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Long-Term Fate of PCB Contamination in the New Bedford Harbor, Massachusetts, System

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Abstract

The transport and fate of polychlorinated biphenyls (PCBs) at the New Bedford Harbor Superfund site is modeled using a three-dimensional hydrodynamics and sediment-contaminant transport model. Simulations projecting the fate of PCBs over a 10-year period are required to assess the effectiveness of remedial action alternatives. A continuous computer simulation for the 10-year period is economically unfeasible; therefore, a method to extend the simulation results over the 10-year period was developed. The method uses a combination of transport-only calculations driven by previously computed hydrodynamics and linear extrapolation of model results. The long-term PCB simulation results for the no-action alternative are presented.

Introduction

New Bedford Harbor, Massachusetts, is an estuarine U.S. Environmental Protection Agency (EPA) Superfund site contaminated with high levels of PCBs and heavy metals (e.g., Cd, Cu, Cr, Pb). The area between the Wood St. and Coggeshall St. bridges (Figure 1) contains most of the PCB contamination in bed sediments; the total mass is approximately 150,000 kg, and typical concentrations exceed 100 ppm with isolated samples above 25,000 ppm.

As part of the remedial investigation and feasibility study (RI/FS), a three-dimensional hydrodynamic and sediment-contaminant transport model is being applied to New Bedford Harbor and an adjoining portion of Buzzards Bay. The goal of the modeling program is to develop a tool

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for the comparative analysis of proposed remedial action alternatives over a 10-year future period.

