

Water Quality Assessment and Protection Measures of a Semi-enclosed Coastal Area: the Bay of Thermaikos (NE Mediterranean Sea)

J. G. GANOULIS

Hydraulics Laboratory, School of Engineering, Aristotle University of Thessaloniki, 54006 Thessaloniki, Greece

Using the results of monitoring in twelve stations over the time period 1984-1990, the water quality in the Thermaikos bay area is presented. In all these stations temperature, salinity, pH, dissolved oxygen, nitrites, nitrates, ammonia, phosphates, silicates, heavy metals, total coliforms and E-coli have been measured in the water column with seasonal frequency. There is a general trend in water pollution increasing from south to north and from the open sea to the rivers estuaries. This reflects the pollutant loads from human population in the northern region and from rivers flow. Mathematical modelling of the transport and fate of pollutants in the bay is reviewed. The use of the models in analysing various combinations between the choice of the disposal site and the degree of sewage treatment is discussed.

Introduction

The bay of Thermaikos (Greece) is located in the NW Aegean region of the Mediterranean sea. It is a shallow continental self terminating in its southern opening to the Aegean sea by an abrupt submarine escarpment. (Fig. 1). The northern part of the bay with a total surface area of 300 km² and max. depth of 30m is actually heavily polluted by the untreated sewage of the city of Thessaloniki (1.000.000 inh.) and industrial effluents. Since 1984, an extensive environmental research programme has been undertaken in the bay, including collection of water quality data, mathematical modelling and proposal of remedial measures for cleaning the bay. The results obtained up to now are summarized in this paper.

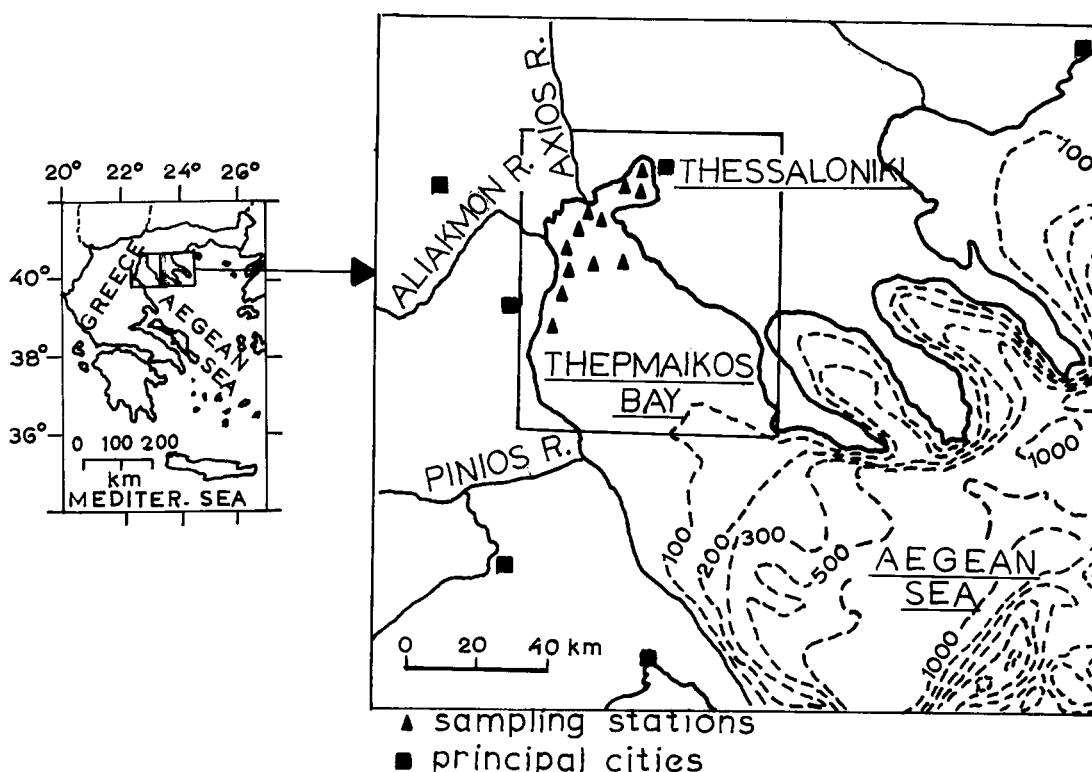


Fig. 1 The study area (bay of Thermaikos)

