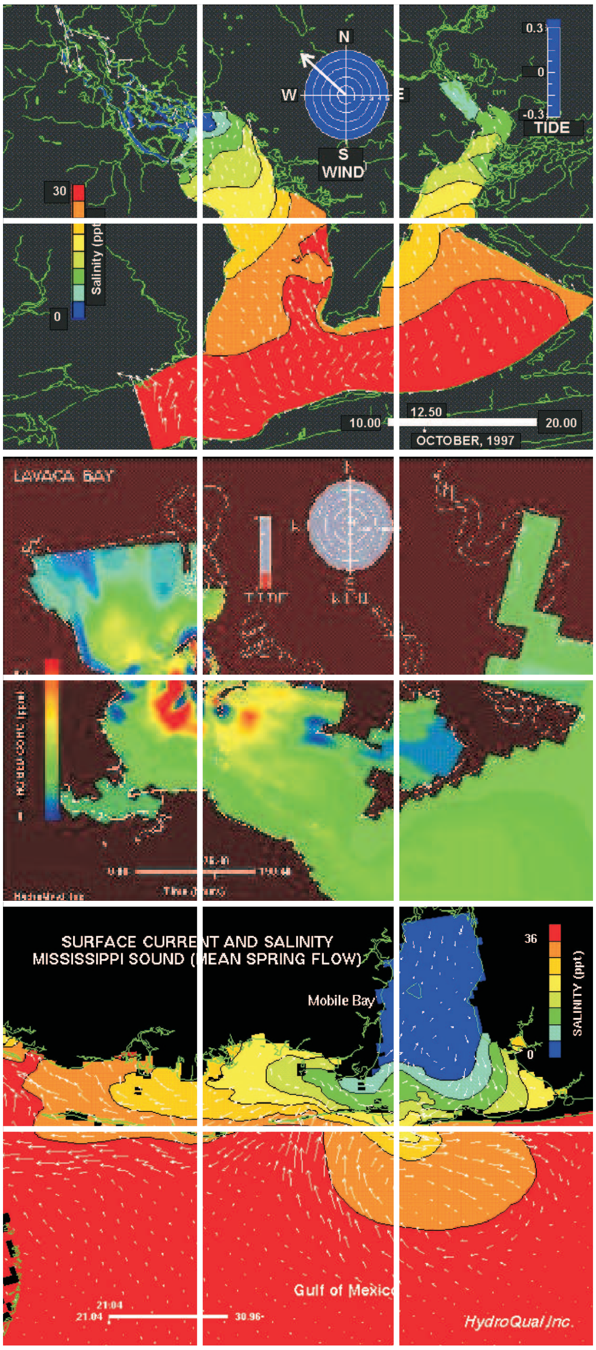
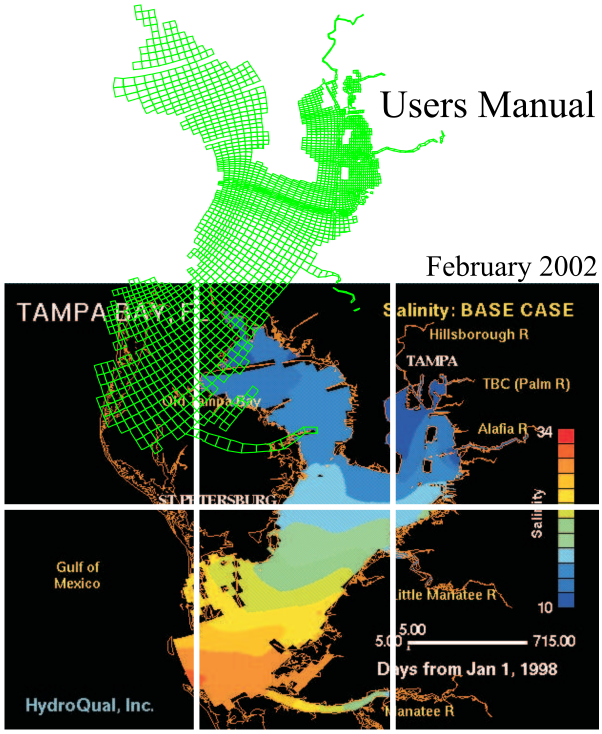