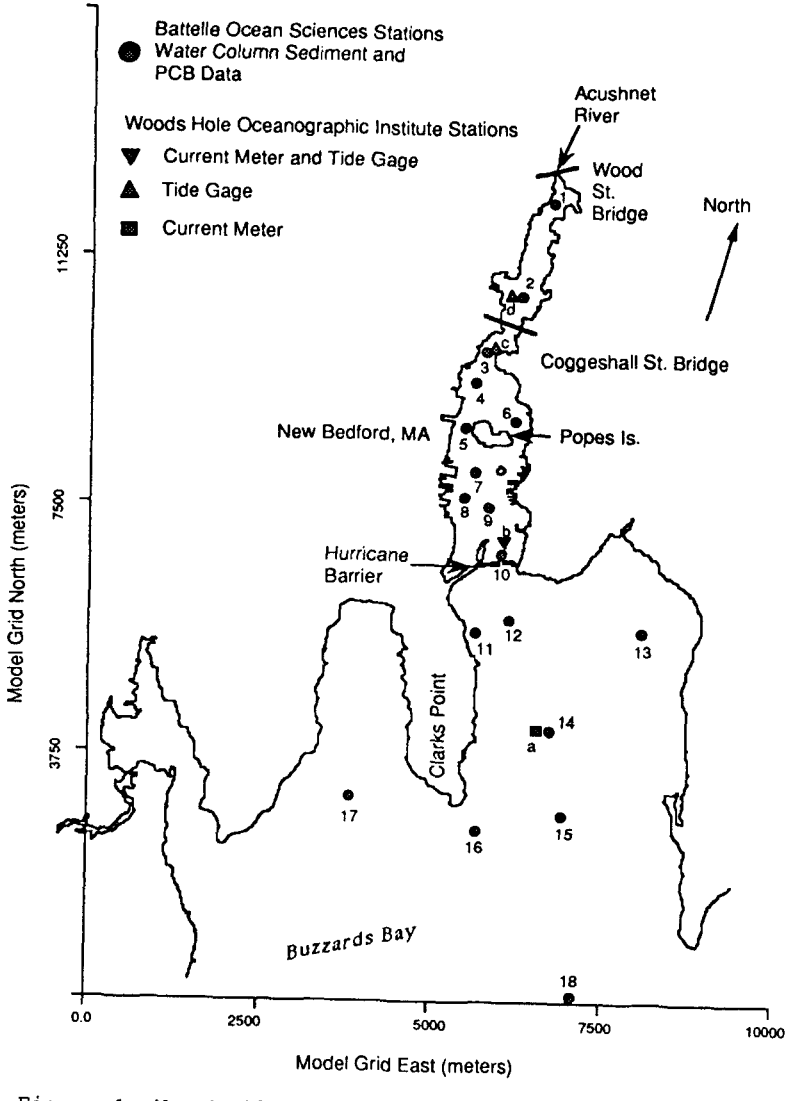

Figure 1. New Bedford Harbor Study Area and Locations of Field Data Stations

Description of the Numerical Model

The numerical model used in this study is the three-dimensional hydrodynamics code TEMPEST (Trent and Eyler 1989) coupled with a sediment-contaminant transport submodel FLESCOT (Onishi and Trent 1982). The governing equations, functional parameterizations, and numerical methods are documented in the references given above. The key modifications implemented in this study include free surface computation, a hydrostatic pressure option, decoupled transport calculations, and a wave-enhanced bottom friction model. The following is a brief description of the general features of the model.

The marine version of TEMPEST solves the conservation of fluid mass, momentum, thermal energy, and constituent transport (e.g., salt) in Cartesian coordinates using finite-difference techniques. The Reynolds-averaged Navier-Stokes equations are closed using a constant but nonisotropic, eddy viscosity. Time-varying free water-surface computations can be performed using the hydrostatic assumption, or a dynamic pressure field can be determined through the solution of a Poisson equation for the pressure field. Constant thickness grid layers in the vertical direction are used (sigma coordinates are not used). A limitation of the model is that water surface fluctuations are confined to the surface layer of grid cells. Constituent transport calculations can be performed using previously computed and stored velocity fields and water surface elevations; this is referred to as the decoupled mode. Transport solutions spanning several months can be done by periodically repeating the stored hydrodynamics. Enhanced bottom friction due to the effects of nontidal waves, parameterized by surface roughness and significant wave height and period, were incorporated using a simplified, noniterative version of the Grant and Madsen (1979) theory.

The sediment-contaminant transport submodel adds the following transport equations and associated source/sink terms to the TEMPEST code: suspended sediment, dissolved contaminant, and sediment-sorbed contaminant. Sediments and sediment-sorbed contaminants are eroded from and deposited to a multilayered seabed. The erosion or deposition rate of noncohesive sediments (sand) is determined by using DuBoy's equation to compute the transport capacity of the flow. For cohesive sediments (silt and clay), the formulas developed by Partheniades and Krone are used to compute erosion and deposition rates. Contaminant mass transfer between the seabed and water column occurs through the erosion and deposition of sediment-sorbed contaminants and direct desorption and adsorption through a bed-water column partition

coefficient (Bed Kd) and a rate constant. The model does not account for the diffusion of contaminants in the pore waters of bed sediments. The partitioning of contaminants in the water column between dissolved and sorbed form is modeled using an equilibrium partition coefficient (Kd) and an associated rate constant. Nonconservative contaminants and the volatilization of dissolved contaminants are modeled as first-order rate processes.

New Bedford Harbor Model Formulation and Calibration

The model domain covers the area shown in Figure 1. The area was discretized onto a 45x45x6 nonuniform rectangular grid. Cell sizes vary from 300x500 m to 33x110 m. Prototype depths range from approximately 0.3 to 10 m at mean low water. The thickness of the vertical grid layers in the model are (from top to bottom) 1.0, 0.9, 1.4, 1.8, 2.4, 3.0 m. Based on estimates of the bioturbation thickness (the layer of sediment mixed by the action of biota), the seabed was represented as a single 4-cm-thick layer.

