

SUMMER SCHOOL

ON

**Environmental Impact Assessment
and Management of Coastal Zone:
An Integrated Approach**

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EIA MODELLING FOR COASTAL ZONE MANAGEMENT (PART II)

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Introduction

All environmental problems are directly or indirectly related to the society and its economics. Mostly these issues result from urbanization and technological development and have direct impact on the environment. They affect the public life in general, and hence the concern for environmental issues is more rapidly increasing day by day. As the environmental problems are directly proportional to the industrial development, the frequently asked question is: how to solve the many environmental problems properly so that we could move ahead with the industrial growth. Basically, most of the problems are related to the industrial pollution and any solution to reduce pollution will obviously increase the cost of the final product. The cost of raw materials and energy has increased tremendously; the resources available to control pollution are very less or minimal.

The major environmental issues are related to:

- Pollution in rivers, estuaries and coastal seas (BOD, CBOD & other pollutants)
- Eutrophication of lakes
- Management of non-point sources of waste
- Water pollution by toxic compounds
- Management of fishery activities
- Pollution of agricultural land
- Global climatic consequences by air pollution

Modelling of environmental parameters

Energy and pollutants are discharged into the ecosystems where they cause more rapid growth of algae or bacteria, damage species or alter the ecological structure. An ecosystem is extremely complex and so it is an overwhelming task to predict the impact, an effluent discharge will have, on the ecosystem. Predictive models come into play a unique role at this juncture. Modelling of environmental parameters has been accepted as the only alternative to zero discharge, if ecologically acceptable solutions are to be provided.

The primary requirement to set up a model is the basic knowledge about the bathymetry, flow velocity, tides and the ecosystem parameters that effect and interact with each other. With the knowledge, it is possible to formulate the features of the ecosystem that are involved in the pollution problem under consideration.

Field measurement of these parameters is necessary to give input data as initial and boundary conditions to the model and for calibration and validation of the model.

Hydrodynamic model

A two-dimensional simulation model can be used to simulate the tides, currents and pollution dispersion. The model provides a transient solution for shallow water bodies and it can accommodate irregular coastline, complex bathymetry and open boundaries. Inlets and outlets can also be included using initial and temporal boundary conditions. This model can be further used for studying transport of pollutants and thermal plumes in rivers, estuaries and coastal regions.

Description of the model

- 2D vertically integrated shallow water momentum equations
- Finite difference method for solutions
- Square grid of 300 m
- Time dependent

The governing equations for mass and momentum conservation are given as follows:

The following assumptions are made:

- Water column is completely mixed
- Hydrostatic pressure, i.e. $\frac{\partial p}{\partial z} = \rho g$
- Momentum exchange is only due to horizontal velocity components

Under such assumptions vertically averaged Navier-Stokes equations become:

$$\frac{\partial \eta}{\partial t} = -\frac{\partial(Hu)}{\partial x} - \frac{\partial(Hv)}{\partial y}$$

$$\frac{\partial u}{\partial t} = -u \frac{\partial u}{\partial x} - v \frac{\partial u}{\partial y} - g \frac{\partial \eta}{\partial x} - fv + \frac{T_{ox}}{\rho H} - g \frac{u}{c^2 H} \sqrt{u^2 + v^2}$$

$$\frac{\partial v}{\partial t} = -u \frac{\partial v}{\partial x} - v \frac{\partial v}{\partial y} - g \frac{\partial \eta}{\partial x} + fu + \frac{T_{oy}}{\rho H} - g \frac{v}{c^2 H} \sqrt{u^2 + v^2}$$

where,

u, v are	vertically averaged velocity components
η	free surface elevation
$H+\eta$	total water column depth
T_{ox}, T_{oy}	wind stress horizontal components
C	Chezy coefficient related to water depth i.e $C=H^{1/6} C_o$
C_o	Roughness coefficient dependent on bottom characteristics
f	Coriolis term

The Navier-Stokes equations are solved by finite difference method using Alternating Direction Implicit (ADI) scheme on a staggered grid.

