APPLICATION OF COUPLED HYDRODYNAMIC-ECOLOGICAL MODELS FOR ENVIRONMENTAL MANAGEMENT OF COASTAL ECOSYSTEMS

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Introduction

In 1950 the Baltic Sea was still regarded as environmentally healthy. Since then the situation has changed considerably and pollution now threatens the entire Baltic Sea catchment area as well as the Baltic Sea itself. Rivers act as large-scale collectors and carriers of waste water due to the inadequate treatment of municipal sewage and the lack of treatment of industrial waste water. Finally, agricultural practices contribute to the high nutrient load in the Baltic Sea.

Problem description

This paper will focus on marine environmental investigations carried out in Tallinn Bay, Estonia. The major water quality problems for Tallinn Bay were considered to be eutrophication and associated algae blooms as well as the poor hygienic water quality along the shore in the inner parts of Tallinn Bay.

The objective of the project was to provide the right basis for decision-making regarding the most optimal solution for pollution reduction with respect to both investments and the hygienic and ecological conditions in Tallinn Bay.

Project investigations

The following main activities were carried out:

- Hydrographic and water quality monitoring of Tallinn Bay. Detailed monitoring of discharges and overflows and the determination of loadings to the bays covering a full year cycle. During a one year period measurements were made of hydrographic conditions (current, salinity, temperature), water chemistry and biological conditions (chlorophyll-a, primary production, bioassays).

- Establishment of a prediction tool for decision-making. Mathematical models, describing the water movements, water quality and ecological conditions in 3 spatial dimensions and one temporal dimension, were calibrated to the present situation. The models measured salinity and temperature variations, density and wind-driven flows, transport and dispersion, nutrient levels, algae growth, oxygen production, mineralisation of detritus and zooplankton grazing.

- Environmental impact assessment and an assessment of the effects of reduction scenarios. Various abatement schemes were identified and defined through detailed discussions with the environmental authorities. The consequences of the reduction of loadings resulting from the abatement schemes were calculated by the models and compared to the present situation.

- Establishment of an action plan for the restoration of the marine environment in Tallinn Bay.

- Transfer of the modelling tool to environmental authorities.

Because of the relatively wide and deep connections to the Gulf of Finland, the hydrodynamics of Tallinn Bay are strongly influenced by the general circulation patterns in the Gulf. The flow pattern in the Gulf of Finland is determined by the mean thermocline circulation of the entire Baltic Sea and the wind forcing. The seasonal cycle of the net heat flux generates a strong thermocline at depths of 10-20 m during the warm season and causes vertical mixing in autumn-winter. A two-layered structure of the water column prevails from May to September. The water column is almost fully mixed in the coastal regions and fully mixed to the permanent halocline in the deeper parts of the sea during the cold season. In order to investigate these complicated flow patterns in the Bay, field campaigns were carried out in the period April - November 1994.

Extensive water quality surveys were conducted in Tallinn Bay from April to November 1994. The measurements of chlorophyll-a showed levels of 7-20 µg/l in Tallinn Bay. The data showed the occurrence of the spring bloom. In the summer period the chlorophyll-a levels were between 1-5 µg/l. Primary production was measured. The daily production in the Bay varied between 11-1081 mg C/m^2/day. On a yearly basis the values varied between 72 and 107 mg C/m^2/day. Bioassays were conducted to assess the importance of nitrogen and phosphorus as limiting factors. The general tendency of the data indicated a pronounced nitrogen limitation in both bays. The hygienic conditions in the open parts of the bay were also studied during 1994 and the highest levels of E. coli were recorded in the inner part of Tallinn Bay and around a major ocean outfall 3-5 km from the coast. High E. coli levels were observed, especially after periods of precipitation.

The basis for the 3D modelling was the modelling system called MIKE 3, developed by Danish Hydraulic Institute. The system is fully three-dimensional, solving the momentum equation and continuity equations in the three cartesian directions. The modelling system simulates unsteady flow, taking into account density variations, bathymetry and external forcing such as meteorology, currents and other hydrographic conditions. The system is composed of the following modules: the hydrodynamic module, the turbulence module, the advection-dispersion module, the water quality module (hygienic problems) and finally the eutrophication module.

A model bathymetry for Tallinn Bay was established, covering an area of 21 x 18 km, with a model resolution of 500 m in the horizontal plane and 5 m in the vertical. Two hydrodynamic modelling tasks were performed. First, short term simulations were carried out, with the purpose of calibrating the model-calculated currents, salinity and water temperature and secondly the generation of one long term simulation was carried out, i.e. an 8-9 month long period covering the biologically active growth season. This hydrodynamic long term simulation was established with the purpose of forcing the water quality model and the eutrophication models. The water quality model and the

eutrophication models were calibrated by comparing measured data from the 1994 field programme and simulated results.

Potential reduction scenarios for nutrient loadings and E. coli were identified and discussed with the environmental authorities in Estonia. Based on these discussions, ten different reduction scenarios (5 eutrophication and 5 bacteria) were identified and simulated by the models. In the eutrophication scenarios the main focus was to assess how a reduction in nutrient loadings to the bay influences the phytoplankton production and in the bacteria scenarios, it was investigated how the water quality along the coast line could be improved. The potential cost of the different scenarios was also evaluated.

Achievements

As a final result, based on the modelling, the priorities and recommendations for obtaining the best improvement of water quality conditions were formulated considering the nutrient removal capacity of the specific scenario, the reduction of nutrient loadings to the Baltic Sea and the necessary investment. The final priority list was presented to relevant authorities. This list should be elaborated by the relevant authorities based on which aspects are emphasized as being most important.

The established operational models were installed on the local authorities' computers to provide a tool for the assessment of the changes in water quality conditions due to future reductions or to the addition of pollution sources in the coastal area of Tallinn Bay. The models will thereby play an active role in environmental management in Estonia.

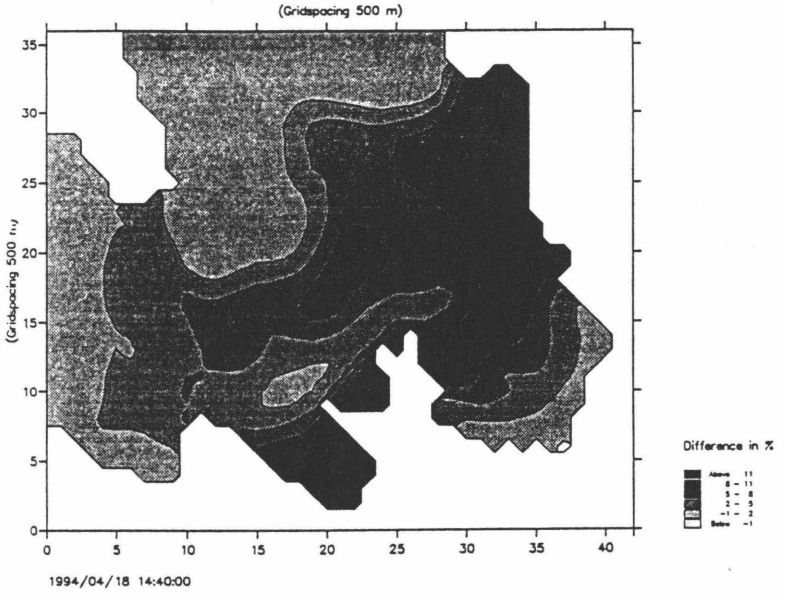

Fig. 1. Difference in phytoplankton production, scenario 4 versus reference situation. Tallinn Bay model.

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