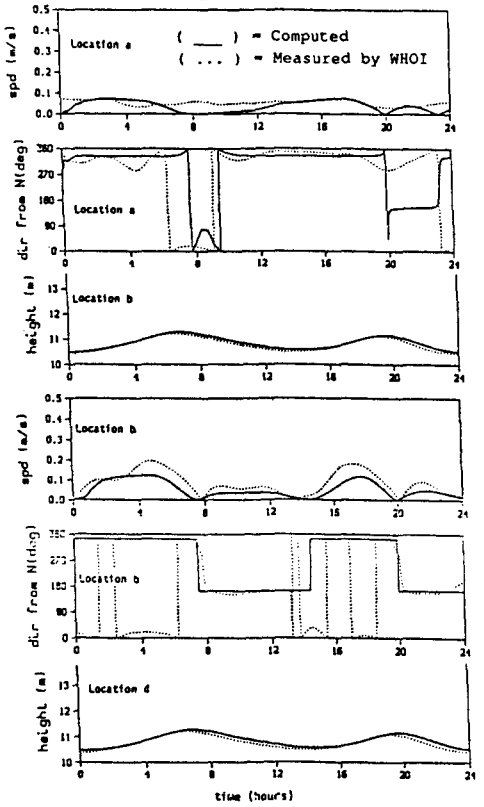

Figure 2. Water Level and Velocity Results - July 31, 1986.

Hydrodynamics were calibrated using two 24-hour periods: July 23 and 31, 1986. The model was forced using tidal data measured near the open boundary by Butman et al. (1988) and wind data measured at the Hurricane Barrier. Because of its low average annual flow rate, approximately 0.85 m^3/s, freshwater input from the Acushnet river was neglected. The model was run in a diagnostic mode using a density field determined from a temperature and salinity survey. After performing several sensitivity simulations, the following coefficient values were found to yield the most

reasonable agreement with the available field data: 0.001 m^2/s vertical eddy viscosity, 1.0 m^2/s horizontal eddy viscosity, and 0.0026 bottom friction coefficient (without wave effects). The computed water surface heights, current speeds, and current directions are compared in Figure 2 to measurements made by Woods Hole Oceanographic Institute.

The time required for the sediment and contaminant transport solutions to reach a quasi-steady state is approximately 10 days. Thus, calibration simulations for the sediments and total PCBs were completed by the decoupled, transport-only mode. The following two scenarios, each 24 hours in duration, were used to generate velocity and surface height time series for the decoupled simulations: a general case with northerly 2 to 10 m/s winds and a storm case with southerly winds of 1 to 15 m/s. Both were forced by a M_2 tide with a 0.55-m amplitude. The storm case used the wave-enhanced bottom friction model with wave parameters determined from the Shore Protection Manual. The sediment-PCB calibration simulations covered a 92-day period by repeating the hydrodynamics computed above in the following five sequential stages: 1) 30 days of the general case, 2) 1 day of the storm case, 3) 30 days of the general case, 4) 1 day of the storm case, and 5) 30 days of the general case. The final water column and bed concentrations for one stage served as the initial conditions for the next.

Initial conditions for bed sediments and total PCBs sorbed to bed sediments were assigned by averaging field survey data onto the model grid. To obtain sufficient detail to assign bed conditions throughout the model, several sets of data taken at different times had to be used. Data to determine open boundary conditions for sediments and total PCBs were quite limited. The open boundary conditions, applied only on the flood-tide, for sediments and PCBs were set to 6 mg/l and 4.8 ng/l, respectively. During the 1-day storm events, these values were elevated by a factor of three to approximate the effects of sediment resuspension near the boundary. These values were within the range of data collected at stations 15-18 (Figure 1). Tests showed that calculated PCB values within the Hurricane Barrier were not sensitive to the PCB open boundary condition.

Sediment calibration parameters included mean grain size for noncohesive sediment, critical shear stress for erosion and deposition, and erodibilty coefficient for cohesive sediments. The primary calibration parameters for total PCBs are the bed Kd value, which controls the mass transfer between the bed and water column, and the water column Kd. Erosion and deposition of sediment-sorbed PCBs

accounted for only a small portion of the mass exchange between the bed and water column. For PCBs, mass transfer by volatilization is significant; the volatilization coefficient was set to 0.000013 m/s based on the mean of several reported values (e.g., Bopp 1983).