At closed boundaries the following conditions are applied:

- zero cross flow
- longitudinal velocity equal to half of the adjacent mesh velocity (slip conditions)

At open boundaries the free surface elevation is imposed

Variable boundaries are defined in areas of shallow water subject to flooding : at each time step the model computes if the mesh is flooded (computational point) or emerged (closed boundary)

Input and output data

The data necessary for running the model are:

- Grid characteristics
- Basin latitude
- integration time step
- water depth for each mesh
- roughness coefficient for each mesh
- wind speed
- initial conditions
- open boundary conditions

The outputs are

Free surface elevation and velocity components for each mesh of the calculation domain

Effluent dispersion plume modelling

The governing equation for effluent dispersion is based on the equation for the mass conservation:

$$\frac{\partial}{\partial t}(Hs) + \frac{\partial}{\partial x_i}(Hv_i s) = \frac{\partial}{\partial x_i} \left(HK_D \frac{\partial s}{\partial x_i} \right)$$

where,

H total water depth

s effluent concentration

x_i Cartesian coordinate in the i th direction

v_i velocity component in the i th direction

K_D diffusion coefficient

The 2D vertically integrated shallow water momentum balance equations for a Cartesian co-ordinate system with x-axis and y-axis directed eastward and northward respectively and the z-axis positive downward, are used in the model for simulation of tides and velocity fields. The governing equations are discretized, by integrating them over each element in the grid, using an integration method known as Nodal Point Integration. Solutions for U , V and η at each node are obtained by

solving the algebraic equations obtained for each of these variables using matrix solvers such as alternating direction implicit (ADI) or successive over-relaxation (SOR) method. The ADI method solves the set of algebraic equations in three sweeps along X, Y and Z co-ordinates. For each sweep only the values at the grid node in that direction are computed at an advanced time step, taking other values from the previous time step. The SOR method employs an explicit scheme in which there is only one unknown per equation. The equation then can be solved for a new value at each node.

Water depth values measured at grid points are used. The wind speed and direction measured are also given as input. The temperature flux at the surface is given as input based on the measured data. The frictional stress at the bottom of the basin is computed using the near bottom current velocity and a constant friction coefficient. Water level variations at the open boundaries are either given from the measured values or taken from the predicted tides in the Indian Tide Tables.

The initial values of U , V and η , given as basic input parameters are selected from the resolved components of observed currents and Tide Tables respectively. The bottom friction (τ_b) is computed from the measured near bottom current velocity. The maximum permissible time step yielding a stable solution is given by $\Delta t \leq \Delta x/c$ where, Δx is space step and c is wave celerity. In shallow water, $c = \sqrt{gH}$. This time step Δt is important for transient flows, as long waves propagate across a grid interval of length Δx in time Δt . For explicit schemes like SOR the time step used must not exceed the value obtained by the above equation.

Effluent dispersion modelling

The above hydrodynamic set up was used to simulate the effluent dispersion. As per the effluent characteristics provided for a project off Ennore the total waste water generated would be estimated as 50,000 m³/day. The total pollution load is estimated to be 18,555 MT/day. The concentrations of each component of the effluent are given in Table. These values have been taken as the initial concentrations of the effluent.

Parameter	Characteristics	Pollution load MT/day
Temperature	+5° of the ambient	
PH	6.5-8.5	
Suspended solids (mg/l)	100	5.0
Oil & grease (mg/l)	10	0.5
Phosphate –PO4 (mg/l)	5	0.25
Ammonical Nitrogen as NH3 (mg/l)	25	1.25
BOD (mg/l)	30	1.5
COD	200	10.0
Phenolic compounds (mg/l)	1.0	0.05
Hexavalent chromium (mg/l)	0.1	0.005

Keeping the outfall at four selected locations, the concentration of the effluent and spread of the plume have been simulated. The maximum concentration of the effluent near the outfall at these four locations are given in the Table below.

