Water quality management of semi-enclosed bays in Greece

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Abstract

In the framework of the bilateral Dutch-Greek cooperation on environmental issues a methodology based on the systems analysis approach was applied to water quality management in Greek coastal waters. A case study was carried out for the Gulf of Thermaikos in Northern Greece. The case study included a quantitative analysis of cause-effect relationships by means of mathematical models. The methodology and the supporting computational tools have been made available to the Thessaloniki Sewerage Authority, in order to support future decision-making related to the treatment and disposal of urban waste water.

1. Introduction

Coastal waters are used intensively by mankind. Relevant functions of the coastal waters include tourism and recreation, fishing, aqua-culture, shipping and sand extraction. Furthermore, they form valuable nature resources. The coastal waters are economically important: Greece for example derives a large part of its national income from coastal tourism and merchandise shipping.

Conflicts between user functions occur, often in the form of pollution problems, due to the discharge of domestic and industrial waste water, run-off and drainage water from agriculture areas, accidental spills from ships and installations on the shore, construction and dredging works. Common problems are the pollution of beaches, the deterioration of the water quality in general and the subsequent deterioration of the aquatic ecosystem.
A consistent methodology towards the management of coastal water quality may be based on the systems analysis approach. This paper describes the application of such a systems analysis approach to the water quality management of the Gulf of Thermaikos in Northern Greece.

Figure 1: Map of the Gulf of Thermaikos, showing the main water uses and the present and future discharge locations of treated domestic waste water.

The Gulf of Thermaikos is a semi-enclosed bay in the Northern Aegean Sea in Greece (figure 1). The greater city of Thessaloniki, with about one million inhabitants and significant industrial activity, is situated in the Northeast corner of the Gulf. Two of the larger rivers in Greece, Axios and Aliakmon, discharge into the Gulf and the plains to the Northwest feature intensive agriculture. Besides, the city has a busy passenger and cargo port. Due to the natural characteristics, the area is well suited for a variety of human activity. At the same time the semi-enclosed character of the Gulf makes it particularly sensitive to pollution problems.

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2. Methodology

The project described in this paper used a methodology towards coastal water quality management based on the systems analysis approach. The main characteristics were derived from the Management North Sea project (MANS), carried out by the Dutch government in recent years [9]. The key steps in this methodology are:

a) the description of the subject of the analysis on three levels: the natural system, the socio-economic system and the administrative system;
b) the description of the interactions between the systems mentioned above;
c) the definition of a framework for evaluation of the present state and future developments;
d) the analysis and evaluation of the present state;
e) the definition of scenarios and pollution control measures;
f) the analysis and evaluation of alternative pollution control measures;
g) the selection of the best alternative.

The process is essentially iterative: steps d to g (or even c) may be repeated several times.

Supporting computational tools

Policy analysis is often supported by a quantitative analysis using predictive models. Such models describe cause-effect relationships and constitute an indispensable tool in assessing the consequences of certain developments or measures. Quantitative analysis based on mathematical modelling also promotes a better understanding of a particular water system under different conditions. Furthermore, it may assist in improving the consistency between different aspects of our knowledge of the system: e.g. the pollution loads and the pollution concentrations in the water system. But mathematical models also play a role in supporting policy development and management. For example, a target situation for water quality can be translated into the necessary pollution reduction, or vice versa, a target situation for pollution sources can be translated in the corresponding state of the water system.

During the project described in this paper mathematical models were used equipped with a user-interface for case management (job control, management of input/output files) and for specific input and output. The user-interface was designed to simplify the use of models for non-specialists.

3. Water quality management analysis

Natural system - Socio-economic system - Administrative system

The natural system of the Gulf of Thermaikos has been studied by numerous authors. The information from existing sources has been collected and
452 Water Pollution

compiled during the present study. Relevant aspects are circulation patterns (a.o. [5]), water temperature (a.o. [1]), water density and stratification (a.o. [8]), microbiological pollution (a.o. [7]), dissolved oxygen concentrations, nutrient concentrations and phytoplankton (a.o. [8]), heavy metals and organic toxic substances in sea water, marine sediments and marine organisms (a.o. [2]).

The socio-economic system with respect to the water quality management can be characterized by two aspects: (a) the human use of the natural system, as far as it imposes restraints on the water quality and (b) the anthropogenic pollution discharges. The relevant uses are bathing, shellfish cultivation and the established protected wetlands of the Axios-Aliakmon delta (see figure 1). Data about the anthropogenic pollution loads have been collected and compiled: the main pollution sources are the rivers, pumping stations for drainage water from agricultural areas, domestic and industrial waste water. Figure 2 shows the estimated total loads and the division over the main sources for BOD, nitrogen and phosphorus. For BOD the domestic waste water discharges dominate, while for nitrogen and phosphorus the rivers’ contribution is the largest.

