waste loads situation.

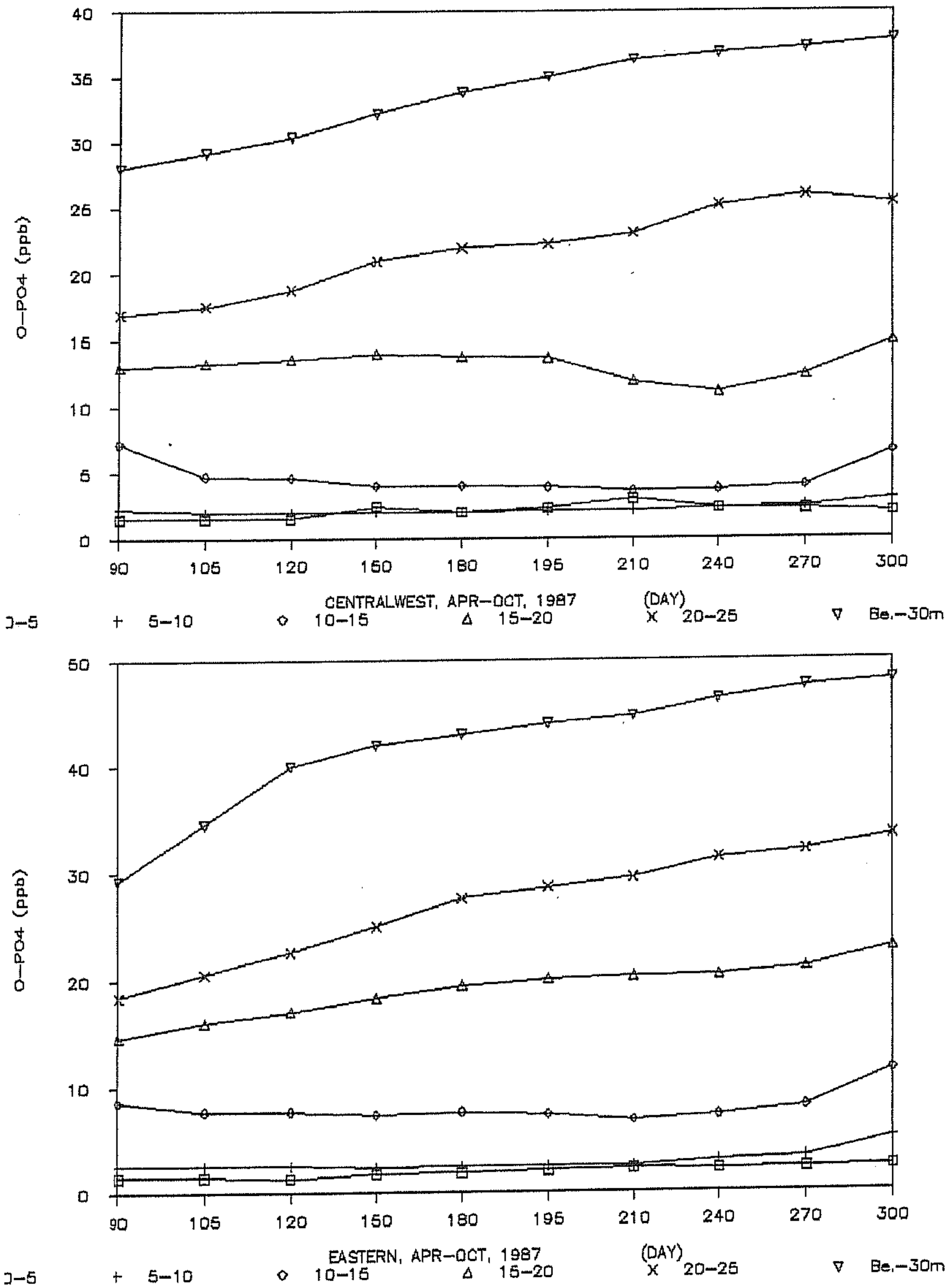
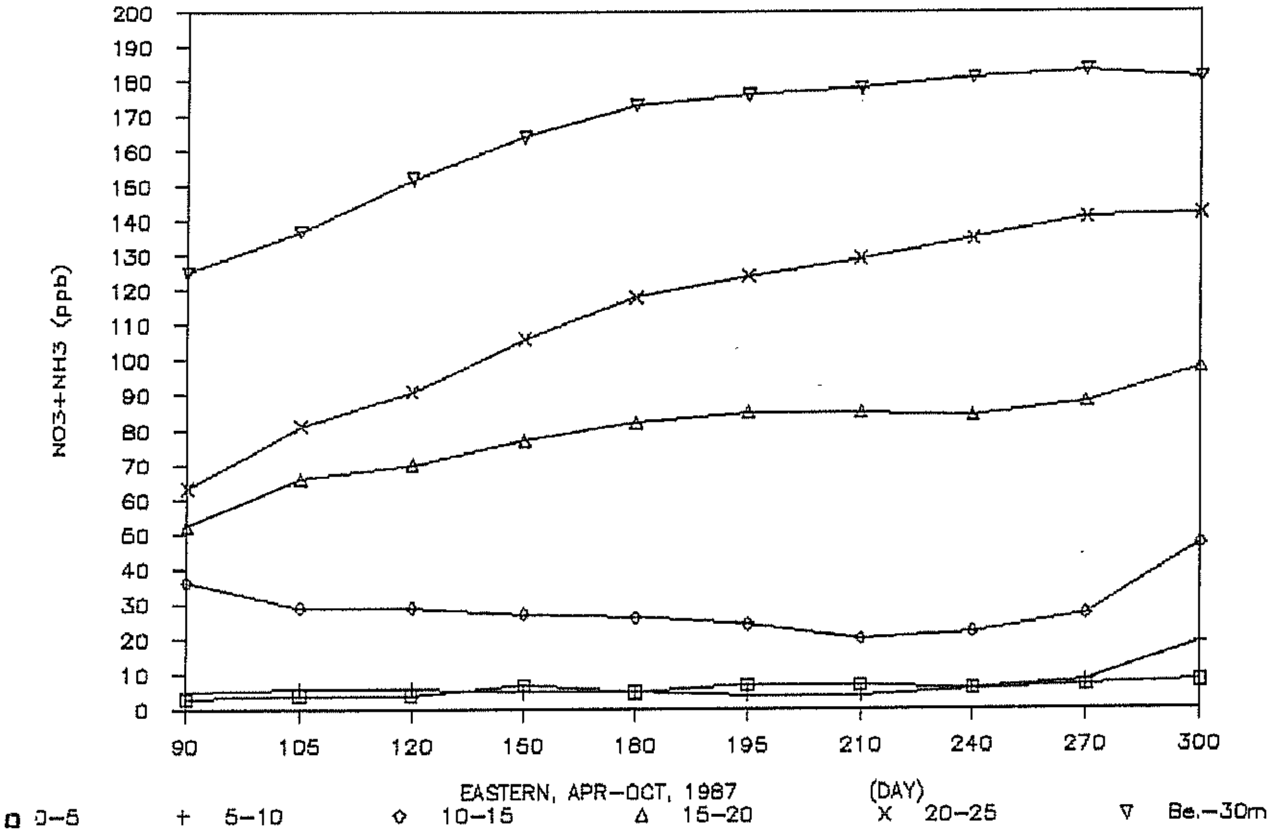


Figure 35d. Simulated o-phosphate cocentrations in different layers of the bay waters.