Distance (m) from land to outfall	Maximum concentration (mg/l) near the outfall				Depth (m)
	at 6hrs	12 hrs	24 hrs	48 hrs	
1200	1.30	0.73	0.91	0.52	10.2
2100	1.30	0.65	0.79	0.44	8.0
3000	1.90	0.89	1.12	0.61	7.0
4200	1.40	0.62	0.87	0.42	12.0

BOD – DO Modelling

The substance that pollutes or impacts an ecosystem can be classified into two groups such as conservative or non-conservative based on their reactive properties.

Conservative substances (e.g. dissolved salts and certain metals)

- No loss due to chemical reaction
- No radioactive decay

Non-conservative substances (BOD, nutrients, volatile chemicals, bacteria)

- substances that decay with time
- undergo chemical reaction
- .. bacterial degradation
- .. radioactive decay

It is assumed that the non-conservative substances undergo decay according to a first order reaction. The rate of loss of the substance is proportional

to the concentration at any time. Then the formulation of the equation for a steady state situation is first order differential equation:

$$\frac{1}{A} \frac{d(QS)}{dx} = KS$$

Where,

K is the decay rate

S the concentration

Q is the flow

A is the area

The boundary condition $S = S_0$ at $x=0$

S_0 can be calculated using

$$\frac{Qu.Su + W}{Q} = S_0$$

Where,

$W=Qe Se$,

u refers to upstream values and e refers to effluent characteristics

If we assume that there is no change of flow between inputs then

$$\frac{dQ}{dx} = 0$$

$$\frac{1}{A} \left(\frac{SdQ}{dx} + \frac{QdS}{dx} \right) = KS$$

$$\frac{Q}{A} \frac{dS}{dx} = KS$$

$$S = S_0 \exp\left(-\frac{Kx}{U} \right)$$

where, x is distance and U is the flow velocity. The above solution refers to any non conservative substance decaying at the rate K.

Water quality indicator of a marine environment is the amount of dissolved oxygen (DO) present in the waters. Oxygen in the marine environment is produced by photosynthesis of algae and plants and consumed by respiration of plants, animals and bacteria, BOD degradation, sediment oxygen demand (SOD) and oxidation of nitrogen compounds. In addition, oxygen is re-aerated through interchange with the atmosphere. The simulation of DO using numerical model becomes complex due to the combined effect of all the above source and sink terms (effective decay or addition rates) with tidal mixing and dispersion. The scenario of water quality analysis becomes further complicated when DO concentration is affected due to the large quantities of effluent of high CBOD and NBOD concentration.

Simulation of BOD/DO independently needs the de-oxygenation coefficients for BOD, CBOD, NBOD and SOD, the rate of DO change associated with photosynthesis, respiration and re-aeration processes.

The steady state equations of BOD-DO that need to be solved are

$$0 = -U \frac{dL}{dx} + E \frac{d^2 L}{dx^2} - K_r L$$

$$0 = -U \frac{dc}{dx} + E \frac{d^2 c}{dx^2} - K_d L(x) - K_N L^N(x) + K_a(c_s - c) - S_b + p_a - R$$

$$0 = -U \frac{dL^N}{dx} + E \frac{d^2 L^N}{dx^2} - K_r L^2$$

where, U is the net velocity

- c the concentration of the dissolved oxygen (DO)
- L CBOD concentration
- E dispersion coefficient
- L^N NBOD concentration
- K_r net loss rate due to settling
- K_d de-oxygenation coefficient
- K_N nitrification rate

- K_a re-aeration coefficient
- S_b sediment oxygen demand
- P_a daily average of gross photosynthesis DO production
- R Phytoplankton DO respiration rate

An initial estimate of the oxygen parameters such as Production, respiration and re-aeration constants can be carried out from measured diurnal variations of the oxygen concentrations.

