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SIMULATION OF ECOLOGICAL IMPACTS OF THE NEW OUTER-HARBOUR DEVELOPMENT IN ZEEBRUGGE

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ABSTRACT

The new outer-harbour in Zeebrugge is to be protected by jetties extending 1,750 m seaward. This development will alter the local distribution of tidal and residual currents. Such hydrodynamic changes will, in turn, affect the dispersion pattern of dissolved and particular matters in the vicinity of Zeebrugge. A mathematical model is presented, which simulates the dispersion - before and after outer harbour development - of dissolved organic matters, faecal bacteria and heavy metals, which are indicative of, respectively domestic, human, and industrial pollutions.

KEYWORDS : mathematical model, dispersion, coastal pollution, harbour pollution.

INTRODUCTION

The belgian coastal waters are strongly influenced by input from rivers and channels, due to the pecularities of the tidal and residual circulation in this part of the North Sea. In particular, the quality of the marine waters in the vicinity of Zeebrugge is largely affected by two effluents, each of which has a significant flow and a high level of pollution.

First, the Leie River contributes to the input of organic nitrogen to the coastal waters nearly as much as the Scheldt River, although its flow is 5 times smaller. This is due to a considerably shorter residence time which prevents recycling.

Second, the sewer outfall of Blankenberge releases considerable amounts of pollutants of domestic origin.

Table I summarizes data on the inputs of faecal coliforms (indicator of human pollution), of dissolved organic matter (BOD5, indicator of domestic pollution), and of dissolved zinc (a heavy metal, indicator of industrial pollution).

The construction of an outer harbour at Zeebrugge, protected by two

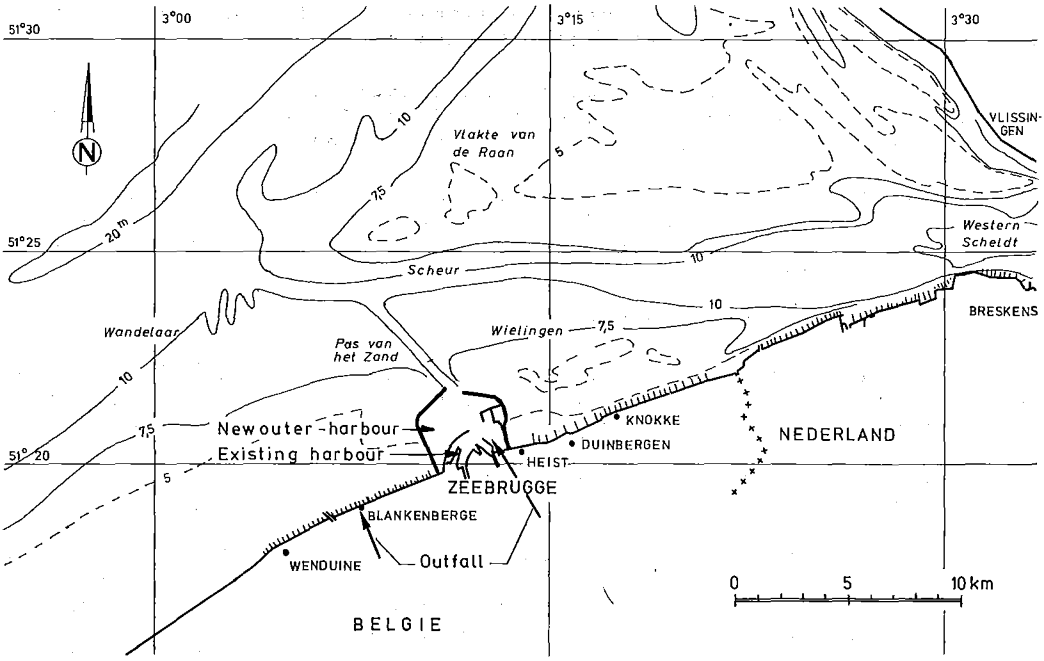

FIG. 1 Belgian coast and Western Scheldt estuary

TABLE 1

	Faecal coliforms (germ/sec)	Dissolved organic matter (gC/sec)	Dissolved zinc (mg/sec)
Leie river branch canal(x)	1.35×10^{10}	227 (summer) 129 (winter)	300
Blankenberge sewer outfall	7×10^{10} (summer) 7×10^{9} (winter)	4.78 (summer) 2.3 (winter)	1.042

(x) for the period of time when the locks are open, that is from the mid-tide following high tide in Zeebrugge to the mid-tide following low tide in Zeebrugge.

jetties extending 1750 m seawards, will modify significantly the coastal line and the bathymetry in the near future. Hence, the conditions governing the transport and dispersion of substances in the local marine environment will also be modified.