Water Quality Assessment

Monitoring of water quality characteristics and data processing is the basis for formulating computerized mathematical models and decide the appropriate remedial measures for environmental protection. The main objective of this study is the assessment of the present environmental situation in the bay of Thessaloniki and the environmental impact analysis of the sewage works, actually under construction in the city of Thessaloniki. As shown in Fig. 1 appropriate sampling stations non-uniformly distributed in space have been selected. Using the research vessel " THETIS " (13m long) during the period 1984-90 , more than 2500 water samples have been collected and analysed . Apart from the currents and winds the following parameters have been monitored with seasonal frequency near the surface, the mean depth and near the bottom of the water column

- (a) Temperature, salinity, density, dissolved oxygen, pH (b) Nutrients as NO_2^- , NO_3^- , NH_4^+ , PO_4^{3-} , SiO_4^{4-}
 (c) Total coliforms and E-coli (d) Heavy metals as Cd, Pb and Cu.

Heavy metals have been also analysed in sediments. Variations of the water quality parameters are very large both in time and space. As an example the time series of dissolved oxygen (DO) at the station 1, located near the city of Thessaloniki is shown in Fig. 2. These variations are due to the irregular physical conditions which prevail in the Mediterranean. In fact, the tides are very low and the wind induced circulation is strongly unsteady and variable in space. In view of the large variations of the data a statistical analysis has been performed . The lines of equal dissolved oxygen and nitrate concentrations are shown in Fig. 3. These are mean values over the time period 1984-89 near the bottom.

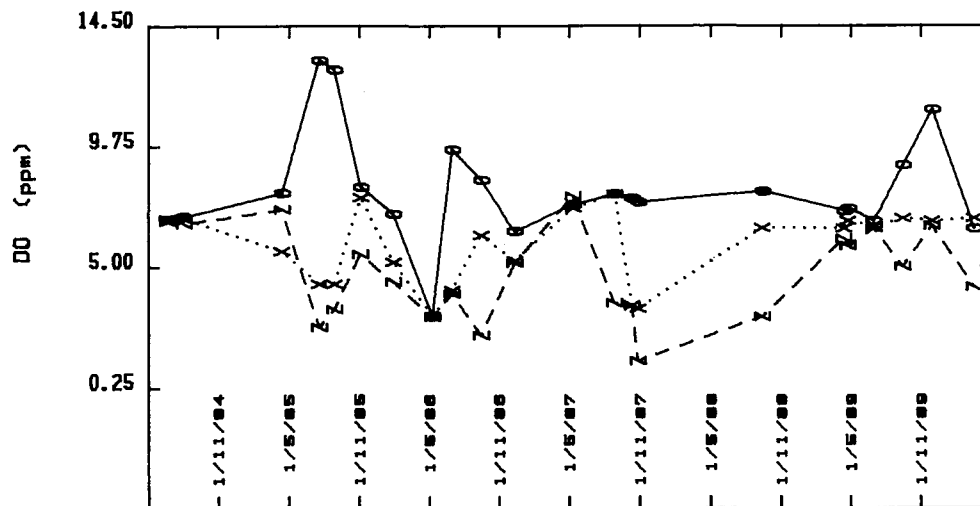


Fig. 2 Time series of dissolved oxygen at station 1

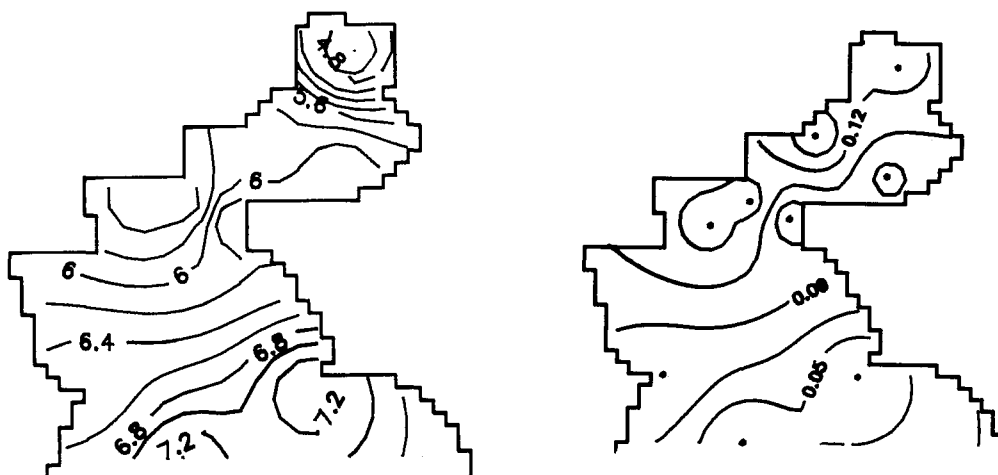


Fig. 3 Distribution of dissolved oxygen (DO) and nitrate concentrations (NO_3^-) in the bay of Thessaloniki (mean values over 1984-89 near the bottom)