Estimation of Re-aeration, respiration and production of Oxygen

The method is based on a simplified oxygen balance assuming that the area of measurement is unaffected by pollution sources e.g. BOD decay, ammonia oxidation and sediment oxygen demand.

The simple balance is

$$\frac{dc}{dt} = K_a(c_s - c) + p_a - R$$

Since the oxygen production at night is nil, the respiration and re-aeration can be estimated from the night measurements. The oxygen concentration measured at a time early in the night and late in the night i.e. $C_{o,t1}$ and $C_{o,t2}$ can be used for this purpose. Similar concentrations are read for $t1+\Delta t$ and $t2+\Delta t$ where Δt is the time step between the two measurements i.e. $C_{n,t1+\Delta t}$ and $C_{n,t2+\Delta t}$ discretization of the differential equation of the simplified oxygen balance for the two stations is :

Early in the night:

$$\frac{C_{n,t1+\Delta t} - C_{o,t1}}{\Delta t} = K_a \left(C_s - \frac{C_{n,t1+\Delta t} - C_{o,t1}}{\Delta t} \right) - R$$

Late in the night

$$\frac{C_{n,t2+\Delta t} - C_{o,t2}}{\Delta t} = K_a \left(C_s - \frac{C_{n,t2+\Delta t} - C_{o,t2}}{\Delta t} \right) - R$$

Solving these two equations, the two unknowns values of R and K_a can be estimated.

The maximum oxygen production is then calculated by measuring the oxygen concentrations at two stations at the time of maximum production (noon time) C_0 , t , and $C_{n,t+\Delta t}$. Substituting these and the estimated coefficients in the above differential equation we get,

$$\frac{C_{n,t+\Delta t} - C_{0,t}}{\Delta t} = K_a \left(C_s - \frac{C_{n,t+\Delta t} - C_{0,t}}{\Delta t} \right) - R$$

The final results thus obtained can be used to select the environmental technology that are best suited to solve the specific problem or for legislation to reduce the impact or to eliminate the discharge.

The simulated variations of BOD and DO at a proposed discharge location are given in Figures 1 and 2. The re-circulation of a thermal plume is given in Figure 3 and the effluent from a chemical and fertilizer plant is given in Figure 4.

Oil spill simulation

Coupling the hydrodynamics module with oil spill module (not explained here), the fate of an oil spill can be studied. The spill undergoes weathering processes such as evaporation, dissolution, emulsification, sedimentation and finally shore deposition. While major part of the oil spill gets evaporated, the remaining quantity will be subjected to weathering processes in the water. The crude oil spilled at sea undergoes a number of chemical changes and some of which lead to its removal from the sea surface. The process of removal depends primarily on the physical and chemical characteristics of the crude, quantity of the spill, the atmospheric condition and the sea state. The main physical properties of the crude are the specific gravity, distillation characteristics, viscosity, etc. Initially, the model simulates flow conditions and the oil spill module tracks the oil particle. The dispersion, and dissolution, etc can be simulated using the model. Figure 5 shows the trajectory of a simulated oil spill off Dhabol, Maharashtra.