A Primer for ECOMSED

Version 1.3

Users Manual



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PREFACE

The development of ECOMSED has its origins in the mid 1980's with the creation of the Princeton Ocean Model (Blumberg and Mellor, 1987) and its version for shallow water environments – rivers, bays, estuaries and the coastal ocean and reservoirs and lakes- named ECOM (Blumberg, 1996). In the mid 1990s, concepts for cohesive sediment resuspension, settling and consolidation (Lick, et al., 1984) were incorporated within the ECOM modeling framework. During the last several years, ECOMSED was enhanced to include generalized open boundary conditions, tracers, better bottom shear stresses through a submodel for bottom boundary layer physics, surface wave models, noncohesive sediment transport, and dissolved and sediment-bound tracer capabilities. The code has been reconfigured to be easily ported to almost any computer system, from PCs to workstations to super mainframes. Model performance has been evaluated by appealing to a large series of simple test cases designed to isolate specific processes and by application of the model to many real-world situations. There have been over 350 journal articles written that are based on the use of the various ECOMSED submodels. While there is a real confidence that ECOMSED is "bug free", it remains the user's responsibility to check and recheck their own results via their own test cases and their own comparisons with data.

The ECOMSED system has proven over the years to be quite robust and reliable. A user's guide on the other hand has been elusive. The material presented herein is directed towards the goal of a detailed, well documented manual that hopefully will allow enable an educated user to address real world environmental problems using sophisticated technology with the labor of learning all the details of the model's composition.

Today's version of ECOMSED and this manual have been made possible by the dedicated efforts of Parmeshwar L. Shrestha, B. Nicholas Kim, Quamrul Ahsan and Honghai Li. They have helped conceive, design and implement the model enhancements and worked diligently to debug their (and my) changes. The manual owes its form and content to them. Important contributions to various aspects of ECOMSED have also been made at one time or another by Boris Galperin, H. James Herring, Eugenio Gomez-Reyes, C. Kirk Zeigler, and Richard P. Signell. Finally, the seminal contributions of George L. Mellor must be acknowledged. It was he who first managed to secure funding which made the Princeton Ocean Model a reality.

Alan F.Blumberg

1.0 Introduction

This primer describes the use of a fully integrated three-dimensional hydrodynamic, wave and sediment transport model, ECOMSED. The model is designed to simulate with as much realism as possible time-dependent distributions of water levels, currents, temperature, salinity, tracers, cohesive and noncohesive sediments and waves in marine and freshwater systems. The three ECOMSED sub-models are designed to work in conjunction with one another, with output from one serving as input to another. The same orthogonal curvilinear computational grid structure and underlying numerical solution techniques are utilized for all sub-models. The wave sub-model embedded in ECOMSED utilizes wave parameters to accurately compute the wave-induced bottom friction necessary for calculation of bed shear stresses at the sediment-water interface. ECOMSED uses an orthogonal curvilinear coordinate system, greatly increasing model efficiency in treating irregularly shaped coastlines and in meeting requirements for high resolution at desired locations.

The ECOMSED model is capable of simulating the transport and fate of suspended sediments, dissolved tracers and neutrally-buoyant particles in estuarine and coastal ocean systems. A wide variety of problems concerning water optics and spill tracking can be studied using the model due to the various options built into ECOMSED. Capabilities of the model include: (1) runtime computed (internal) or precomputed (external) hydrodynamics; (2) cohesive and non-cohesive sediment transport; (3) sediment-bound tracer transport (conservative or first-order decay); (4) dissolved tracer transport (conservative or first-order decay); (5) neutrally-buoyant particle tracking; and (6) inclusion of wind wave effects on hydrodynamics and sediment transport. Descriptions of ECOMSED options and capabilities are provided in the following section.