Sediment and PCB transport were calibrated using water column data and by comparing mass fluxes beneath Coggeshall St. bridge. The comparison of computed values and water concentrations measured by Battelle Ocean Sciences in Figure 3 shows fair agreement. The computed net fluxes of sediment and PCBs were 446 kg per tidal cycle up-estuary and 0.22 kg per tidal cycle down-estuary (toward Buzzards Bay), respectively. Corresponding mean values of 2202 kg per tide cycle up-estuary and 1.55 kg per tide cycle down-estuary were measured by Teeter (1988).

Long-Term No-Action Simulation for Total PCBs

Each 92-day sediment-contaminant calibration simulation consumed about 5 hours of CPU time on a Cray X-MP supercomputer. The computer costs to generate a 10-year projection are prohibitive, even using the decoupled mode. The 10-year projections were done using the following method. For each 92-day series, the rate of mass change for sediments and contaminants in each bed cell was computed. Using this rate of change, the mass in each bed cell was linearly extrapolated forward using a 2-year time step. The extrapolated bed conditions defined a new initial bed condition for the next 92-day simulation. The steps were repeated, using the same 92-day series, until the 10th year was reached.

Using this scheme, no-action simulations were calculated for years 0,2,4,6,8, and 10. Year 0 corresponds to the end of final calibration simulation. The extrapolated changes in the water column are shown in Figure 4. The contour plots in Figure 5 show the progressive redistribution of PCBs in the bed sediments. The net mass fluxes beneath Coggeshall St. bridge at the end of the 10th year are 288 kg per tidal cycle up-estuary and 0.20 kg per tidal cycle down-estuary for sediments and PCBs, respectively.

Discussion and Conclusion

Only a qualitative calibration of the model was possible because of the limited field data available. The flux data show that the model does reproduce the observed net transport direction. The absolute accuracy of the 10-year simulations is uncertain because of the lack of synoptic data gathered at different points in time. It is significant that the results show little change in the