From these data a statistical trend is deduced for increasing of the water pollution from south to north (high population density) and to the rivers estuary (high pollutant loads). In fact four different zones are distinguished, ranged from very bad to excellent water quality situation (Ganoulis et al.,1988)

Modelling Coastal Hydrodynamics and Pollution

The transport and fate of pollutants in a coastal area are dominated by the following processes (a) advection by currents (b) turbulent dispersion and (c) biochemical interactions. The mass conservation of the pollutant species c_i ($i=1,2, \dots, n$) can be expressed by the following set of coupled, nonlinear partial differential equations

$$\partial c_i / \partial t + \nabla (\bar{V}c_i) = \nabla(\bar{D}_t \nabla c_i) + f_i(c_1, c_2, \dots, c_n) \quad (1)$$

where \bar{V} is the velocity field of the currents, \bar{D}_t the turbulent dispersion tensor and $f_i(c_1, c_2, \dots, c_n)$ the temperature dependent biochemical production (or depletion) rate of pollutants i .

The understanding of the water circulation is of great importance. Previous measurements of currents using drogues, driftcards and currentmeters (Balopoulos & James,1984 ; Ganoulis & Koutitas,1981) and the application of hydrodynamic models(Ganoulis & Koutitas,1981 ; Krestenitis & Ganoulis,1987) have led to the following conclusions: (a) tidal currents are very low(< 5 cm/s) (b) external circulation from the N.Aegean sea creates a current entering the bay along the eastern coast and creating a cyclonic circulation (c) currents are mainly due to the winds.The N-NW wind is the most prevailing in the area.The hydrodynamic circulation due to such a wind is shown in Fig.6.Duringt he summer,sea breezes create a residual water circulation, which is very characteristic for the pollutant transport.In fact , this is the most critical circulation state for the pollutant advection because , as the currents are small,an increasing in pollutant concentration is observed.In the present development of mathematical modelling,steady state hydrodynamic conditions corresponding to the prevailing winds are used.

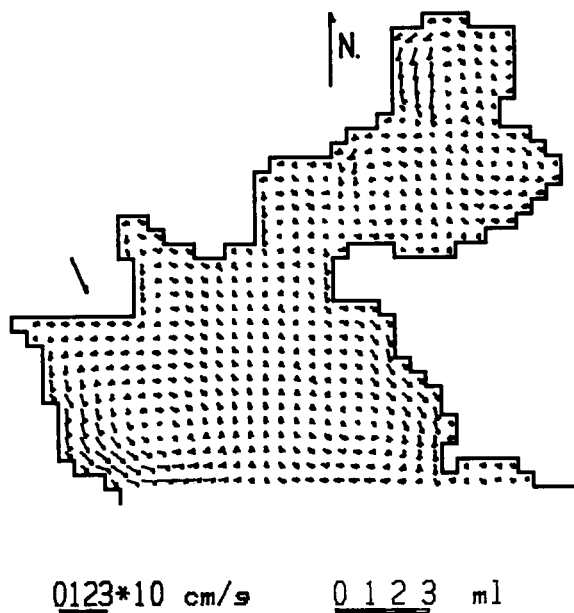


Fig. 5 Wind-induced circulation in the bay for N-NW wind

For the numerical integration of the convective dispersion equation various numerical algorithms have been introduced during the last decade. Algorithms based on finite differences or finite elements suffer from numerical diffusion and trailing effects. Lagrangian models based on random walk simulation or using a mixed Eulerian-Lagrangian approach have been successfully used to simulate the fate of pollutants in the bay of

Thermaikos(Ganoulis et al.,1988). These models have been tested in simple cases where analytical solutions are available and validated by using the collected data.They have been adopted as operating tools for studying the environmental impacts of several alternatives and remedial measures aiming to protect the water quality in the bay.