The development of ECOMSED is an ongoing topic of research. The user of this version (1.2) can expect modifications, some of which will be "fixes" to the code and others which will be enhancements to the present water physics and sediment dynamics. Many changes in this primer are planned and some already implemented. Please direct any suggestions and critical comments to *ecom_support@hydroqual.com*. All ideas are welcome and many may find themselves in the next version of this primer.

2.0 ECOMSED Model Features

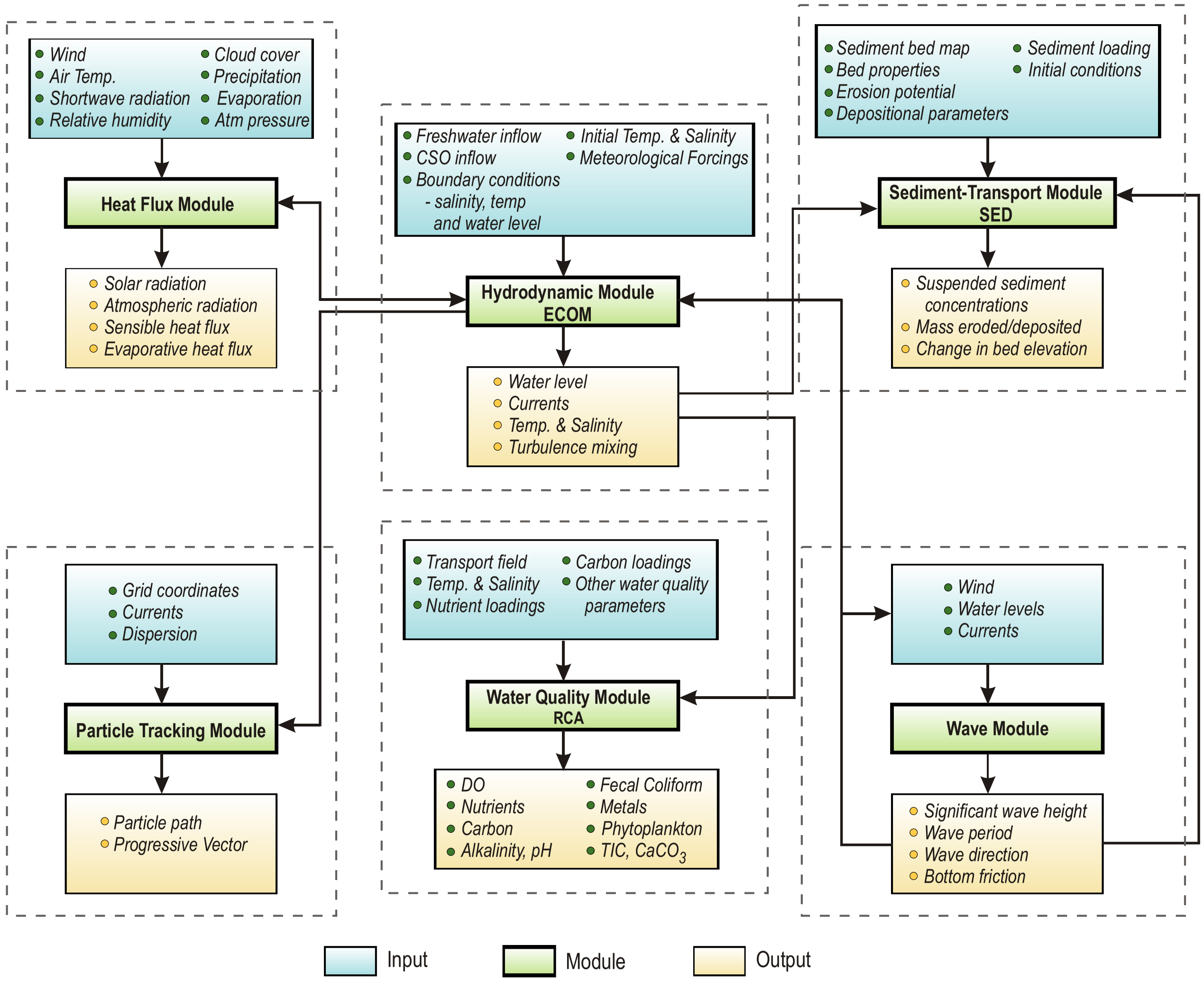
The ECOMSED is a state-of-the-art hydrodynamic and sediment transport model which realistically computes water circulation, temperature, salinity, and mixing and transport, deposition and resuspension of cohesive and non-cohesive sediments. The complete ECOMSED model consists of several modules. These are hydrodynamic module, sediment transport module, wind induced wave module, heat flux module and particle tracking module. Figure 2.1 illustrates the ECOMSED modeling framework. The ECOMSED is also coupled with HydroQual's state-of-the-art water quality model, RCA by a sophisticated and efficient interface. The modules within the ECOMSED modeling framework are linked internally. These modules can be turned on and off by the users depending upon their needs. The ECOMSED modeling framework also allows for linking each module externally. For example, the hydrodynamic module can be run stand alone and transport information can be saved in a separate file. Then the sediment module can be run stand alone using the previously saved transport information, and so is the water quality module, RCA. The following section describes the various features of ECOMSED in detail.

