Circulation Modeling Capabilities

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Office of Oceanography and Marine Assessment
National Ocean Service
National Oceanic and Atmospheric Administration
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1.0 Introduction and Summary

This report describes the circulation modeling capabilities and activities of the National Ocean Service's Office of Oceanography and Marine Assessment (OMA) as provided by the following subordinate organizations:

Physical Oceanography Division
- o Estuarine and Ocean Physics Branch

Ocean Assessments Division
- o Hazardous Materials Response Branch
- o Strategic Assessment Branch
- o OAD Alaska Office

The objectives and activities of each of these organizations are summarized below.

Estuarine and Ocean Physics Branch

This Branch is responsible for predicting and simulating currents and water levels, mainly through the application of numerical circulation modeling techniques.

Hazardous Materials Response Branch

This Branch is concerned with both geophysical process models and information synthesis procedures in response to spills of toxic materials. They provide planning and contingency evaluation for future actions at waste sites, or stabilized accident sites that require additional clean-up action.

Strategic Assessment Branch

This Branch is involved in the development of an estuarine water quality screening model to assess the health and use of the nation's estuaries by providing order-of-magnitude approximations of the sensitivity of water quality conditions within an estuarine system to various hydrologic and pollution discharge conditions.

Ocean Assessments Division (OAD) Alaska Office

This office manages the Outer Continental Shelf Environmental Assessment Program (OCSEAP) and uses various models to develop pollutant transport information to provide timely environmental information for decisions on offshore oil and gas exploration and development.

OMA personnel and contractor's personnel involved in modeling activities are summarized in Table 1.

ADP facilities used in modeling are listed in Table 2 as NOAA facilities or those facilities time shared or used under contract.

A summary of the models/applications provided by the OMA are presented in Table 3.

The main body of this report provides a description of the modeling capabilities and activities in each organization and covers personnel, experience, ADP facilities and present activities.

OMA has developed a good base of experience in circulation modeling which continues to be utilized in a variety of applications. This capability is vital to developing future oceanographic/environmental programs in the coastal regions and in the open ocean.

Table 1 - Personnel

OMA Organizations	NOAA Personnel	Contractor's Personnel Est. Annual Avg. (Man Years)
Estuarine & Ocean Physics Branch	7	
Hazardous Materials Response Branch	6	5
Strategic Assessment Branch	2	
OAD Alaska Office	1 - 2	4

Table 2 - ADP Facilities for Modeling

OMA Organizations	NOAA Facilities: Mini Computers	NOAA Facilities: PC's	Other Facilities (Shared/Contract)
Estuarine & Ocean Physics Branch	HP 9000	5	1 - Cyber 205 (National Weather Service)
	PE 3210		1 - Cyber 205 (National Bureau of Standards)
Hazardous Materials Response Branch	5 IBM 9000	5	1 - Cyber 205 (NOAA's Environmental Research Laboratory)
Strategic Assessment Branch	IBM 9000		
OAD Alaska Office	PRIME 9750	2	Prime 550 (Applied Science Associates, Wakefield, R.I.) DEC 10 (SAIC, LaJolla, CA)

Table 3 - Models/Applications

OMA Organization	Models/Applications
Estuarine & Ocean Physics Branch	Nonlinear One-Dimensional Hydrodynamic Model Mellor-Blumberg Two-Dimensional Circulation Model Mellor-Blumberg Three-Dimensional Model OMA Estuarine Circulation Model Waterways Implicit Flooding Model
Hazardous Materials Response Branch	Oil Spill Simulation Model Streamline Analysis of Currents (SAC) Model Diagnostic Analysis of Currents (DAC) Model Wind-Driven Analysis of Currents (WAC) Model SALT (Salinity) Model Aerial Location of Hazardous Atmospheres (ALOHA) Model
Strategic Assessment Branch	Estuarine Water Quality Screening Model Application in Breton, LA (with U.S. Corps of Engineers) Estuarine Water Quality Screening Model Application to Long Island Sound (support of EPA Region I Bays Program)