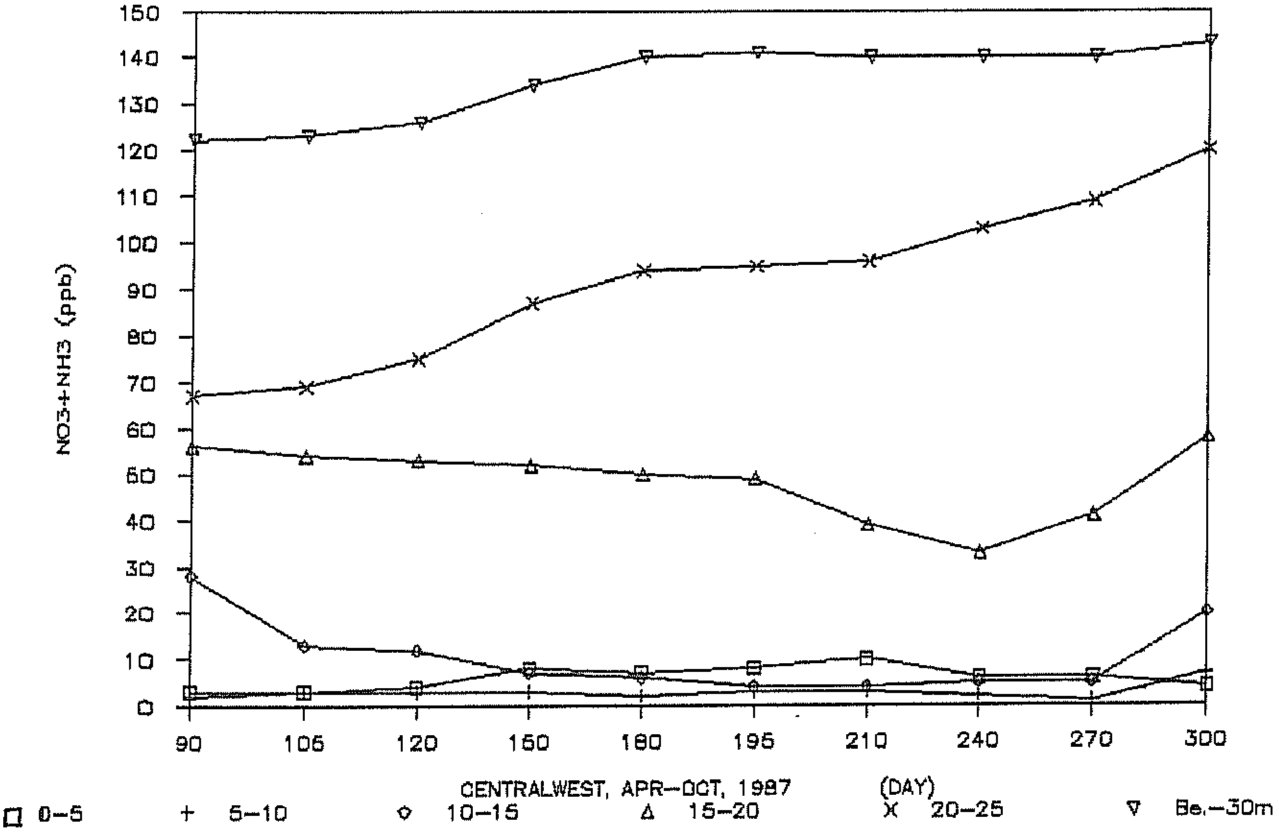
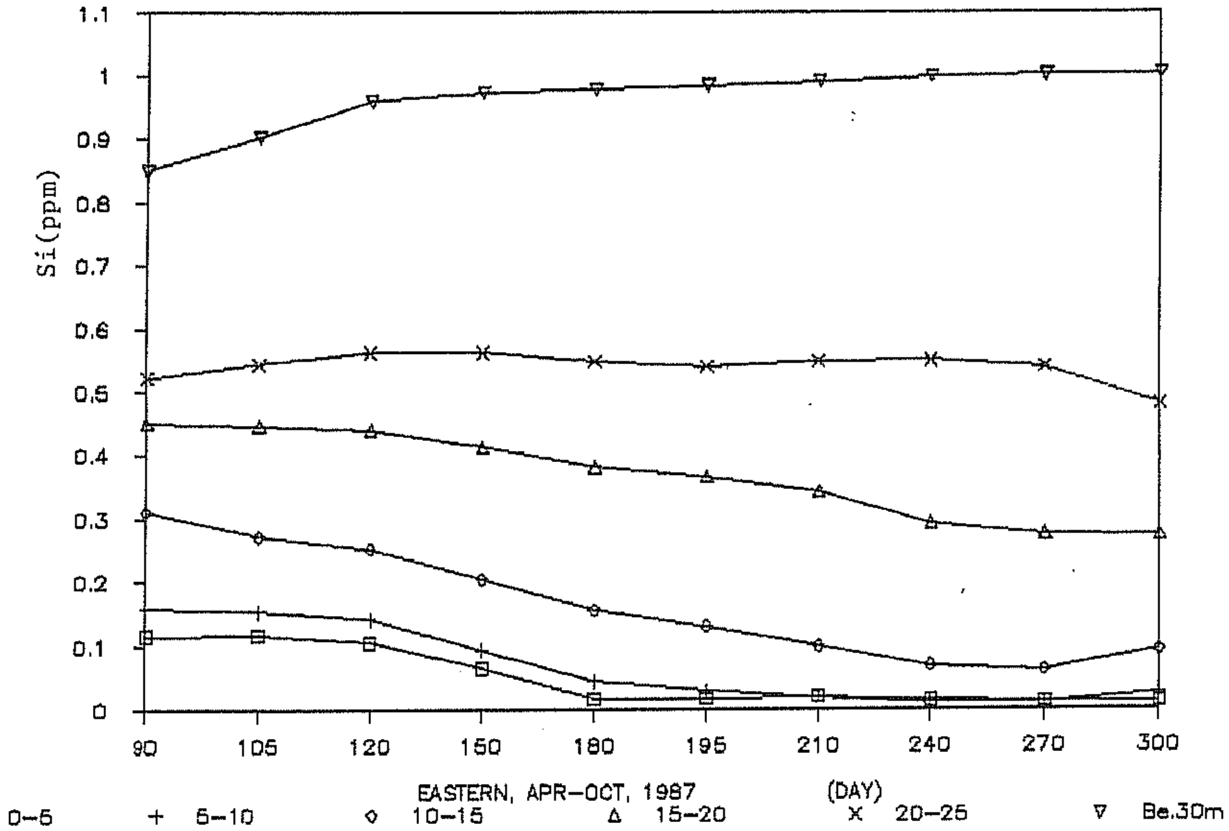


Figure 35e. Simulated nitrate+ammonia concentrarions in different layers of the bay waters.



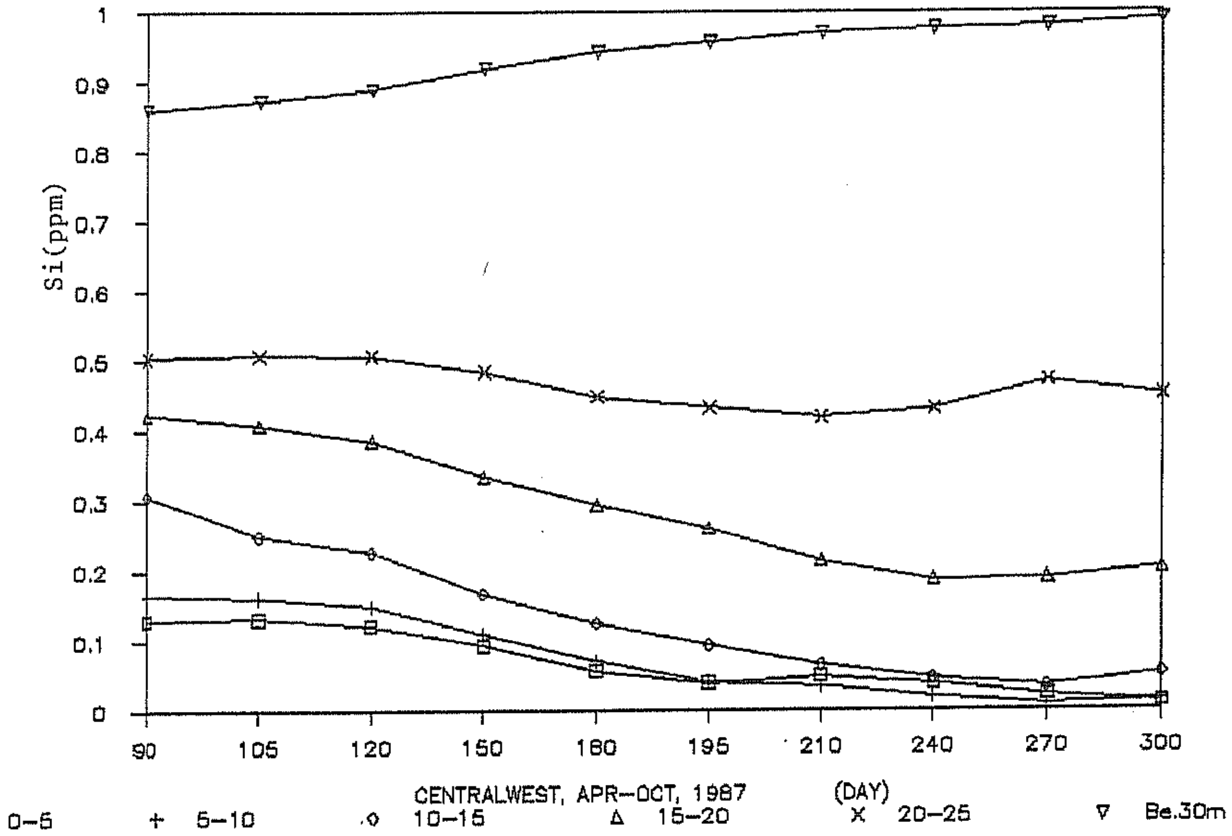
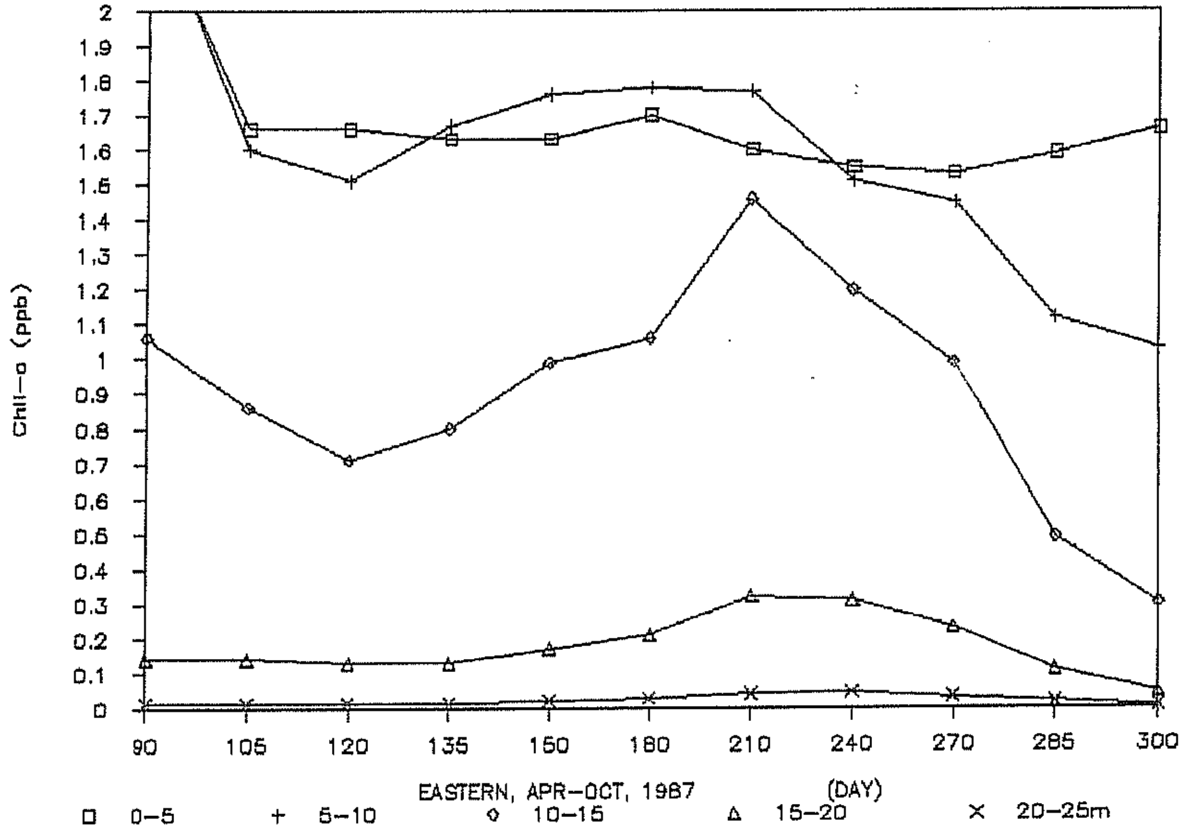


Figure 35f. Simulated silicate concentrations in the layers of the bay.