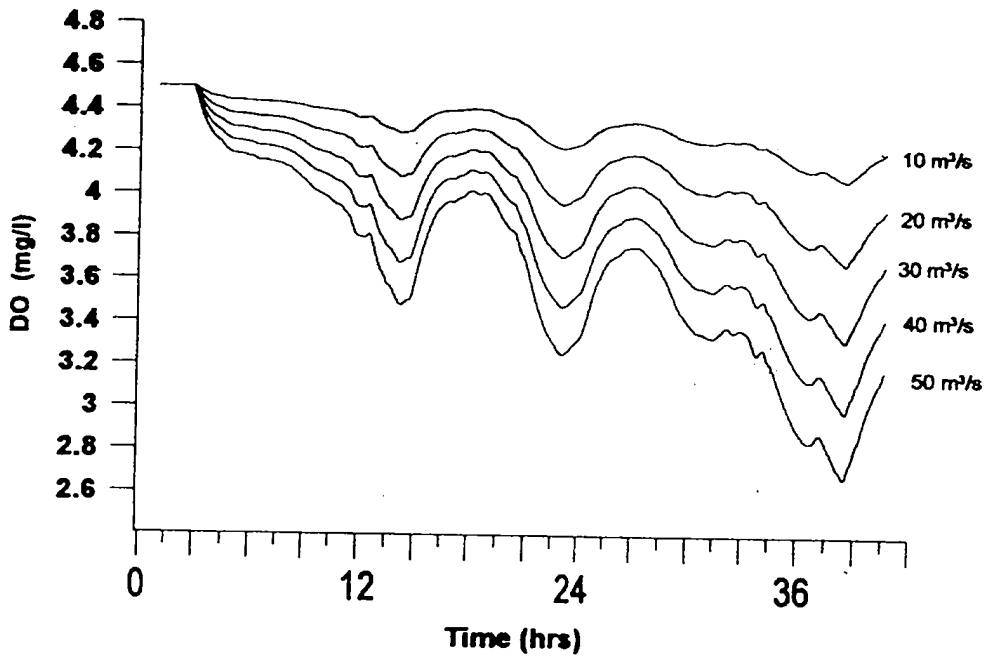


Fig. 1 Concentration of DO at the outfall for varying effluent quantities (Ambient DO = 4.5mg/l, depth of outfall = 10m)

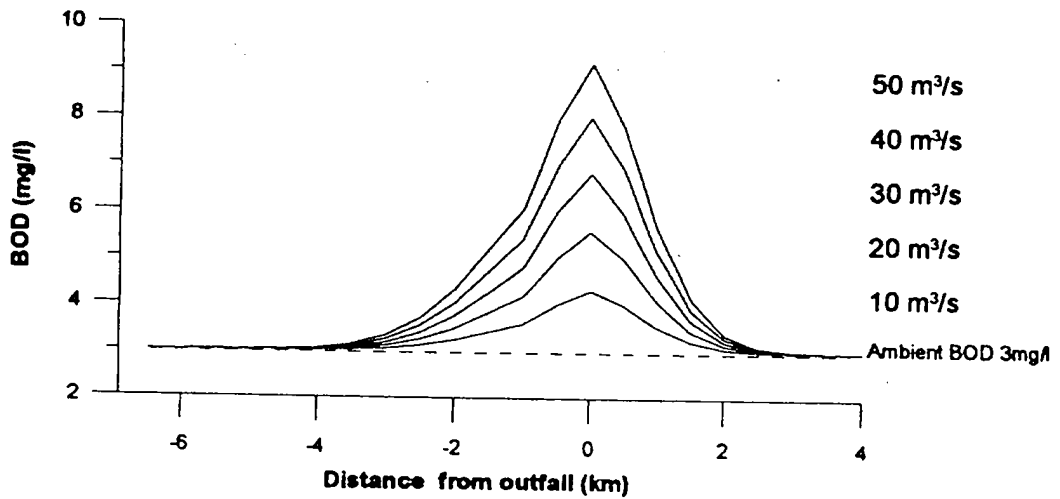


Fig. 2 Distribution of BOD (mg/l) after 24hrs of discharge (effluent BOD = 30 mg/l)