Table 3 - Models/Applications (Continued)

OAD Alaska Office	Open Ocean Oil-Weathering Model Oil-Suspended Particulate Interaction Model Oil-Ice Interaction Model Oil-Ice Suspended Particulate Materials Interaction Model Ocean Circulation/Oil Trajectory Model

2.0 Estuarine and Ocean Physics Branch

The Estuarine and Ocean Physics Branch (EOPB) of the Physical Oceanography Division, is responsible for predicting and simulating currents and water levels. To accomplish this, EOPB uses traditional methods as well as numerical and analytical models. It changed technical direction during the past several years by emphasizing the application of numerical circulation modeling to develop new current and water level data products and to improve the traditional ones.

Personnel

The EOPB modeling group consists of three full-time physical oceanographers, and one full-time physical science technician. There are also seven oceanographers and computer specialists who are assigned part-time for a combined effort amounting to three full-time equivalents. The total staffing now available is seven, and is expected to reach nine by mid 1986. The effectiveness of the modeling staff is strengthened through frequent interaction with modeling groups throughout the Nation.

Modeling Experience

The total experience of the present modeling group, including both physical oceanographers and computer specialists, exceeds 100 staff-years, and includes the following types of models:

One-Dimensional Models:

- Nonlinear hydrodynamics
- Atmospheric/ocean boundary/mixed layer
- Nonlinear spectral wave growth
- Water mass formation

- Vertical dispersion
- Sediment Transport

Two-Dimensional Models:

- Estuarine total circulation
- Estuarine gravitational circulation
- Turbulent kinetic energy mixing
- Equatorial undercurrent dynamics
- Ecosystem dynamics, biomass, nutrients, oxygen
- Topographic internal wave generation
- Thermocline development
- Storm surge and inundation of coastal areas

Three-Dimensional Models:

- Coastal baroclinic/barotropic dynamics
- Effluent dispersion modeling
- Baroclinic geostrophic eddy dynamics

The EOPB's automated data processing (ADP) expertise includes the entire range of computers from microcomputers to supercomputers. Experience in several architectural and software environments provides an ADP foundation which enables the group to respond rapidly to new technologies.

ADP Facilities

EOPB's access to computers which are well suited for its modeling activities and include a Hewlett-Packard (HP) 9000 system, a Perkin-Elmer (PE) 3210 system, both on site; and two CDC Cyber 205 systems, one jointly shared by the National Oceanic and Atmospheric Administration (NOAA) and the National Bureau of Standards (NBS) and a second system owned by the NOAA National Weather Service, National Meteorological Center (NMC). In addition to two onsite minicomputers and two local supercomputers, EOPB is equipped with an IBM PC/AT and various other microcomputers.

The HP 9000 system is used principally for model development and validation, and for model-generated data products; the PE 3210 system is used for circulation survey data processing, preparation, and archiving; the NOAA/NBS Cyber is used for model simulations; and the NMC Cyber is used in a standby mode for model forecasts using real-time data inputs.

Present Modeling Activities

EOPB is presently working directly with four models. These are (1) a nonlinear one-dimensional hydrodynamic model, (2) the Mellor-Blumberg two-dimensional circulation model, (3) the Office of Oceanography and Marine Assessment (OMA) estuarine circulation model, and (4) the Waterways Implicit Flooding Model (WIFM). A fifth model is under development and evaluation through a grant to Princeton University; this is a three-dimensional model applied to the Delaware River and Bay and the adjacent continental shelf. The models are described below:

Nonlinear One-Dimensional Hydrodynamic Model

A nonlinear, one-dimensional, finite-difference numerical hydrodynamic model was developed by EOPB. Its efficiency and ability to represent important nonlinear effects make it useful for two primary functions.