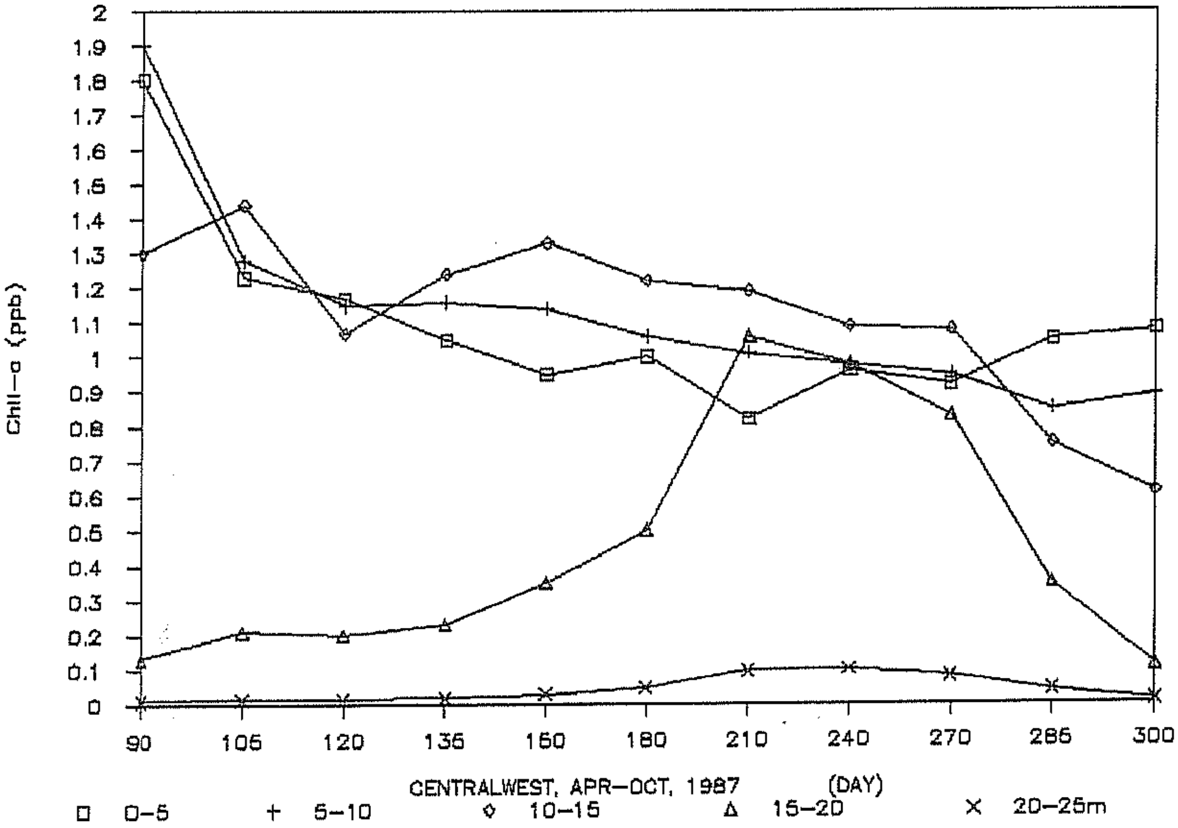


Figure 35.g. Chll–a concentrations simulated for the present situation, assuming an algal carbon/chll–a ratio of 50.

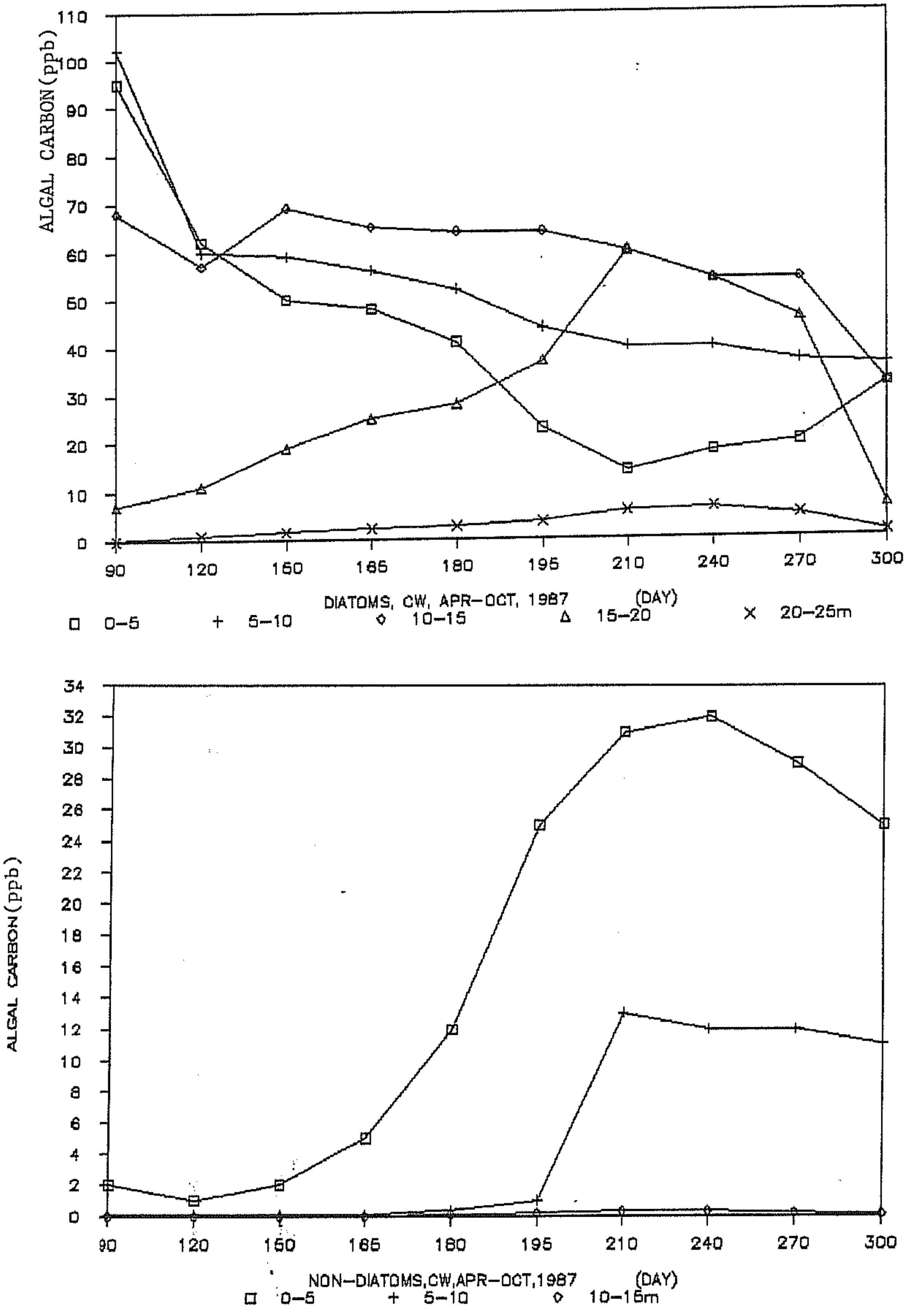
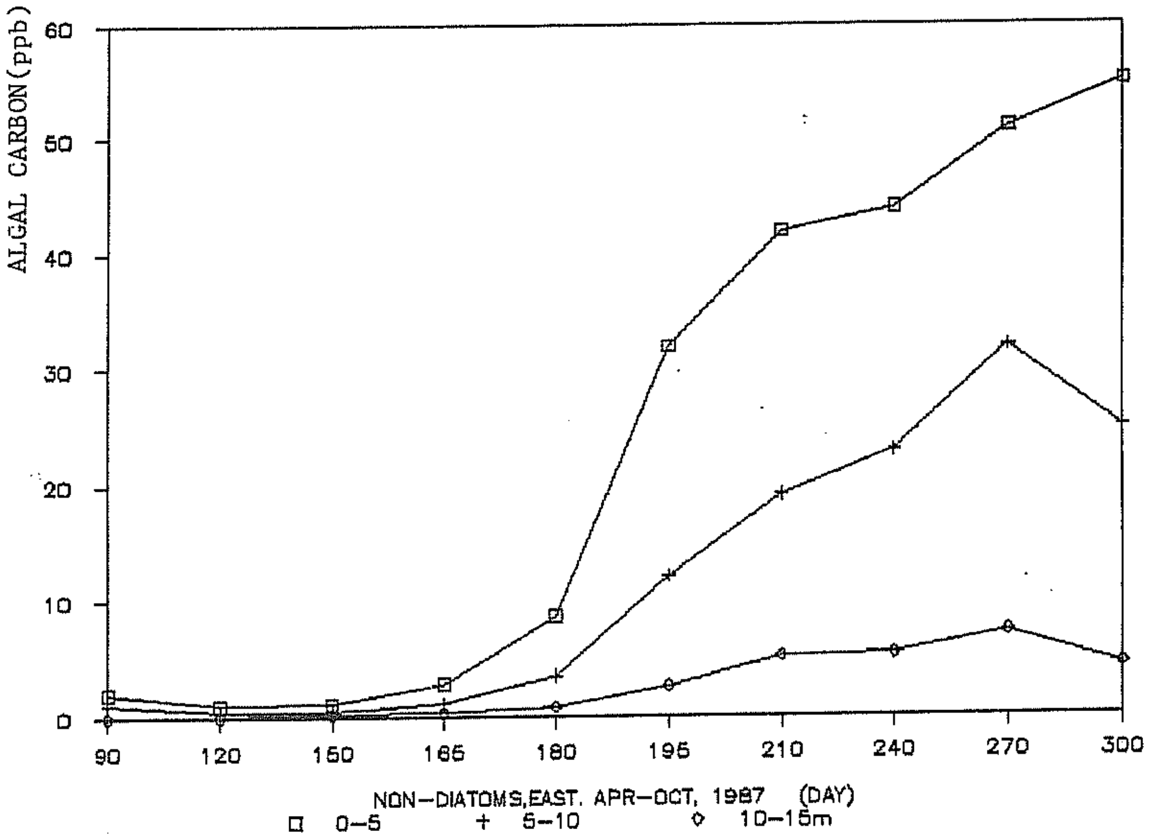


Figure 35.h. Variation of algal carbon with time in the centralwest region of the bay under the present situation.