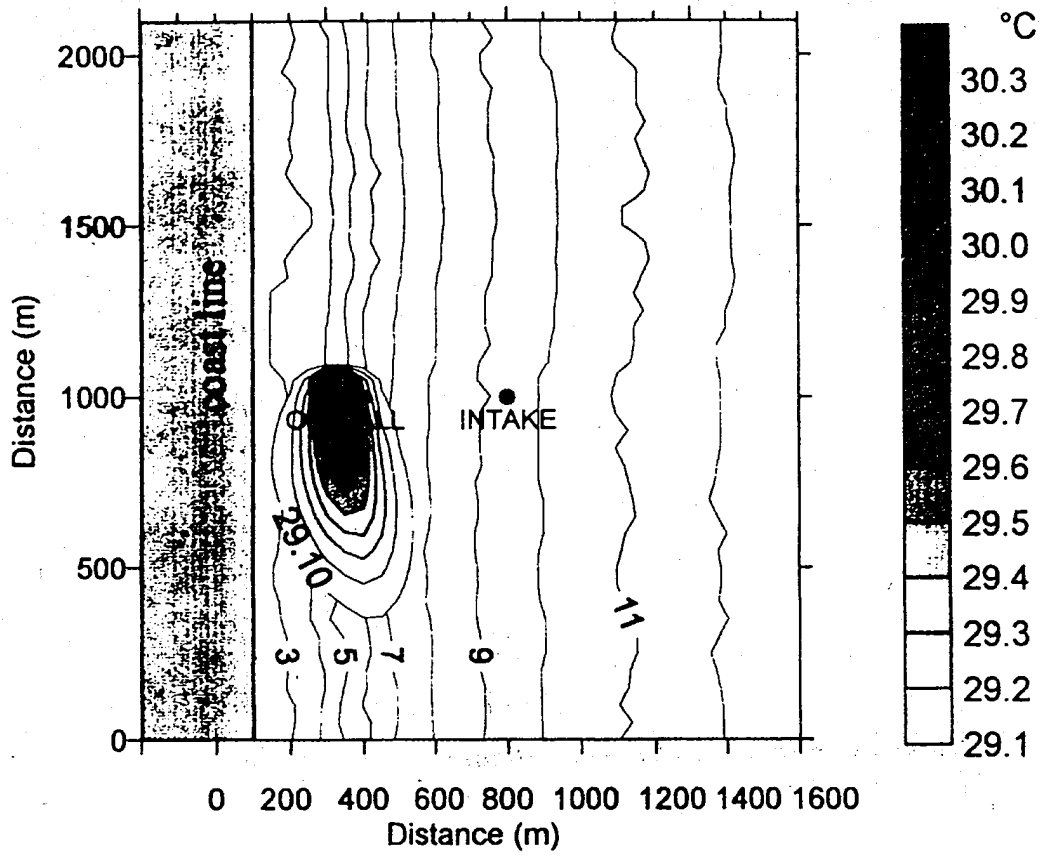


Fig. 3 Warm water plume after 1 hr of discharge during October (NE winds)