First, it is used as a tool to investigate dynamical effects that may affect the quality of NOS products. Efficiency is necessary for such investigations because numerous and lengthy simulations must be made. Scaling and Fourier analyses, combined with analytical modeling, are used to determine the model's applicability to specific problems. Studies so far have included the effect of storm surge and river flow on the tide (and on the tidal constituents used to make predictions), and the generation of compound tides and overtides in shallow water. It can be applied to estimates of dynamically-produced uncertainties in predictions for quality assurance purposes.

Second, the model can be used in a very cost efficient real-time/forecast system where water level is the main concern, and it can also be used for currents if the waterway is narrow and the water is well-mixed vertically. The model was evaluated for its handling of nonlinear effects and river discharge, and is thus applicable to tidal rivers. It is useful for extrapolating the combined predicted tide and statistically forecast storm surge (taking into account their interaction) up an estuary.

Mellor-Blumberg Two-Dimensional Circulation Model

The two-dimensional model is a subset of the three-dimensional model developed by George Mellor and Alan Blumberg. Using finite difference methods, solutions to the vertically averaged Navier-Stokes equations are obtained for currents and water levels on a grid comprised of uniform squares. Solution points for velocities and water levels are separated and staggered along the sides of these squares. Leapfrog time integration is used in which past and present values of velocity and water level from the solution point and surrounding points are used to predict the next set of values. The use of three time levels limits the size of the allowable time step by the Courant stability criterion.

Forcing is required at the open boundary using observed water level data or tidal predictions. One-dimensional river models can be coupled to any square of the two-dimensional grid to simulate fresh water inflows. Wind forcing is modeled as a uniform field which is variable in time. This model was applied by EOPB to the Delaware River and Bay during 1984. It was used for making 36-hour real-time forecasts through June 1985. Since then, it has been on a standby status, to be run when required.

OMA Estuarine Circulation Model

OMA developed and is presently validating an estuarine circulation model with the capability for high resolution, vertically integrated current and water level calculations. New methods have been incorporated to include nonlinear effects and boundary conditions with emphasis on river flow. High resolution vertical calculations at user-specified locations are incorporated to determine bottom stress and vertical structure of the horizontal currents accurately. The bottom stress calculated from the vertical model is used by the vertically averaged model to improve prediction accuracy. The OMA two-dimensional model is being applied to Columbia River, Oregon. Initial analysis of the model prediction indicates a high skill level in predicting the significant effects of river inflow as well as tidal effects.

Waterways Implicit Flooding Model (WIFM)

The WIFM model was developed at the U.S. Army Corps of Engineers Waterways Experiment Station (WES), Vicksburg, Mississippi. This model was obtained by EOPB from WES through cooperation between the two modeling groups. It is a two-dimensional, vertically integrated model with an exponentially contracted grid allowing for higher resolution in areas of specific interest. Water level and velocity solution points are staggered around each square. The alternating direction, implicit time integration method uses vectors in a four-step procedure of solving water levels and velocities implicitly and explicitly in X and Y directions by coupling the Navier-Stokes and continuity equations. Inclusion of nonlinear terms and eddy viscosity is optional. Rainfall, evaporation, and inverse manometer effects are included.

Water level data or tidal predictions are used as open boundary conditions. Submerged barriers are modeled and the formulation includes flooding and drying of cells. River input is specified as a discharge through a cellface. Wind and bottom stresses can be uniform or variable in time and space over the modeled area. The model can be applied to tidal circulation, storm surges, or tsunami simulations.

Mellor-Blumberg Three-Dimensional Model

This a full three-dimensional model. The two-dimensional "external mode" solves the vertically integrated Navier-Stokes equations including Coriolis and nonlinear terms at every time step. Solution points for water levels and velocities are staggered around each square. The three-dimensional "internal mode" is solved implicitly using a second-moment turbulence closure scheme and sigma coordinate system with variable depth layers for increased resolution in the surface and bottom boundary layers. The three-dimensional calculation is made at variable multiples of the two-dimensional time steps. Water fields are required for input at the open boundary. Two-dimensional river models (X-Z plane) are coupled to the three-dimensional model to reduce computer expenses. Surface stresses are modeled using a spatially uniform, time varying wind field over the modeled area.