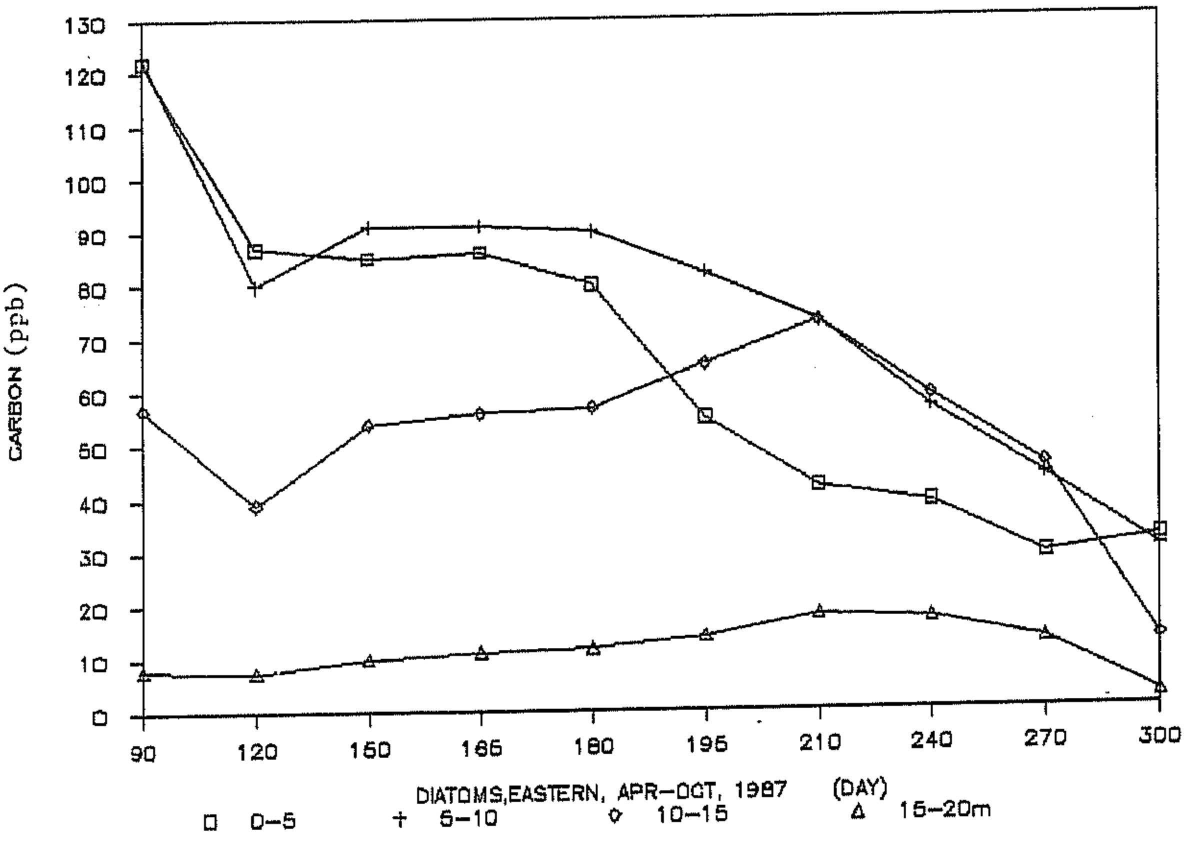


Figure 35.i. Variation of algal carbon with time in the eastern region of the bay under the present situation.

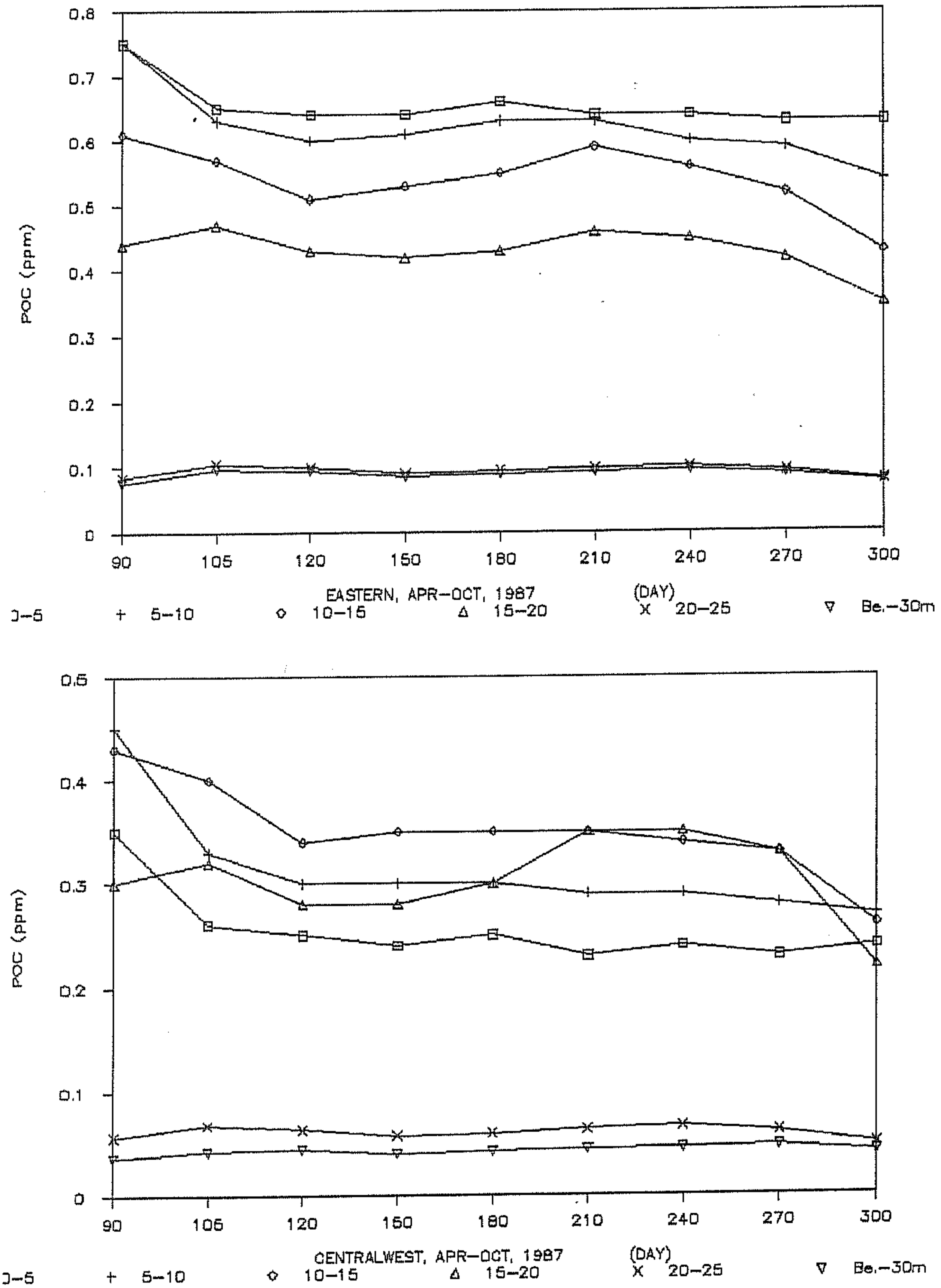
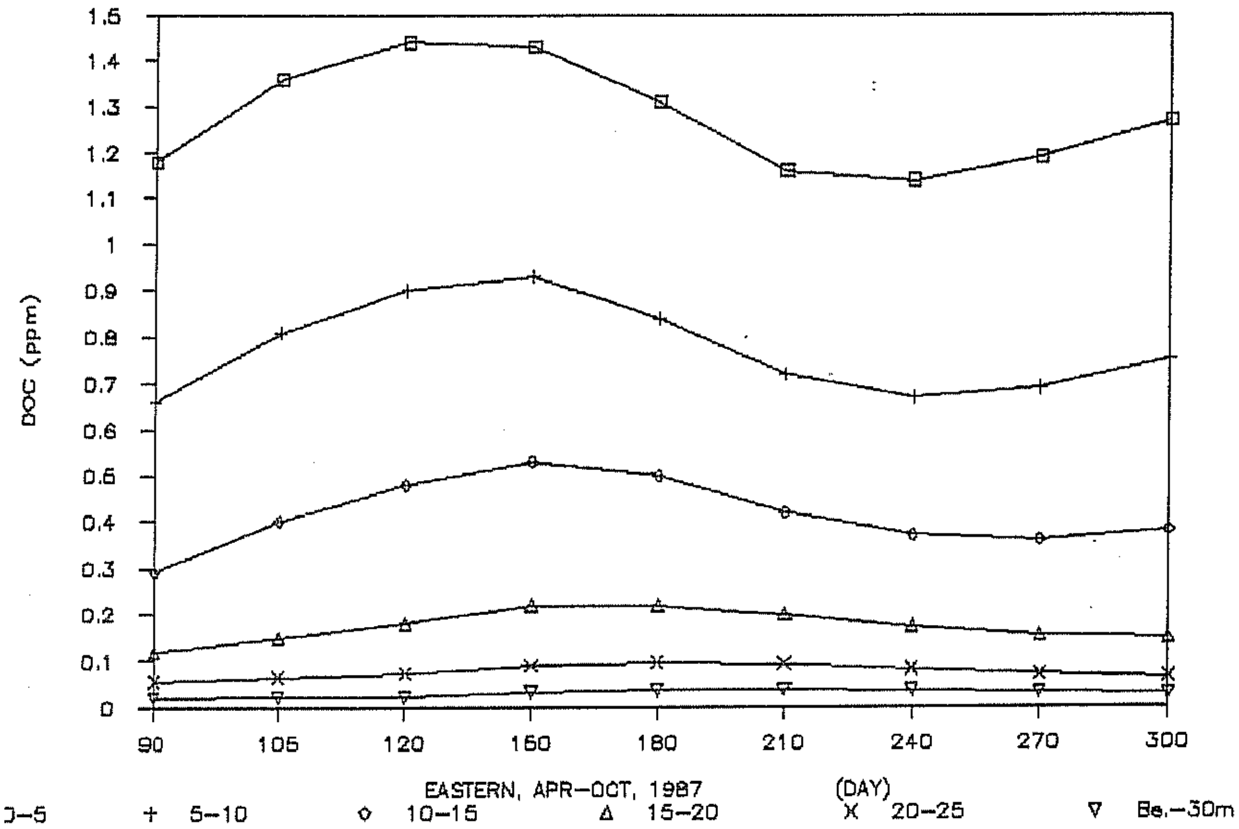


Figure 35k. Simulated T-POC concentrations in different layers of the bay waters under present waste loads situation.