![Figure 2: Estimated pollution loads in 1992/1993 for BOD, N and P.](image)

The administrative system has been mapped thoroughly during the project. Several source-directed regulations exist: for the treatment of domestic waste water, EU legislation for black-list substances, EIA obligation for new projects. Effect-directed regulations exist as well: bathing and shellfish water standards. However, the enforcement and control of the applicable legislation forms a weak point.
Interactions between the natural, socio-economic and administrative system

Following Pulles [9] the interactions between the natural, the socio-economic and the administrative systems were analyzed in three steps: (a) obtain insight in human activities, (b) analyze what happens in the natural system and (c) establish the resulting effects on the natural system and on the human activities. Mathematical models were used for microbiological pollution, for oxygen-eutrophication and for toxic substances, based on software from Delft Hydraulics. The first was a Lagrangian or "particle" model with a random walk to account for dispersion [3]. The latter two were three-dimensional finite volume models [4]. The modelling of transport phenomena was based on steady state 2D flow fields computed by the Aristotle University of Thessaloniki [1]. The set-up and calibration was successful in the case of the micro-biological pollution and oxygen-eutrophication models: quantitative cause-effect relations could be established between the pollution loads and the observed water quality. The toxic substances model however, could not (yet) be calibrated due to a lack of consistent and reliable data.

Evaluation of the present state

Microbiological pollution  According to the annual report by the Ministry of the Environment no violation of bathing water standards was observed in 1992 on any of the official beaches along the Gulf of Thermaikos [7]. These beaches however are far from the city of Thessaloniki, which is the primary source of microbiological pollution but whose inhabitants represent an important demand for clean bathing water. In the inner part of the Gulf of Thermaikos (Bay of Thessaloniki) bathing is forbidden. (The violation of the associated standards is confirmed by measurements and reproduced by model computations.) Shellfish cultures are also sensitive for microbiological pollution. Shellfish cultivation in the Bay of Thessaloniki is forbidden as well. Measurements in surface water and shellfish intervalvular fluids in existing cultures outside of this area indicate that the present levels of pollution may present public health risks.

Oxygen problems - eutrophication  Oxygen levels below the standards in the Greek legislation have been measured regularly in recent years. The treatment of 20% of the domestic waste water since 1992 seems to have improved the situation, but still the visual degradation of the water quality in the Bay of Thessaloniki is evident. The increased discharges of nutrients in the Gulf of Thermaikos have lead to an increasing algae biomass with some negative effects, in particular the regular occurrence of red tides and an increase of the oxygen demand due to dead organic matter. (The observed nutrient levels in the Gulf can be reproduced by model computations.)

Toxic substances  The measured concentrations of some black-list substances
Water Pollution

in the Gulf are a reason for concern since they are close to the water quality standards imposed by the EU legislation. Unfortunately, not all black-list substances are measured. For cadmium (Cd) and mercury (Hg) the total concentrations are being measured in stead of the dissolved concentrations for which the EU imposes water quality standards. For grey-list substances no applicable water quality standards have been found. In stead, the measured concentrations have been compared to target values derived from Dutch governmental policy documents: the so-called Dutch Target Values [6]. The Dutch Target Values have been based on assessments of the toxicity of the substances. The evaluation of the measurements in the Gulf of Thermaikos revealed that the most serious toxic effects should be expected from cadmium, mercury and some pesticides.

Scenarios and pollution control measures

During the demonstrative case study some pollution control measures were studied related to the collection, treatment and disposal of urban waste water. The reference situation ("S0") was defined as the present state (1994): the secondary treatment of about 20% of the urban waste water with surface disposal of the treated effluents at some distance from the city (see figure 1). The pollution control measures considered were:

S1) Secondary treatment of all waste water, with denitrification during the summer months. Disposal through an outfall (figure 1). This is the projected alternative.

S2) As S1, with denitrification all year.

S3) As S2, with phosphorus removal.

![Figure 3: Assumed reduction of phosphorus loads for the pollution control measures defined in the text.](image-url)
Furthermore, an alternative discharge option was considered for S1: a surface discharge through an existing ditch near the present surface discharge location (S1a). As an illustration, figure 3 shows the reduction of the phosphorus loads in the different pollution reduction alternatives.

Evaluation of measures

The pollution control measures mentioned above have been analyzed by two mathematical models: the model for microbiological pollution and the model for oxygen-eutrophication. The analysis lead to the following conclusions:
• the projected pollution control measures (option S1) will have a large positive effect on the water quality in the Bay of Thessaloniki;
• the use of the outfall (option S1) has a positive effect over the alternative of the surface discharge (option S1a);
• the additional positive effect of denitrification in the winter (option S2) is relatively small;
• the additional positive effect of phosphorus removal (option S3) is negligible;
• the resulting levels of pollution depend strongly on the development of the other pollution sources.

Figure 4 illustrates these conclusions by showing the effects of the measures on the summer chlorophyll-α concentration, which is assumed representative for the risk of negative eutrophication effects.

![Figure 4: Summer averages of chlorophyll-α in the Bay of Thessaloniki under different conditions of urban waste water treatment and disposal.](image-url)
4. Conclusions

Reviewing the results from the project as a whole we observe the successful development of the methodology and the operationalization of computational tools at the Thessaloniki Sewerage Authority in order to support future decision-making. Furthermore, a rather complete picture of the present state of the aquatic environment in the Gulf of Thermaikos has been drawn, based on a large number of available information sources. Finally, recommendations for future monitoring activities have been formulated. The project has been presented in December 1994 in Thessaloniki to the water management authorities, national, regional and local, to research institutes, universities and private consultants.

5. References