Data Acquisition for Model Calibration and Validation

The Office of Oceanography and Marine Assessment (OMA) and its predecessor organizations have collected and archived current and water level data for well over a century. This capability progressed from rudimentary measurements with drifting poles, stop watches, and simple hand-calculations during the mid Nineteenth Century to today's use of the latest technologies in mechanical, acoustic, and electromagnetic current meters coupled with sophisticated data acquisition and processing systems.

Data acquisition for modeling purposes falls into two categories: (1) the conventional deployment of moored current meters, water level gages and anemometers at multiple locations, and (2) the deployment of real-time measurement systems centered around the recently developed remote acoustic Doppler current meters. OMA engineers and oceanographers are leading experts in circulation data acquisition. Circulation surveys, previously carried out by NOAA ships and measurement systems, are now conducted by contracts with the private sector. During 1985, a survey was performed in the Port of Miami and approaches. Real-time measurement systems are presently installed in Delaware Bay and Port of Miami.

3.0 Hazardous Materials Response Branch

The Hazardous Materials Response Branch (HAZMAT) of the Ocean Assessments Division is involved with modeling activity which covers both geophysical process models and information synthesis procedures. These automated routines are used to support the Branch's response to spills of toxic material and to provide planning tools and contingency evaluation for future actions at waste sites, or stabilized accident sites that require additional cleanup action. The modeling and ADP activity within HAZMAT has also provided guidance, training, and demonstration of procedures to a variety of other organizations in the U.S.

Personnel and Experience

Within HAZMAT, there are six full-time professional modelers, all of which have extensive backgrounds in applied mathematics and geophysical processes. Most group members have been working in spill response for a decade. With the HAZMAT Branch responding to spill incidents at a rate of 200 or more calls per year, this group has more experience than any other center in the world at applying computer-aided modeling techniques to real-time accident problems. The HAZMAT group has an active research program in addition to its response role and, as such, is a truly applied mathematics organization that is not only developing modeling procedures, but applying them continually to real problems. In addition to the modelers in the HAZMAT group, there are a number of contract specialists that have expertise in numerical procedure and/or computer modeling. The actual number of these personnel varies but, typically, five to six person-years of effort are involved.

ADP Facilities

The HAZMAT group has access to a variety of computers which are adequate to carry out their response and research activities.

HAZMAT ADP facilities used for modeling include five IBM 9000 minicomputers and five PC's. In addition, the group has access to a Cyber 205 computer facility located at NOAA's Environmental Research Laboratory, Boulder, Colorado.

Present Modeling Activity

OSSM (Oil Spill Simulation Model)

OSSM is a pollutant trajectory model used to predict where a pollutant will go or where it may have come from. Its inputs are coastline maps, current patterns, wind, pollutant half-life, a horizontal mixing parameter, and spill location or impact site. The model then advects 1-1000 Lagrangian elements subject to the physical parameters specified by the user. OSSM returns maps showing the pollutant distribution over time or, if used in the receptor mode, it returns maps showing the probability of where the pollutant may have come from.

SAC (Streamline Analysis of Currents)

SAC is a model used primarily for developing river flow patterns and tidal current patterns. It comes in two parts. The first part returns a stream-function for the area, subject to user-specified boundary conditions, bathymetry, and coastline geometry. The user has the option of solving for an amplitude function to correct for divergency in the flow. The final result is a current pattern field which can be used by OSSM.

DAC (Diagnostic Analysis of Currents)

DAC is a geostrophic model used for producing current patterns on continental shelf areas. It incorporates an Ekman bottom friction layer and is usually forced only by user-specified boundary conditions. However, if the necessary density data is available, a baroclinic version of DAC can be used. The output from DAC is also a current pattern which can be used by the OSSM.