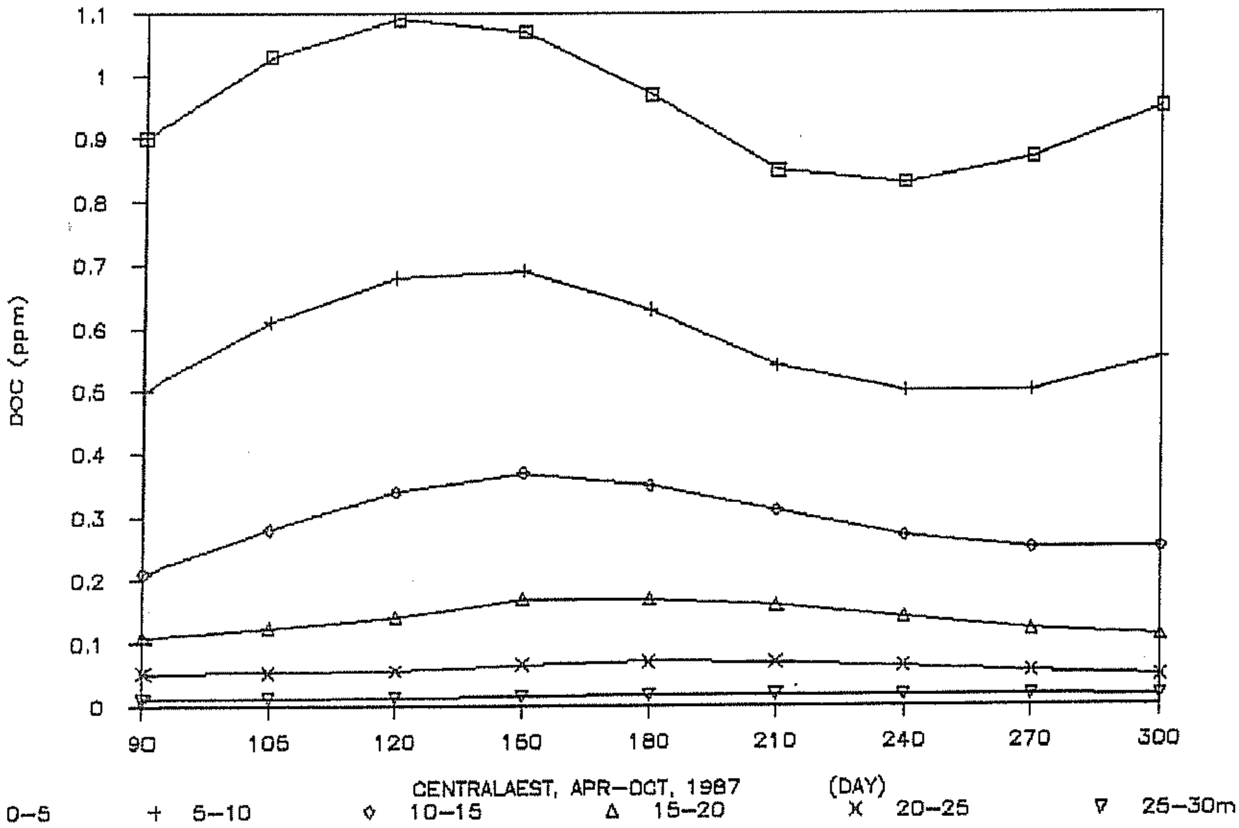


Figure 351. Distribution of biodegradable dissolved organic carbon(DOC) simulated for the present waste loads situation.

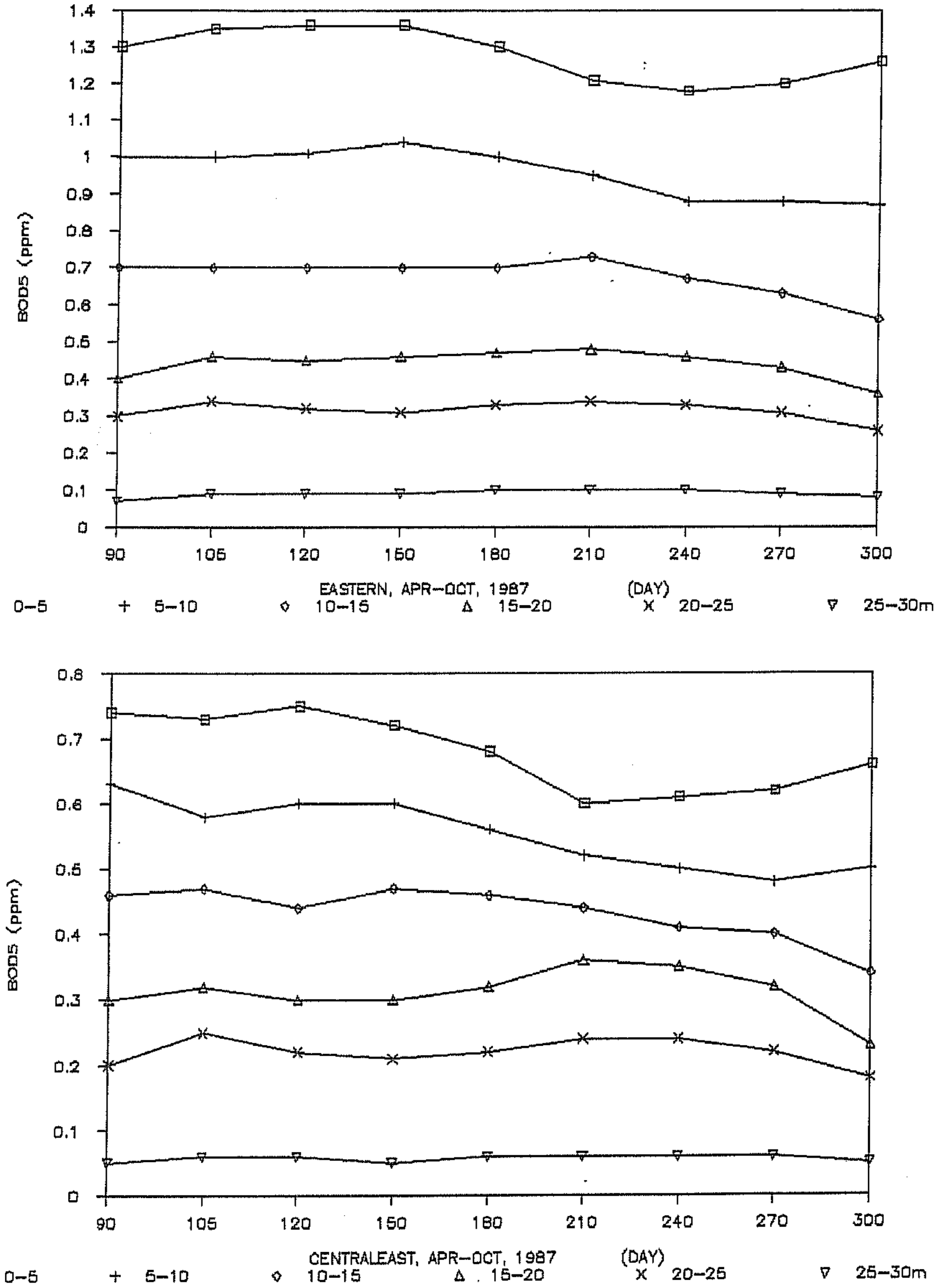


Figure 35m. $BOD_5$ distribution simulated for the present waste loads situation.

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## APPENDIX - Structure of the model and description of input file

The complete model consists of two parts:

1. the input file which contains the description of the model area and the transport pattern etcetera;
2. the subroutines that describe the water quality processes.

The input file is read by the first part of the model programme. This part produces a report, with which you can check what values are used in the actual model calculation.

Then the second part of the model programme can be run. It performs the actual calculation of transport and water quality processes. The result is written to two output files and can later on be examined. For this a third programme is supplied.

### Structure of the input file

The input file has the following structure:

1. Model identification (most important: the number of constituents of systems and the number of segments).
2. Output options (at which interval output is wanted, for which segments extra, readable, output is wanted).
3. Description of the geometry and the transport pattern (volumes of all segments, exchanges between the segments).
4. Boundary conditions (they are always prescribed concentrations, but an option is included to let them vary during the simulation).
5. Specification of waste loads (the amount of matter that enters from outside into certain segments. The amount can be varied during the simulation).
6. Data for the water quality processes. Four types of data are available:
   a. constants, which can be used as coefficients in the description of the processes;
   b. parameters, for each parameter and each segment a value can be prescribed or alternatively calculated in the water quality module (examples: thickness of the segments is presented in the input as a parameter. An estimate of BOD is calculated in the water quality module and

the result is stored in the array which also contains the thickness parameter);

   c. functions, these are piecewise linear functions to describe for instance the irradiation at the surface;
   d. functions per segment, for each segment a function can be specified.
7. Initial conditions: for each segment and each systems a value must be specified in order to initialise the calculation.
8. Integration options: the beginning and the end of the simulation time, the timestep and the integration method. Three are available, but in models where the transport is determined mainly by dispersion (mixing) they are equivalent.

The information read from the input file is written to a large number of output files which are subsequently read by the second part. The initial conditions are written to a separate file, so that the result of an earlier calculation can be inserted without specifying it in the input file.

The second part of the model programme solves the model equations. To do this, first of all the non-varying parameters are read, among others, the geometric data, the transport characteristics (flows and dispersion coefficients), initial conditions, integration options. Then the whole calculation is initialised, that is, the amount of matter is calculated for all segments and systems and the time is set to the initial time.

For each timestep the water quality processes and the transport processes are evaluated and the new concentrations are calculated.

At regular intervals output is produced. The output of all concentration values is done in the water quality module. If required, output is also given in readable form.
At the end of the simulation the concentration values are written to a separate file, so that these values can be used as initial values for another simulation.

<u>Notes</u>:

1. The concentration should be changed only by integrating the differential equations. The concentration must not be changed in the water quality module.
2. The constants and parameters are only used in the water quality module. The programme itself only initialises the values. The functions and the functions per segment are evaluated for each timestep on the basis of the input data. The values of the functions and functions per segment must not be changed in the water quality module.
3. The present module that describes the water quality processes, outputs first the values of the parameters and then the values of the concentrations. The first number on each record is the time according to the water quality module. This layout is expected by the post-processing programme. So it should not be changed.
4. The concentration units in the model programme are arbitrary, but caution must be taken:
   a. always use the same unit of length, both for describing the concentrations and the geometrical parameters and transport parameters. It is best to use meters throughout the model;
   b. always use the same unit of mass, both for describing the concentrations and the waste loads. If the concentration is specified in $g/m^3$, then the waste loads should be in g/day;
   c. the unit of time is the day, except for flows and dispersion coefficients (there it is the second).
5. The water quality module must calculate the derivative of the mass in a segment. So, at the end in the original module the concentration derivative is multiplied by the volume of the segment.