Sanitary Engineering Works

The initial design of the sewer system of the city of Thessaloniki is shown in Fig.6.The main collector is a tunnel of 2m in diameter,located underground in an averaged depth of 20m. This pipe collects all the sewage of the city from the eastern to the western part of the greater Thessaloniki metropolitan area.It is ending in the sewage treatment station,located close to the river Gallikos(Fig.6).An advanced primary waste treatment has been provided,including bio-oxydation of the wastewaters and settling (A-B system).After this treatment , the disposal of the wastewaters has been provided into the river Axios using a twin-pipe system between the sewage treatment station and the river Axios(Fig.6).All the civil engineering works of the system are now completed , but because of the environmental concern about the water quality in river and sea , the operation of the system has delayed for more than one year now.This is due to the fact that the flow rate of the river Axios is constantly decreasing during the last few years,leading to lower wastewater dilution.In the same time , for the protection of fresh and marine waters, the new water quality standards are applied , according to the directives issued by the EC Community.The marine area close to the river mouth is considered as a protected area of very great importance from the biological point of view.According to the RAMSAR convention this area is a special protected estuary.

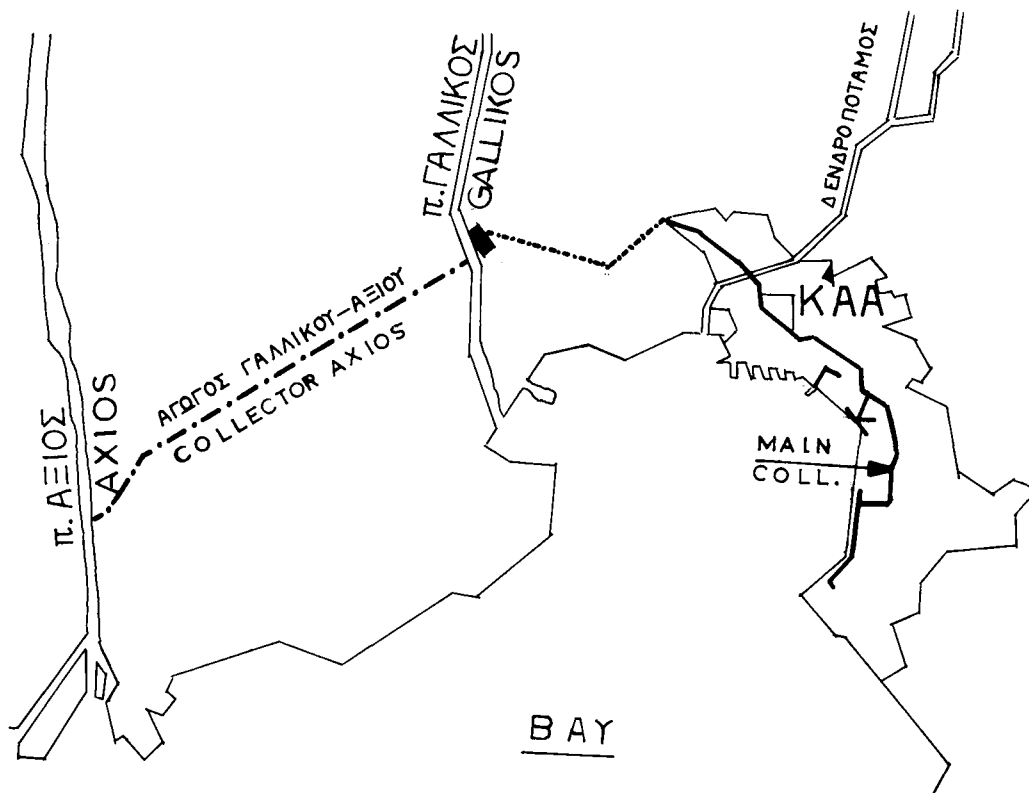


Fig.6 Sewage collection and treatment in the city of Thessaloniki

Application of the water quality modelling indicates that the pollutant loads coming from the mouth of the river Axios,greatly affect the marine area close to the river delta. This result is shown in the Fig.7 for two different wind conditions. In fact,this coastal area forms a shallow semi-enclosed basin, having a very limited water renewal.The degree of dilution of the pollutant loads is also limited by the density stratification due to the fresh

water from the river flow. In this case, high concentrations of pollutants such as nitrate nitrogen and ammonia nitrogen are expected.