WAC (Wind-Driven Analysis of Currents)

WAC is a very flexible model which solves the time-dependent, non-linear, shallow water wave equations. Currently, the model is being used to generate currents in an enclosed area subject to wind forcing. However, after further testing, the model will be utilized for a much wider range of flows.

SALT (refers to salinity)

SALT is a model being developed to examine flushing rates and water exchange in well-mixed estuary systems. It utilizes the distribution of variables equations along with output from the SAC model to examine the concentration of pollutants in vertically-mixed estuaries over time.

ALOHA (Aerial Location of Hazardous Atmospheres)

ALOHA is an air plume model being developed for response to chemical spills releasing hazardous gas. The model includes a library of toxic-volatile chemical algorithms for estimating source strength and dispersion routines to simulate continuous or instantaneous releases. Continuing development is concentrating on: (1) improved spill characterization; (2) near-field patchiness algorithms and the incorporation of more comprehensive atmospheric turbulence parameters.

SAM (Station for Atmospheric Measurements)

SAM is a data acquisition/telemetry system under development as a research and response tool for atmospheric dispersion modeling and monitoring of toxic vapors. A microcomputer contains a number of algorithms to preprocess and error-check the data. Ongoing research to develop parameters for turbulence and near-field patchiness phenomena will help define which algorithms (i.e., eddy correlations, friction velocities, temperature fluxes, etc.) which SAM will use to provide the most useful output either directly to ALOHA or for another use.

4.0 Strategic Assessment Branch

An estuarine water quality screening model has been developed as part of a series of efforts being conducted by the Strategic Assessment Branch (SAB), Ocean Assessments Division (OAD) to develop a capability to assess comprehensively the health and use of the Nation's estuaries. The model's objective is to provide order-of-magnitude approximations of the sensitivity of water quality conditions within an estuarine system to various hydrologic and pollutant discharge conditions. It has been designed to be applied with readily available data and applied to any given system in 1 or 2 weeks. It is not a substitute for the detailed circulation or water quality models needed to evaluate site specific decisions within a given system, although it can be used for preliminary assessments in this context under certain conditions. It is primarily intended for use in conjunction with atlases and data bases of the National Estuarine Inventory (NEI) being developed by the SAB. The model is now being tested to determine how it may be applied to all or a subset of the 92 estuaries in the NEI. Its use in the program, if successful, would enable a comprehensive assessment of water quality conditions within the estuaries of the U.S.A.

Personnel

The SAB's modeling group consists of two full-time positions (one Environmental Engineer and one Physical Scientist). However, model development work is done in joint cooperation with OAD's Hazardous Material Response Branch's modeling group in Seattle.

ADP Facilities

The modeling software consists of 15 sub-programs covering all phases of application from digitizing system geometry to water quality predictions. The programs are written in Fortran 77, the largest of which is the matrix solver that requires 75K memory. The modeling programs are operational on an IBM 9000 microcomputer. Data entry to the IBM 9000 is performed using a digitizing pad interfaced with an Apple IIe.

Applications

A major test of the model has been its application to Breton Sound, Louisiana, for the U.S. Army Corps of Engineers. The model was used to provide a relatively quick and inexpensive assessment of probable changes in salinity distributions under varying hydrodynamic conditions. Model results are being used by the Corps of Engineers to develop detailed analysis plans for evaluating proposed flow diversions for the region.

The model has also just been applied to Long Island Sound in support of EPA's Region I Bays Program. This application is still being evaluated.

5.0 Ocean Assessments Division (OAD) Alaska Office

The OAD Alaska Office manages the Outer Continental Shelf Environmental Assessment Program (OCSEAP). This office is responsible for providing timely environmental information for decisions on offshore oil and gas exploration and development. This office provides pollutant transport information from a three-dimensional circulation model coupled with a stochastic wind model, as well as other numerical models.