Moreover, further modifications in the dispersion pattern may be expected, because the mouth of the Leie River will no longer be located outside the eastern jetty, but inside the new harbour.

In this paper, we present results of computer simulations of the dispersion of faecal coliforms, dissolved organic matter and dissolved zinc, in the "reference" (or initial) situation, as well as in the "perturbed" situation.

THE DISPERSION MODEL

The equation governing the dispersion of matter in a shallow turbulent sea takes into account the effect of advection, the so-called shear effect diffusion and the biochemical interactions among the variables (Nihoul (1972)). The general tridimensional equation can be simplified, taking into account that some necessary assumptions are satisfied in this part of the North Sea (Adam (1976)).

The main assumption states that the distribution of the substance is homogeneous over the water column; this has been verified in situ for most substances and living microscopic organisms, like phytoplankton and bacteria, and is clearly due to the strong turbulent mixing (e.g. Pichot (1980)).

Hence, the equation governing the evolution of any of the three state variables considered here, i.e. faecal coliforms, dissolved organic matter and dissolved zinc, reads :

$$\frac{\delta}{\delta t}\,\bar{r}_a = -\,\underline{\bar{u}}\cdot\nabla\,\bar{r}_a + H^{-1}\,\nabla\cdot\left[\gamma\,\frac{H^2}{\underline{\bar{u}}}\,\underline{\bar{u}}\;(\underline{\bar{u}}\cdot\nabla\,\bar{r}_a)\right] + I$$

with $\bar{r}_a$: the state variable integrated over the depth H

$\underline{\bar{u}}$: the tidal current integrated over the depth H, as given by a parallel hydrodynamical model

γ : the shear stress coefficient

For each of the three state variables, the interaction term I is assumed of the form :

$$I = -k\ r$$

This was verified - thanks to an intensive field work (Pichot and Barbette (1978)) - for the faecal bacteria, whose number in seawater decreases exponentially with a rate k = 1.925 10-5 sec-1, due to natural mortality.

Dissolved biodegradable organic matter has also been shown to decrease exponentially with time. The rate k = 2.58 10-6 sec-1 was derived from numerous field measurements of heterotrophic respiration and BOD (Billen et al. (1980)).

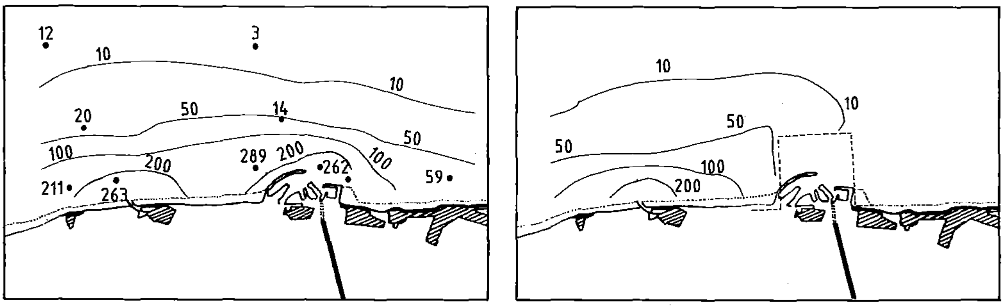

FIG. 2a FIG. 2b

Distribution of faecal coliforms (germs/dl) averaged over one tidal cycle, as simulated with the dispersion model
a. in the present situation (black circles indicate actually measured concentrations)
b. in the future situation

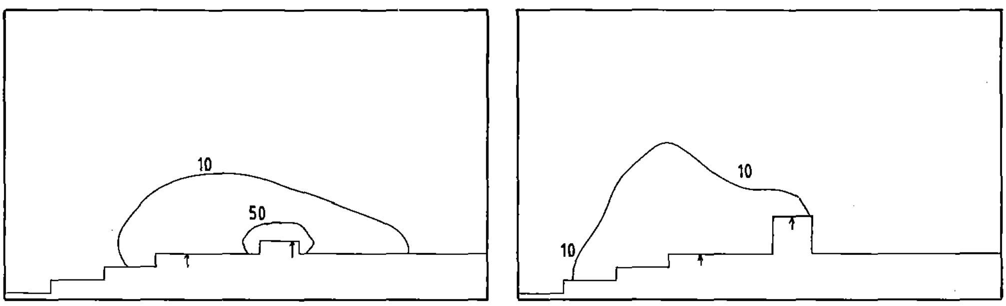

FIG. 3a FIG. 3b

Distribution of superimposed concentrations of dissolved organic matter (mg C/m3), averaged over one tidal cycle, as simulated with the dispersion model
a. in the present situation
b. in the future situation