## Detailed description of the lay-out of the input file

A listing of the input file is given in the next appendix. It is shortened and truncated, because the original file contains about 700 lines and 180 columns. Real numbers are usually read with the use of the FORTRAN format F10.0 and integer numbers with the format I5. It is recommendable to use explicitly the decimal point in the specification of the real numbers.
The input can be subdivided in 11 blocks representing:

### ad 1.

The first lines contain the following information:

1. model and run identification (three numbers, they do not effect the calculation)
2. the number of segments and systems
3. logical unit numbers for input and output (not used)
4. options for readable output: output for each n-th timestep, number of segments for which this is requested, identification of the segments (the segment numbers are read with the format 20I5).

### ad 2 and 3.

In the next two blocks of lines the general geometrical information is specified. The first block specifies:

1. the model option (in this case it should not be equal zero, since this is a stand alone model)
2. the number of exchanges
3. an option which is not used at the moment
4. the number of segments for which the volumes are given in the next lines (should be the same as above)
5. the volumes of the segments (they are multiplied by the scale factor; the volumes are read with 8F10.0).

The table of exchanges begins with the scale factors for the flow rates and the dispersion coefficients. The next lines specify the transport parameters for the interface between adjoining segments (format: 2I5,5F10.0):

1. the segments on both sides of the interface. A value of zero indicates a boundary;
2. the rate of the flow over the interface (positive if the flow is from the first segment to the second segment; in $m^3/s$);

3. the dispersion coefficient (in $m^2/s$);
4. the area of the interface (in $m^2$);
5. the distances of the centres of the two segments to the interface (in m).

The sequence is arbitrary.

ad 4.

This block comprises the boundary conditions. The first line specifies the number of segments for which constant boundary values are given and the number of segments for which a time function is specified. An extra option (a value of 1) enables the specification of a particular read-format for the numbers, in this case the values for all systems are given on the same line, hence the width of 180 columns. The segment numbers are given thus: first the segments with constant boundary values, then the ones with varying condition. For each segment a Thatcher-Harleman time-lag is expected (read as 5E15.0). This option is useful only in the case of tidal flow. Usually, a value of zero is specified.

The rest of the block consists of:
1. the scale factors for each system (8F10.0);
2. the values for the segments with constant boundary conditions (absent in this case; to be specified either in the standard format 8F10.0 or in the user's format);
3. the number of break points for the time functions and the break points (in days). In this case, for each month a new value is given;
4. the values for each system per segment per break point (according to the appropriate format).

ad 5.

The same lay-out is used for the specification of the waste loads. The unit is however: mass unit per day, (e.g. for organic carbon: g/day).

ad 6.

The constants are used in the water quality module only. The number of them and the read-format are specified in an analogous manner as for the boundary conditions. The format in the listing was chosen so that for each constant the meaning can be given.

ad 7.

Parameters are constants that can be specified for each segment. The scale factors are to be specified for each parameter separately (8F10.0). They are used to specify extra information that is needed by the water quality module, such as the thickness of the segments and the bottom/water surface ratio. They are also used to provide extra output, such as B.O.D. and chlorophyll-a.

ad 8.

The functions are piece-wise linear functions of time. The number of functions and the number of break points are given first, then the break point and the values of the functions at this time.

ad 9.

Segment functions are not used in the model. They are functions that apply separately for each segment. The lay-out is a combination of the parameters and the functions. Each block (8F10.0) contains the break point and the values of the segment function per segment. For each break point all segment functions are to be given before the next break point is read.

ad 10.

The initial conditions can be given in two manners: for each system and each segment a separate value, or for each system one value that applies to all segments. If the option is 2, the second lay-out is expected (the format: 8F10.0). If it is not 2, then the first is to be used (for each system: a block of values that are read with the format 8F10.0)

ad 11.

The integration options:

1. the integration method (1 - Euler's method, 2 - second order Runge-Kutta, 3 - second order Lax-Wendroff; 1 and 3 are most widely used);
2. an option that should be zero. It concerns the time step, but a constant time step is most appropriate;
3. the beginning and the end of the time interval over which the equations are integrated (in days; 2E15.0);
4. the time step (in days; E15.0).