Personnel

The OCSEAP staff consists of four full-time oceanographers, two biologists, one computer specialist, one chemist, and operations and administrative personnel. The staff is involved in numerical modeling through the administration of modeling contracts with the private sector, and is directly involved in modeling pertaining to open ocean weathering of oil.

Modeling Experience

The OAD Alaska office's modeling experience is derived from the administration of contracts with private sector organizations and includes the following types of models:

- Open Ocean Oil-Weathering Model
- Oil-Suspended Particulate Interaction Model
- Oil-Ice Interaction Model
- Oil-Ice-SPM Interaction Model
- Ocean Circulation/Oil Trajectory Model

In addition to the above, other models developed and/or applied under the auspices of the OCSEAP but no longer actively used, are:

- Fish-Oil Interaction Model

- Circulation Model for Cook Inlet
- Storm Surge Model in Norton Sound
- Storm Surge Model in the Beaufort Sea
- Circulation Model for the Gulf of Alaska and for the Kodiak Shelf areas

ADP Facilities

The OAD Alaska office's ADP facilities used for modeling consist of two IBM PC microcomputers and a new PRIME 9750 minicomputer. In addition to the above, OCSEAP has access to a PRIME 550 computer through existing contracts. While most models presently being developed are on contractors computers, the models will be relocated on the PRIME 9750 to provide better access and more rapid development of products.

Present Modeling Activities

The OAD Alaska office is presently working primarily with two groups of models: (1) Oil Weathering Models; and (2) Oil Trajectory Models. These groups are described below:

Oil Partitioning Models

Oil Partitioning Models consist of a suite of models and subroutines which are used to define the weathering and partitioning processes of oil. The main model is the open ocean weathering model which includes the processes of spreading, dispersion, evaporation, and dissolution. A library of oil types/characteristics is included within the model and provides an option to input specific values or utilize default parameters. This model is fully functional and has been reprogrammed to run on IBM personal computers.

Other models in this category provide routines to model the interaction of oil with ice (both annual and multi-year), suspended particulate materials (spm), and ice and spm together. These models are able to predict the partitioning of oil under variable environmental conditions and variable oil composition. Ultimate usage of the models will be for biological risk assessment.

Oil Trajectory Model

The Oil Trajectory Model presently being used in the OCSEAP is a three-dimensional hydrodynamic model coupled to a stochastic wind model, an ice dynamics model, and a shallow water wave forecast model. The model is used to produce oil spill trajectories for hypothetical spills on the Alaskan OCS and to compute oil concentration fields resulting from a spill. This model numerically solves the three-dimensional equations of motion and conservation of mass, density, and momentum subject to boundary conditions of the Alaskan OCS. The stochastic weather model employs a statistical hindcast methodology using past weather records from Alaskan weather recording stations. The ice model and shallow water wave models are couples as required by the conditions of the area being modeled.

6.0 Contacts for Modeling Activities

Additional information on the modeling activities described herein and information pertaining to new applications for these models may be obtained by contacting the offices listed in Table 4.

General inquiries pertaining to overall OMA modeling capabilities and cooperative ventures between other government agencies, industry and academia should be addressed to:

Director
Office of Oceanography and Marine Assessment
Room 323
6001 Executive Boulevard
Rockville, Maryland 20852
(301) 443-8487

Table 4 - OMA Contacts for Modeling

OMA Organization	Contacts
Estuarine & Ocean Physics Branch	Chief, Estuarine & Ocean Physics Branch Physical Oceanography Division 6001 Executive Boulevard Rockville, MD 20852 (301) 443-8510
Strategic Assessment Branch	Chief, Strategic Assessment Branch Ocean Assessments Division 11400 Rockville Pike Rockville, MD 20852 (301) 443-8921
Hazardous Materials Response Branch	Chief, Hazardous Materials Response Branch 7600 Sand Point Way, N.E. Seattle, WA 98115 (901) 392-6273
OAD Alaska Office	Manager, NOAA/OAD Alaska Office 701 C Street, Box 56 Anchorage, AK 99513 (907) 271-3033