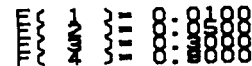
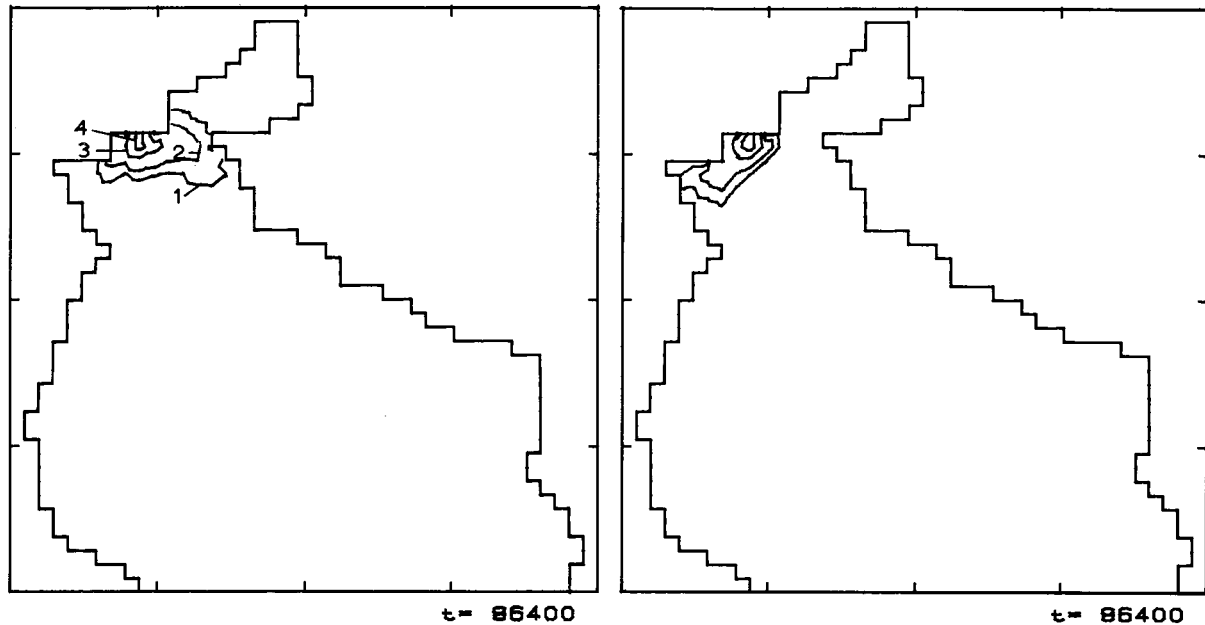


Fig.7 Impacts from pollutant loads issued from the river Axios

A further biological treatment of the wastewaters has been decided. In the mean time, a preliminary operation of the wastewater treatment station is provided. During this transitional period, the wastewater disposal is planned in the upper part of the bay, by using a ditch parallel to the bed of the river Gallikos (Fig.6). The local environmental impacts in this area and especially the concentrations in coliforms are actually studied, using mathematical modelling.

Conclusions

Many semi-enclosed bays and coastal areas in the Mediterranean are actually heavily polluted, mainly from domestic sewage. Collection and analysis of water quality data is the basis for assessing the environmental situation and calibrate the mathematical models. These models are very useful tools for exploring the efficiency of several remedial measures. This is illustrated in this paper for the bay of Thermaikos (NE Mediterranean sea).

References

Balopoulos, E. and James, A.E. (1984) Drogue measurements of the upper layer circulation in Thermaikos Gulf (Greece). *Thalassographika*, 7, 73
 Ganoulis J., Krestenitis, Y., Papachristou El. et al. (1988) Environmental impacts from the sewage works to the bay of Thessaloniki. Phase B': 1988-91. Report submitted to the Ministry of Environment & Public Works, 244pp. (in Greek)
 Ganoulis J. and Koutitas, C. (1981) Utilisation de donnees hydrographiques et de modeles mathematiques pour l'etude hydrodynamique du Golfe de Thessaloniki. *Rapp.Comm.int.Mer.Medit.*, 27, 41
 Krestenitis, Y. and Ganoulis, J. (1987) Forecasting coastal currents using curvilinear coordinates, *Technika Chronika*, 7, No4, 33 (in Greek).