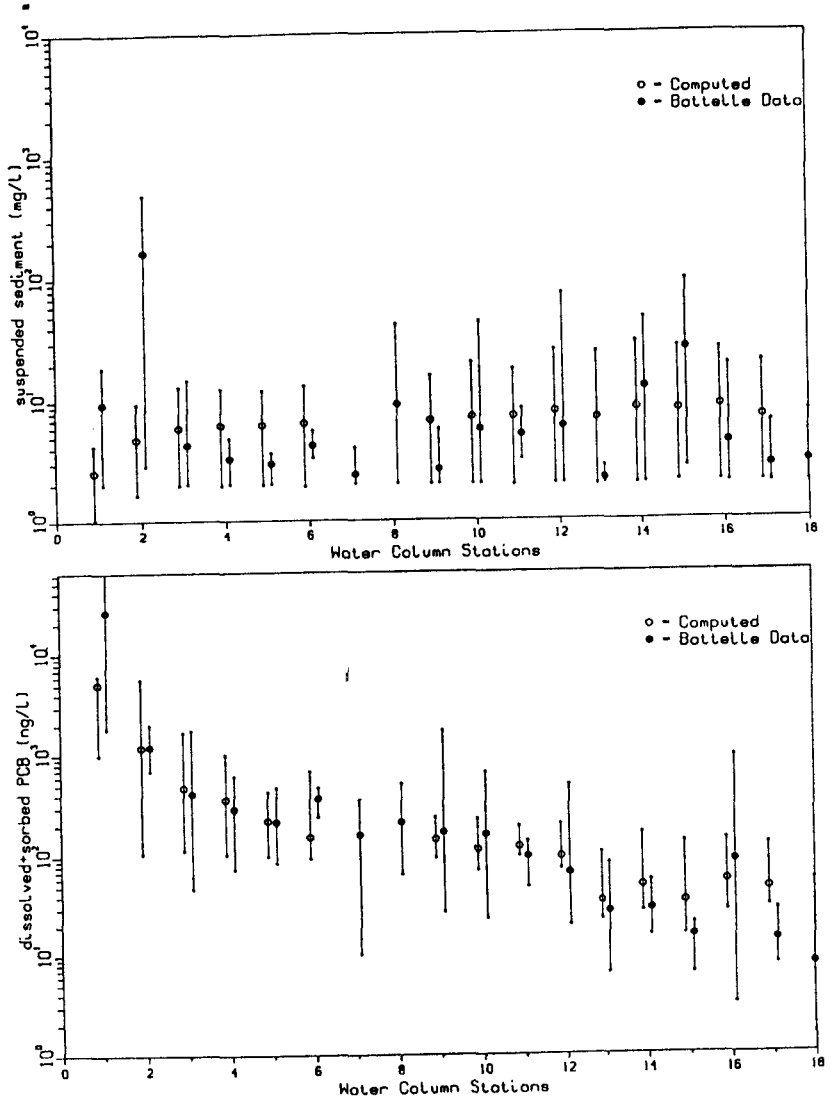

Figure 3. Calibration Results for Total Suspended Sediments and Total PCBs (Dissolved + Sorbed) in the Water Column. Station Locations are Shown in Figure 1. The Symbols Correspond to Mean Values and the Bar Endpoints to High, Low Values. Field Data Collected by Battelle Ocean Sciences.

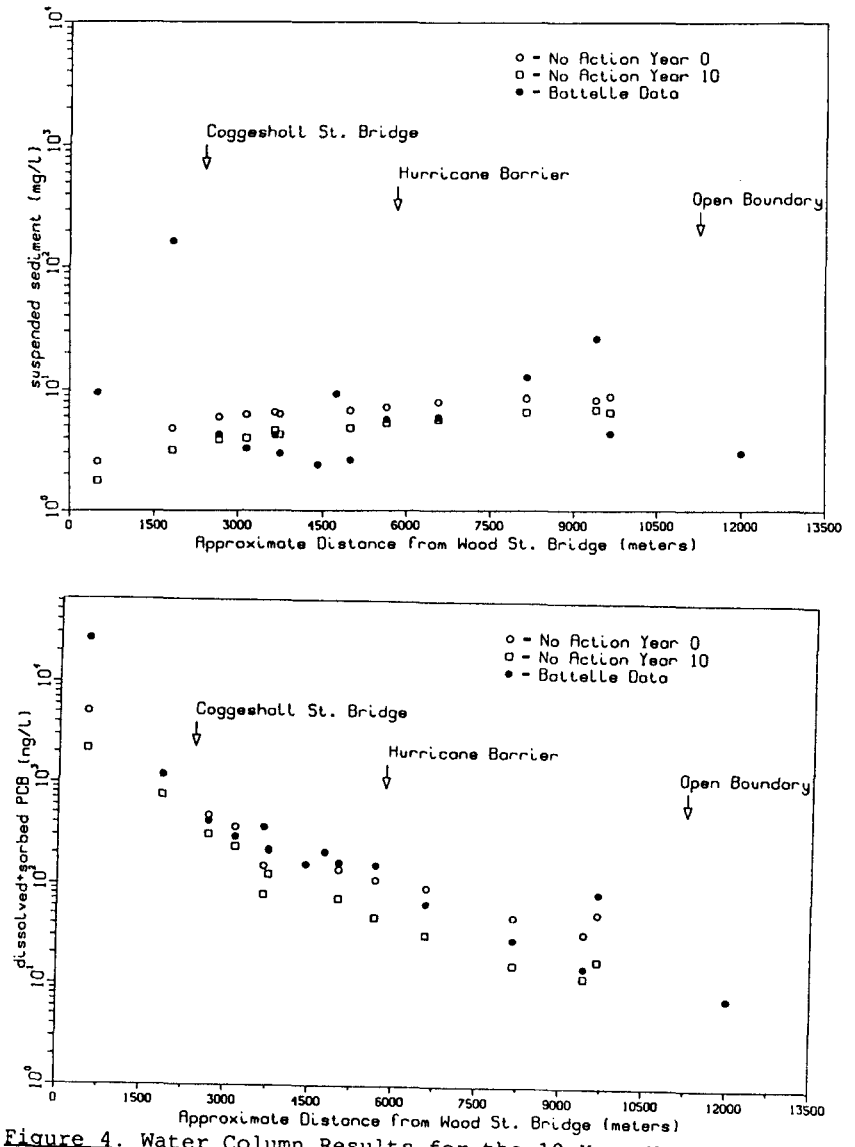

Figure 4. Water Column Results for the 10-Year No-Action Simulation. The Symbols Correspond to Mean Values and the Bar Endpoints to High, Low Values.