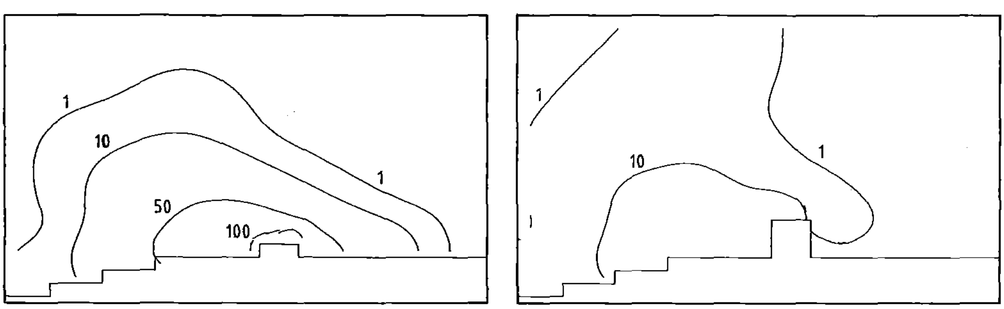

FIG. 4a FIG. 4b

Distribution of superimposed concentrations of dissolved zinc (ng/l), averaged over one tidal cycle, as simulated with the dispersion model
a. in the present situation
b. in the future situation

As for dissolved zinc, the rate was taken equal to zero, since the characteristic time scale of phenomena affecting this substance (e.g. uptake by phytoplankton), is much larger than that of the dispersion phenomena considered in this study.

This equation is solved numerically using the finite-differences technique described by Adam (1977) ; special care is taken to conserve the mass and to represent adequately steep concentration gradients.

RESULTS

Figures 2, 3 and 4 show the distribution induced by the two effluents - averaged over one tidal cycle - of faecal coliforms, dissolved organic matter and dissolved zinc in the reference and in the perturbed situation.

It can be seen that, in both situations, either in the reference, or in the perturbed situation, averaged concentrations superimposed by the two effluents to the background concentrations of all the three state variables are higher on the western side of the outer-harbour than on its eastern side. This phenomenon cannot be explained on the basis of the residual circulation pattern, since the flow is roughly parallel to the coast, in the North-East direction. The asymmetry of the calculated distribution is due to the fact that the sluices of the derivation channel of the Leie River are opened only during the ebbing periods of the tidal cycle.

The results of the simulation for the dispersion of zinc and of organic matter cannot be verified, because the superimposed concentrations lie well below the detection limits of the best available methods. However, the result obtained in the case of faecal coliforms compares favourably with the observations (e.g. Figure 2a). This dispersion model has also been extensively validated in other areas of the North Sea by Rhodamin-B diffusion experiments.

In the perturbed situation, the asymmetry of the average superimposed concentration is even more pronounced and these concentrations are much lower than in the reference situation. Such a decrease in pollutant concentration is explained by an increase of the residence time of the water of the Leie River inside the new outer-harbour. The latter acts as a buffer zone between the discharge and the coastal waters, and so mortality and sedimentation processes become locally important.

DISCUSSION

The simulations performed with the dispersion model show that the construction of the new outer-harbour would be rather beneficial to the closely surrounding marine ecosystem. Indeed, the ecological and sanitary impact of an important outfall will be considerably reduced, due to the increase in residence time in the new outer-harbour. It is clear that the bacteriological cleanness of the beaches on the east side of the harbour will be specially enhanced. The buffer zone will also decrease the amount of organic matter brought to the coastal zone by the former outfall, and the eutrophisation of the marine environment will lessen, to some extent.

However, the degradation of the water quality inside the outer-harbour will increase the eutrophisation, and chronical formation of organic mud will occur, requiring intensive dredging of a material rich in organic matter and heavy metals. Such a situation is very common for harbours situated in estuaries or in deep embayments. It is clear that dumping at sea of these dredging wastes could cancel the advantages temporarily gained from the creation of a buffer zone.

Nevertheless, this procedure would not add more pollutants to the marine ecosystem than presently brought directly by the outfall along the coast.

It is not known where the dredged muds will be dumped. The quality of the coastal marine environment would be improved if land-based uses for these (polluted) muds could be found. An alternative approach would be the cleaning of the outfall itself.

However, if dumping at sea were chosen as the best solution, it should be kept in mind that such dumpings fall under the rules of the international Oslo Convention, which requires preliminary scientific evaluation of the dumping sites. In this case, the evaluation should obviously take into account the erosion and sedimentation characteristics of the dumping site, the local and global pattern of tidal and residual currents, as well as of living resources.

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