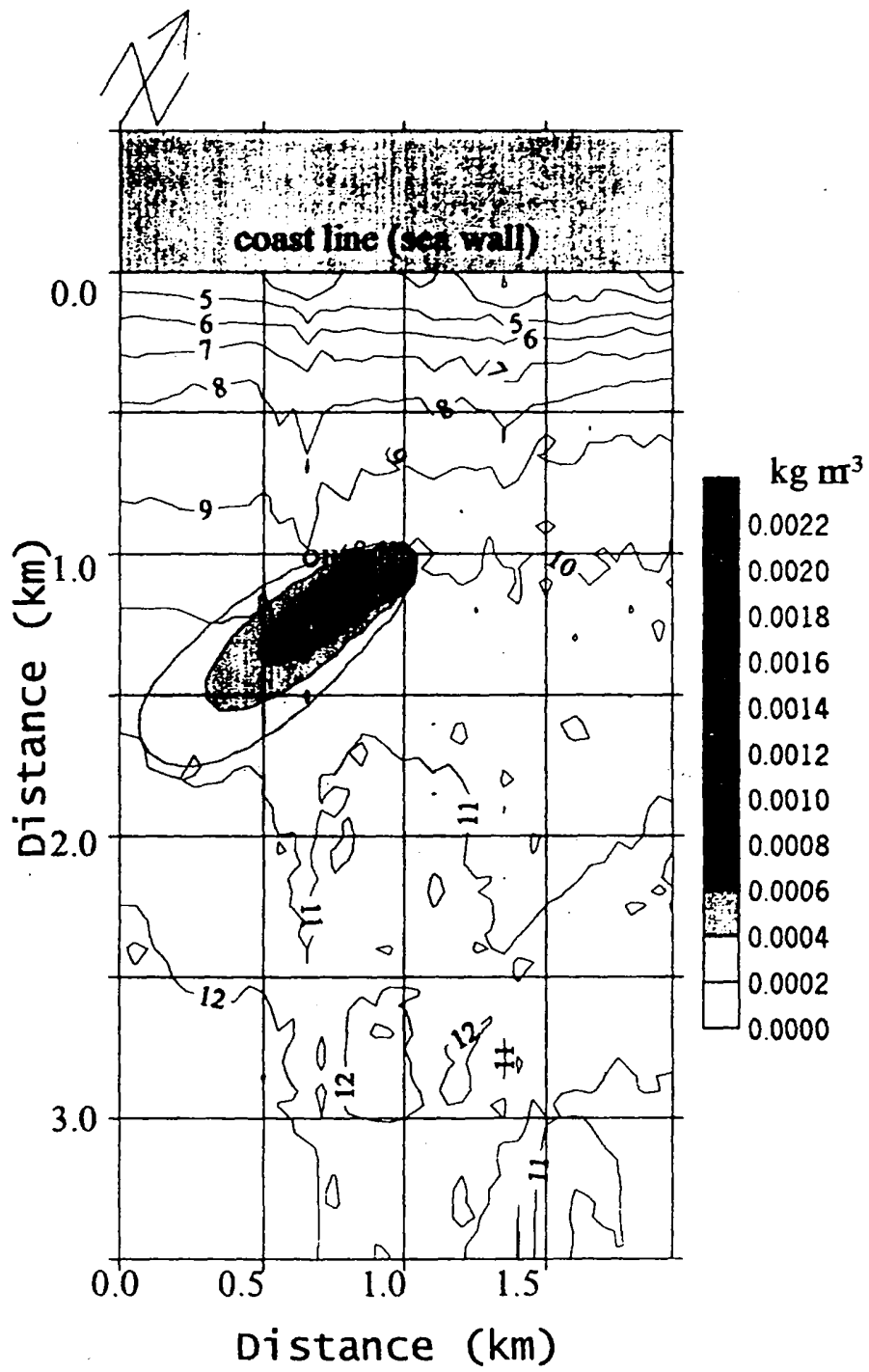


Fig. 4 Concentration of the effluent after 60 minutes (depth contours are in metres)

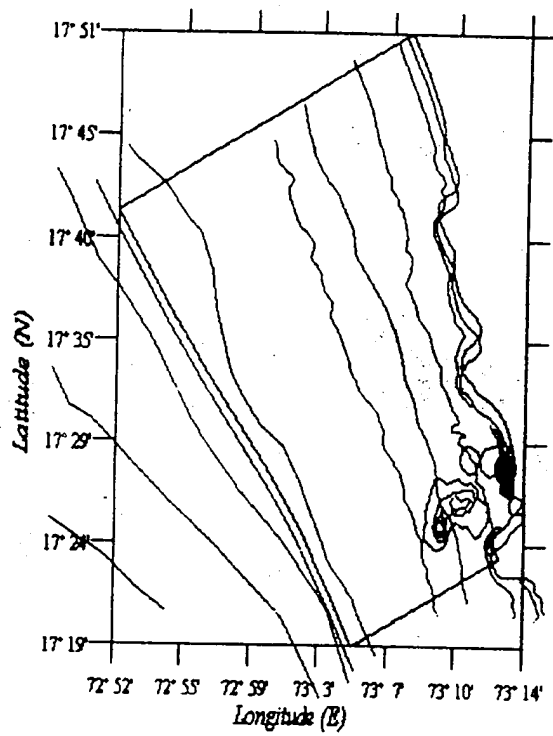


Fig. 5 Oil spill after 50 hrs