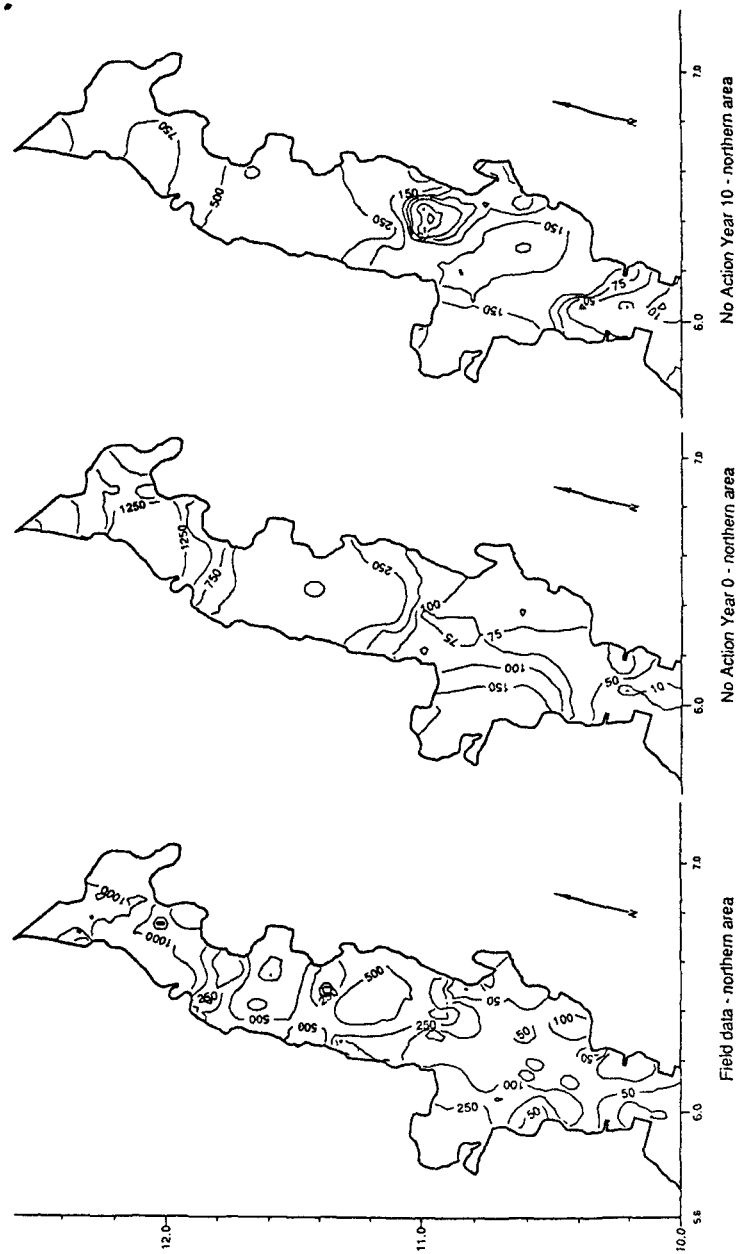

Figure 5. Contour Plots of PCBs in Surficial Bed Sediments Located Between Coggeshall St. Bridge and Wood St. Bridge. Contour Levels are in units of mg/kg.

magnitude and direction of PCB discharge through Coggeshall St. bridge over the 10-year period. The extrapolation procedure would be improved by using a set of statistically determined hydrodynamic forcing conditions, as suggested by McAnally et al. (1988). Despite these shortcomings, the model is still a useful tool to perform comparative evaluations of remedial action alternatives.

Acknowledgements

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