Input File of the İzmit Bay Water Quality Model

```
   1    1    1   28   18    5    6    *** MODEL PARAMETERS=---------------- 1
IZMIT BAY WATER QUALITY MODEL, REVISED: TRANSPORT - SALINITY, TEMPERATURE
  20                                   *** OUTPUT EACH FIFTH TIMESTEP
   7                                   *** SEGMENTS READABLE OUTPUT
   3    7   11   15   19   23   27
   1   52                              *** OPTION, NUMBER OF EXCHANGES-------- 2
   4   28                              *** NUMBER OF SEGMENTS
    1.0E6                              *** SCALE FACTOR VOLUMES, VOLUMES
     274.      401.      425.      215.      263.      388.      411.      193.
     253.      375.      397.      168.      242.      362.      383.      140.
     231.      349.      369.      105.      220.      336.      355.       64.
    1320.     3355.     4970.       43.
      1.0       1.0                       *** TABLE OF EXCHANGES------------- 3
   0    1      -6.0      70.0    45000.     3850.     3850.
   1    2      -6.0     500.0    12500.     3850.     4800.
   2    3      -4.0     150.0    44500.     4800.     6750.
   3    4      -2.0     200.0    12500.     6750.     6400.
   0    5       0.0      60.0    43800.     3850.     3850.
   5    6       0.0     450.0    11700.     3850.     4800.
   6    7       0.0     120.0    44500.     4800.     6750.
   7    8       0.0     180.0    11000.     6750.     6400.
   0    9       0.0      40.0    42500.     3850.     3850.
   9   10       0.0     350.0    10800.     3850.     4800.
  10   11       0.0     100.0    44500.     4800.     6750.
  11   12       0.0     160.0     9200.     6750.     6400.
   0   13       0.0      40.0    41300.     3850.     3850.
  13   14       0.0     200.0    10100.     3850.     4800.
  14   15       0.0      50.0    44000.     4800.     6750.
  15   16       0.0     150.0     8000.     6750.     6400.
   0   17       0.0      30.0    40000.     3850.     3850.
  17   18       0.0     200.0     9300.     3850.     4800.
  18   19       0.0      50.0    44000.     4800.     6750.
  19   20       0.0     130.0     7100.     6750.     6400.
   0   21       0.0      30.0    38700.     3850.     3850.
  21   22       0.0     150.0     8300.     3850.     4800.
  22   23       0.0      50.0    43500.     4800.     6750.
  23   24       0.0     110.0     5000.     6750.     6400.
   0   25       0.0     100.0   105000.     3850.     3850.
  25   26       0.0     400.0    18000.     3850.     4800.
  26   27       0.0       4.0   783000.     4800.     6750.
  27   28       0.0      80.0     3500.     6750.     6400.
   1    5       0.0    0.8E-5    52.6E6       2.5       2.5
   2    6       0.0    1.0E-5    78.8E6       2.5       2.5
   3    7       0.0    1.5E-5    83.6E6       2.5       2.5
   4    8       0.0    2.5E-5    40.7E6       2.5       2.5
   5    9       0.0    0.6E-5    50.1E6       2.5       2.5
   6   10       0.0    0.6E-5    73.6E6       2.5       2.5
   7   11       0.0    0.8E-5    77.5E6       2.5       2.5
   8   12       0.0    1.5E-5    35.5E6       2.5       2.5
   9   13       0.0    0.4E-5    47.3E6       2.5       2.5
  10   14       0.0    0.4E-5    71.5E6       2.5       2.5
  11   15       0.0    0.5E-5    75.2E6       2.5       2.5
  12   16       0.0    0.7E-5    31.3E6       2.5       2.5
  13   17       0.0    0.3E-5    45.1E6       2.5       2.5
  14   18       0.0    0.3E-5    68.3E6       2.5       2.5
  15   19       0.0    0.3E-5    72.4E6       2.5       2.5
  16   20       0.0    0.7E-5    24.5E6       2.5       2.5
  17   21       0.0    1.0E-6    45.1E6       2.5       2.5
  18   22       0.0    1.0E-6    68.3E6       2.5       2.5
  19   23       0.0    1.0E-6    72.4E6       2.5       2.5
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 20   24       0.0   0.7E-5   16.9E6       2.5        2.5
 21   25       0.0   0.1E-6   44.0E6       2.5       15.0
 22   26       0.0   0.1E-6   67.1E6       2.5       25.0
 23   27       0.0   0.1E-6   71.0E6       2.5       35.0
 24   28       0.0   4.0E-6    8.5E6       2.5        2.5
  0    7    1(18F10.0)                     *** BOUNDARY CONDITIONS--------------------- 4
  1    5    9   13   17   21   25
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00
      1.0       1.0       1.0       1.0       0.7       0.7       0.7       0.3
      0.3       0.3       0.5       0.1       0.1       0.1       1.0       0.2
      1.0       1.0
        9       0.0      15.0      60.0      99.0     115.0     133.0     165.0
    207.0     245.0      TEMP    DIS.OX     PHYTO      DIAT    F-DETC    F-DETN    F-DETP    F-DETS    S-DETC    S-DETN
    100.0      24.0       7.8      10.0     0.002     0.120      0.10     0.030    0.0050     0.050      1.20      0.17
    100.0      24.0       7.8       9.9     0.001     0.090      0.15     0.030    0.0040     0.050      0.90      0.15
    100.0      26.0       7.9       9.9     0.001     0.030      0.15     0.020    0.0040     0.030      0.30      0.09
    100.0      29.5       8.0       9.0     0.001     0.001      0.08     0.020    0.0020     0.030      0.10      0.07
    100.0      31.0       8.5       8.0     0.001     0.001      0.07     0.015    0.0020     0.025      0.05      0.06
    100.0      33.5       9.5       7.0     0.001     0.001      0.05     0.010    0.0015     0.015      0.02      0.03
    100.0      38.3      14.6       3.0     0.001     0.001      0.04     0.007    0.0014     0.012      0.01      0.01
    100.0      23.5       9.0       9.5     0.005     0.120      0.10     0.040    0.0070     0.080      1.40      0.17
    100.0      24.0       8.5       9.9     0.002     0.110      0.15     0.045    0.0070     0.080      0.90      0.17
    100.0      26.0       8.3      10.0     0.002     0.030      0.20     0.045    0.0070     0.080      0.50      0.14
    100.0      28.0       8.0       9.0     0.001     0.002      0.15     0.035    0.0060     0.060      0.20      0.10
    100.0      29.5       8.0       8.3     0.000     0.000      0.12     0.025    0.0040     0.050      0.05      0.06
    100.0      31.5       8.5       7.3     0.000     0.000      0.08     0.015    0.0025     0.030      0.02      0.05
    100.0      38.3      14.6       2.8     0.000     0.000      0.05     0.008    0.0015     0.015      0.01      0.01
    100.0      24.0      15.1       8.6     0.005     0.120      0.12     0.040    0.0070     0.070      1.20      0.20
    100.0      24.5      12.5       9.6     0.001     0.110      0.13     0.045    0.0070     0.075      0.90      0.18
    100.0      26.5       9.5       9.9     0.001     0.030      0.15     0.045    0.0070     0.075      0.30      0.17
    100.0      28.2       8.7       9.0     0.001     0.001      0.15     0.040    0.0060     0.060      0.20      0.14
    100.0      29.5       8.3       8.5     0.001     0.001      0.13     0.030    0.0040     0.050      0.05      0.09
    100.0      31.0       8.5       7.3     0.001     0.001      0.07     0.017    0.0030     0.030      0.02      0.05
    100.0      38.3      14.6       2.3     0.001     0.001      0.06     0.008    0.0014     0.015      0.01      0.01
    100.0      22.5      18.1       8.0     0.015     0.080      0.10     0.040    0.0065     0.060      1.20      0.18
    100.0      23.5      15.8       8.5     0.010     0.090      0.12     0.040    0.0070     0.080      0.90      0.18
    100.0      26.1      11.2       9.0     0.001     0.030      0.15     0.040    0.0070     0.080      0.30      0.17
    100.0      27.6       9.7       8.5     0.001     0.003      0.15     0.035    0.0060     0.060      0.20      0.13
    100.0      29.5       9.0       7.6     0.001     0.001      0.13     0.030    0.0045     0.050      0.05      0.10
    100.0      31.5       9.5       6.3     0.001     0.001      0.08     0.017    0.0030     0.030      0.02      0.04
    100.0      38.3      14.6       1.8     0.001     0.001      0.06     0.008    0.0014     0.015      0.01      0.01
    100.0      24.0      20.0       7.0     0.040     0.030      0.10     0.040    0.0065     0.065      1.20      0.25
    100.0      24.8      17.0       8.3     0.025     0.040      0.12     0.045    0.0070     0.080      0.90      0.24
    100.0      27.0      12.5       8.5     0.005     0.020      0.13     0.045    0.0070     0.080      0.30      0.18
    100.0      30.0      10.0       7.5     0.001     0.001      0.12     0.040    0.0060     0.080      0.05      0.16
    100.0      33.0      11.0       5.0     0.001     0.001      0.10     0.030    0.0040     0.050      0.03      0.06
    100.0      36.5      13.0       2.3     0.001     0.001      0.08     0.017    0.0030     0.030      0.02      0.05
    100.0      38.5      14.7       1.5     0.001     0.001      0.06     0.008    0.0014     0.015      0.01      0.01
    100.0      23.8      21.8       7.0     0.040     0.025      0.10     0.040    0.0060     0.070      1.20      0.24
    100.0      24.7      18.0       8.0     0.025     0.040      0.13     0.045    0.0070     0.085      0.90      0.20
    100.0      26.5      15.0       8.0     0.005     0.020      0.14     0.045    0.0070     0.080      0.30      0.18
    100.0      29.0      11.0       7.5     0.001     0.003      0.12     0.020    0.0060     0.070      0.20      0.14
    100.0      32.5      12.0       4.5     0.001     0.001      0.10     0.030    0.0045     0.050      0.05      0.06
    100.0      36.5      13.5       2.3     0.001     0.001      0.08     0.017    0.0030     0.030      0.02      0.03
    100.0      38.5      14.7       1.5     0.001     0.001      0.06     0.008    0.0014     0.015      0.01      0.01
    100.0      24.0      21.7       7.0     0.040     0.030      0.10     0.040    0.0060     0.070      1.20      0.25
    100.0      24.6      20.0       7.4     0.025     0.040      0.12     0.045    0.0070     0.085      0.90      0.24
    100.0      27.0      16.0       7.8     0.005     0.020      0.13     0.045    0.0070     0.080      0.30      0.18
    100.0      31.0      13.5       7.0     0.001     0.003      0.12     0.040    0.0060     0.070      0.10      0.14
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  100.0     34.3     13.3      4.0    0.001    0.001    0.10    0.030   0.0040    0.050    0.05    0.06
  100.0     37.0     13.7      2.2    0.001    0.001    0.08    0.018   0.0030    0.030    0.02    0.03
  100.0     38.5     14.7      1.4    0.001    0.001    0.06    0.008   0.0014    0.015    0.01    0.01
  100.0     23.8     17.7      8.0    0.025    0.040    0.10    0.040   0.0060    0.070    1.20    0.24
  100.0     24.1     17.5      8.6    0.010    0.040    0.12    0.045   0.0065    0.085    0.90    0.22
  100.0     26.0     16.0      9.7    0.005    0.020    0.13    0.045   0.0065    0.080    0.30    0.18
  100.0     28.3     14.2     10.0    0.001    0.005    0.12    0.040   0.0060    0.070    0.10    0.16
  100.0     33.5     13.0      9.5    0.001    0.001    0.10    0.030   0.0040    0.055    0.03    0.08
  100.0     37.0     13.7      7.6    0.001    0.001    0.08    0.018   0.0030    0.030    0.02    0.03
  100.0     38.5     14.7      2.1    0.001    0.001    0.06    0.008   0.0014    0.015    0.01    0.01
  100.0     25.2     12.0      9.3    0.050    0.030    0.10    0.040   0.0060    0.070    1.00    0.18
  100.0     26.5     12.6      8.5    0.025    0.040    0.12    0.040   0.0060    0.080    0.60    0.18
  100.0     28.0     13.2      8.0    0.005    0.020    0.13    .0.040  0.0060    0.080    0.30    0.18
  100.0     29.0     13.7      6.5    0.001    0.005    0.10    0.025   0.0050    0.070    0.10    0.14
  100.0     33.5     15.0      5.0    0.001    0.001    0.10    0.022   0.0040    0.050    0.04    0.06
  100.0     36.9     15.5      3.5    0.001    0.001    0.08    0.018   0.0030    0.030    0.01    0.03
  100.0     38.5     15.3      3.0    0.001    0.001    0.05    0.008   0.0014    0.015    0.01    0.01
 4    0    1(18F10.0)                     *** WASTE LOAD----------------------------------- 5
 2    3    4    8
 86400.   86400.   86400.   86400.    1.0E6    1.0E6    1.0E6    1.0E6
  1.0E6    1.0E6    1.0E6    1.0E6    1.0E6    1.0E6    0.1E6    1.0E6
  0.1E6    1.0E6     TEMP   DIS.OX    PHYTO     DIAT   F-DETC   F-DETN   F-DETP   F-DETS   S-DETC   S-DETN
  200.0      2.5     55.0     15.0     0.00     0.00      5.0      0.3     0.05      0.5     10.0     0.60
  200.0      2.5     55.0     15.0     0.00     0.00     15.0      2.0     0.30      1.0     20.0     2.00
  200.0      2.5     55.0     10.0     0.00     0.00     20.0      0.6     0.10      1.5     20.0     1.20
    0.0      0.0     00.0     00.0     0.00     0.00      0.0      0.0     0.00      0.0      0.0     0.00
 53    1(F10.0)                         CONSTANTS----------------------------------- 6
 7.          -         Number of layers                                 *layout
 4.          -         Number of segments per layer                     *layout
75.00        d         Time at which simulation starts (see below)      *simula
 0.25        d         Time step (note: should be the same as below)    *simula
 2.0         m/d       Heat exchange coefficient                        *physic
 0.1         -         Fraction of light reflected on surface (average)*physic
 0.5         -         Fraction of light in range of photosynthesis     *physic
 2.67        g O2/g C  Stoich. constant: amount of oxygen in CO2        *chemic
 4.58        g O2/g N  Stoich. constant: amount of oxygen in NO3        *chemic
 1.90        1/d       Maximum production rate non-diatom, NOT averaged*algae
 1.90        1/d       Maximum production rate diatoms, NOT averaged    *algae
16.0         h         Maximum length prod. period non-diatoms          *algae
12.0         h         Maximum length prod. period diatoms              *algae
46.0         W/m2      Light saturation value for non-diatom growth     *algae
35.0         W/m2      Light saturation value for diatom growth         *algae
 0.3300      1/d       Maximum mortality rate                           *algae
 0.1000      1/d       Maximum respiration rate                         *algae
 0.0639      1/*C      Temperature coefficient algal processes          *algae
 0.0100      g N /m3   Monod parameter nutrient limitation: nitrogen    *algae
 0.0010      g P /m3   Ditto: phosphate                                 *algae
 0.0270      g Si/m3   Ditto: silicon                                   *algae
 0.050       m/d       Maximum settling rate diatoms                    *algae
 0.1400      g Si/m3   Monod parameter: settling rate of diatoms        *algae
 0.1200      1/m       Background extinction                            *algae
 0.4000      m3/gm     Specific extinction non-diatoms                  *algae
 0.5000      m3/gm     Specific extinction diatoms                      *algae
 0.1000      m3/gm     Specific extinction detritus                     *algae
 0.150       g N /g C  Stoichiometry:  nitrogen/carbon                  *algae
 0.025       g P /g C  stoichiometry:  phosphate/carbon                 *algae
 0.350       g S /g C  stoichiometry:  silicate/carbon                  *algae
 0.070       1/d       Mineralization rate rapidly degrading detritus   *detr
 0.050       1/d       Mineralization rate nonsinking  detritus         *detr
 5.0         -         Layer below which the pycnocline is situated     *detr
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  0.70       m/d      Maximum settling rate rapidly degrading detritus*detr
  2.80       m/d      Ditto  - below pycnocline                       *detr
  0.00       m/d      Maximum settling rate slowly degrading detritus *detr
  0.00       m/d      Ditto  - below pycnocline                       *detr
  0.2000     1/d      Nitrification rate in water                     *water
  0.0040     1/d      Denitrification rate in water                   *water
  0.0050     1/d      Anaerobic mineralisation rate                   *water
  1.0900     -        Temperature exponent microbial processes        *water
  0.0500     -        Monod parameter for N/C ratio (mineralisation)  *water
  1.5000     g O2/m3  Monod parameter for oxygen availability (miner.)*water
  1.5000     g O2/m3  Ditto in case of (de)nitrification              *water
  0.5000     g O2/m3  Ditto in case of anaerobic mineralisation       *water
  0.0004     m        Thickness boundary layer bottom-water          .*bottom
  2.00E-4    m2/d     Diffusion rate oxygen                           *bottom
  0.1000     1/d      Mineralisation rate benthic detritus (complex)  *bottom
  0.0050     1/d      Maximum anaerobic mineralisation rate (complex) *bottom
  1.0000     -        MAXIMUM NITRIFICATION RATE ON NH4-FLUX (COMPLEX)*bottom
  1.0000     -        Maximum denitrification rate on nitrate flux    *bottom
  1.5000     G O2/M3  MONOD PARAMETER FOR OX.AVAIL. (DENITRIFICATION) *bottom
  0.5000     G O2/M3  DITTO IN CASE OF BENTHIC ANAER. MINERALISATION  *bottom
  10    1(4F5.0)                   *** PARAMETERS-------------------------7
      1.0       1.0     1.0      1.0      1.0      1.0      1.0      1.0
      1.0       1.0     1.0      1.0      1.0      1.0      1.0      1.0
  5.   5.   5.   5.                *** LAYER THICKNESS IN METERS
  5.   5.   5.   5.
  5.   5.   5.   5.
  5.   5.   5.   5.
  5.   5.   5.   5.
  5.   5.   5.   5.
 15.  50.  70.   5.
0.04 0.03 0.03 0.10                *** SURFACE RATIO BOTTOM/WATER
0.04 0.03 0.03 0.13
0.04 0.03 0.04 0.16
0.04 0.04 0.04 0.25
0.05 0.04 0.04 0.40
0.01 0.01 0.01 0.33
1.00 1.00 1.00 1.00
2.3  2.3  2.3  2.6                 *** DETRITUS IN COMPLEX (C)
2.3  2.3  2.3  2.6
2.3  2.3  2.3  2.6
2.3  2.3  2.3  2.6
2.3  2.3  2.3  2.6
2.3  2.3  2.3  2.6
2.0  2.5  2.5  3.5
0.23  .23  .23  .26                *** DETRITUS IN COMPLEX (N)
0.23  .23  .23  .26
0.23  .32  .24  .26
0.23  .23  .23  .26
0.23  .23  .23  .26
0.13  .13  .12  .16
0.13  .13  .13  .16
.033 .033 .033 .036                *** DETRITUS IN COMPLEX (P)
.033 .033 .033 .036
.033 .033 .033 .036
.033 .033 .033 .036
.033 .033 .033 .036
.013 .013 .013 .016
.013 .013 .013 .016
 .36  .36  .36 0.4                 *** DETRITUS IN COMPLEX (SI)
 .36  .36  .36 0.4
```

```
.36  .36  .36 0.4
.36  .36  .36 0.4
.36  .36  .36 0.4
.36  .36  .36 0.4
.36  .36  .36 0.4
.00  .00  .00  .00                    *** CHL-A (OUTPUT ONLY!)
.00  .00  .00  .00
.00  .00  .00  .00
.00  .00  .00  .00
.00  .00  .00  .00
.00  .00  .00  .00
.00  .00  .00  .00
.00  .00  .00  .00                    *** B.O.D. (OUTPUT ONLY!)
.00  .00  .00  .00
.00  .00  .00  .00
.00  .00  .00  .00
.00  .00  .00  .00
.00  .00  .00  .00
.00  .00  .00  .00
.00  .00  .00  .00                    *** P.O.C. (OUTPUT ONLY!)
.00  .00  .00  .00
.00  .00  .00  .00
.00  .00  .00  .00
.00  .00  .00  .00
.00  .00  .00  .00
.00  .00  .00  .00
.00  .00  .00  .00                    *** T.O.C. (OUTPUT ONLY!)
.00  .00  .00  .00
.00  .00  .00  .00
.00  .00  .00  .00
.00  .00  .00  .00
.00  .00  .00  .00
.00  .00  .00  .00
 4   13                          *** FUNCTIONS----------------------------8
     0.        2.      8.5   1200.0     0.50
    15.        2.      9.5   1300.0     0.52
    45.        2.     14.0   1350.0     0.54
    60.        2.     16.0   1850.0     0.56
    75.        2.     18.0   2200.0     0.58
   105.        2.     22.0   2300.0     0.63
   135.        2.     24.5   2450.0     0.58
   150.        2.     22.5   2100.0     0.56
   165.        2.     22.0   1800.0     0.54
   195.        2.     19.0   1600.0     0.50
   210.        2.     17.7    900.0     0.48
   225.        2.     15.0    800.0     0.46
   260.        2.     12.0    500.0     0.43
0                                 *** SEGMENT FUNCTIONS (NONE)----------------9
1                                 *** INITIAL CONDITIONS--------------------10
 100.0    100.0    100.0    100.0    100.0    100.0    100.0   100.0
 100.0    100.0    100.0    100.0    100.0    100.0    100.0   100.0
 100.0    100.0    100.0    100.0    100.0    100.0    100.0   100.0
 100.0    100.0    100.0    100.0    *** CONTINUITY
  24.3     24.5     24.5     24.7     24.6     25.0     25.0    25.2
  26.5     26.5     26.5     27.0     28.5     29.0     29.0    29.0
  30.0     30.5     30.5     30.5     33.5     33.5     33.5    33.5
  38.3     38.3     38.3     37.0    *** SALINITY
   7.7      7.7      7.7      7.8      7.8      7.8      7.8     8.0
   8.0      8.0      8.0      8.0      8.0      8.0      8.0     8.0
   8.2      8.5      8.5      8.5      9.8      9.8      9.8     9.8
```

```
   14.7      14.7      14.7      13.0     *** TEMPERATURE
    8.5       8.5       8.5       8.5       9.0       9.0       9.0       9.0
    8.5       8.5       8.5       8.5       8.0       8.0       8.0       8.0
    7.5       7.5       7.5       7.5       6.5       6.5       6.5       6.8
    2.6       2.3       2.1       4.5     *** DISSOLVED OXYGEN
  0.005     0.005     0.005     0.005     0.002     0.002     0.002     0.002
  0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
  0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
  0.000     0.000     0.000     0.000   *** OTHER PHYT.
  0.120     0.130     0.130     0.150     0.090     0.080     0.080     0.080
  0.020     0.025     0.025     0.025     0.005     0.005     0.005     0.005
  0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
  0.000     0.000     0.000     0.000   *** DIATOMS
  0.190     0.190     0.270     0.350     0.200     0.250     0.350     0.400
  0.190     0.250     0.350     0.390     0.190     0.250     0.290     0.290
  0.170     0.170     0.170     0.170     0.060     0.060     0.060     0.080
  0.040     0.040     0.040     0.050   *** FDET-C
  0.030     0.030     0.030     0.030     0.030     0.030     0.030     0.030
  0.012     0.012     0.012     0.012     0.010     0.010     0.010     0.010
  0.010     0.010     0.010     0.010     0.010     0.010     0.010     0.010
  0.010     0.010     0.010     0.010   *** FDET-N
  0.004     0.004     0.007     0.009     0.006     0.006     0.008     0.010
  0.005     0.005     0.007     0.009     0.004     0.004     0.006     0.007
  0.003     0.003     0.003     0.004     0.002     0.002     0.002     0.003
  0.001     0.001     0.001     0.002   *** FDET-P
  0.06      0.07      0.07      0.08      0.07      0.07      0.08      0.09
  0.07      0.07      0.08      0.09      0.06      0.06      0.06      0.07
  0.03      0.05      0.05      0.06      0.030     0.035     0.035     0.04
  0.018     0.015     0.015     0.035   *** FDET-SI
  0.55      0.55      0.65      0.75      0.35      0.32      0.45      0.45
  0.12      0.12      0.12      0.12      0.11      0.11      0.11      0.11
  0.05      0.05      0.05      0.05      0.01      0.01      0.01      0.01
  0.00      0.00      0.00      0.00    *** SDET-C
  0.05      0.05      0.06      0.07      0.011     0.01      0.01      0.01
  0.003     0.002     0.002     0.002     0.002     0.002     0.002     0.002
  0.002     0.002     0.002     0.002     0.002     0.002     0.001     0.002
  0.000     0.000     0.000     0.000   *** SDET-N
  0.001     0.001     0.001     0.001     0.001     0.001     0.001     0.001
  0.001     0.001     0.001     0.001     0.001     0.001     0.001     0.001
  0.001     0.001     0.001     0.001     0.001     0.001     0.001     0.001
  0.000     0.000     0.000     0.000   *** SDET-P
  0.010     0.010     0.010     0.010     0.010     0.010     0.010     0.010
  0.004     0.004     0.004     0.004     0.003     0.003     0.003     0.003
  0.002     0.002     0.004     0.002     0.002     0.002     0.002     0.002
  0.000     0.000     0.000     0.000   *** SDET-SI
  0.04      0.04      0.04      0.04      0.04      0.04      0.04      0.04
  0.04      0.04      0.04      0.04      0.05      0.05      0.05      0.05
  0.06      0.06      0.06      0.06      0.06      0.06      0.06      0.06
  0.11      0.11      0.12      0.10    *** DIS-NITRATE
  0.01      0.01      0.01      0.01      0.01      0.01      0.01      0.01
  0.01      0.01      0.01      0.01      0.01      0.01      0.01      0.01
  0.01      0.01      0.01      0.01      0.01      0.01      0.01      0.01
  0.01      0.01      0.01      0.01    *** DIS-AMMONIA
  0.01      0.01      0.01      0.01      0.01      0.01      0.01      0.01
  0.01      0.010     0.010     0.010     0.013     0.013     0.013     0.013
  0.017     0.017     0.017     0.017     0.020     0.020     0.020     0.020
  0.027     0.027     0.029     0.025   *** DIS-PHOSP.
  0.20      0.20      0.20      0.23      0.25      0.25      0.25      0.25
  0.35      0.37      0.40      0.40      0.40      0.43      0.45      0.45
  0.50      0.50      0.50      0.50      0.60      0.60      0.60      0.60

  0.83      0.85      0.85      0.80    *** DIS-SILICATE ------------------ 11
1 0                                   *** INTEGRATION OPTIONS
  0.0000E+00    2.250000E+02
0.2500000E+00
```