2.1 Internal/External Hydrodynamics

Hydrodynamic simulations are required to provide advection and dispersion information for the water-borne constituent transport algorithms. ECOMSED can use either internal or external hydrodynamic information. When the internal hydrodynamic option is chosen, the ECOM hydrodynamic model, which is built into ECOMSED, runs in parallel with the sediment and tracer transport algorithms. The external hydrodynamic option of ECOMSED allows the model to use previously-generated hydrodynamic information that has been stored in computer files. Simulation of sediment and tracer transport is accomplished by reading hydrodynamic information from the previously-generated computer files. This method has the advantage of reduced computational times when compared to the internal hydrodynamic option. However, care must be taken when using the external option because the previously-generated transport files required to study a particular aquatic system may be too large to handle. In other words, computer storage requirements could limit the temporal length of simulations to the point that the external option cannot be used effectively for a specific problem.

2.2 Sediment Transport

The transport and fate of cohesive and non-cohesive sediments can be simulated with ECOMSED. Resuspension, deposition and transport of cohesive sediments, which are composed of clays, silts and organic material, are simulated using the SED module. The suspended transport of non-cohesive sediments, i.e., fine sands, is calculated using the van Rijn procedure (van Rijn, 1984). The effects of bed armoring due to particle-size heterogeneity can also be included in non-cohesive sediment transport simulations. Bed load transport is not considered here because



ECOMSED Modeling Framework

FIGURE 2-1

it does not significantly affect optical properties in the water column. See Section 5 for a more detailed description of the sediment dynamics included in the cohesive and non-cohesive sediment modules. The sediment transport module can predict temporal and spatial distributions of: (1) suspended sediment concentrations (cohesive and non-cohesive); (2) sediment bed elevation changes; (3) fluxes at the sediment-water interface; and (4) changes in sediment bed composition. The module can accept as input: spatially-variable sediment bed properties and time-variable sediment loading at river discharges and open boundaries.

2.3 Sediment-bound Tracer Transport

The fate of sediments from a particular source, e.g., river discharge or specific sediment bed location, can be determined using ECOMSED. This type of simulation is accomplished by using a sediment-bound tracer, which is analogous to a hydrophobic contaminant, e.g., organic chemical, heavy metal or radionuclide, that adsorbs to fine-grained sediment particles. However, in these simulations the tracer is permanently adsorbed to the sediment particles; actual hydrophobic contaminants are partially soluble and exist in both particulate and dissolved form, with a high percentage of the contaminant being adsorbed to sediment particles.

The transport and fate of sediment-bound tracers can be simulated for both cohesive and non-cohesive sediments. In addition, the tracer can be conservative or be assigned a first-order decay rate, which would approximate a sediment-bound radionuclide. Of particular importance is the use of a sediment bed model that makes it possible to simulate changes in tracer bed concentrations due to deposition and erosion; temporal and spatial (horizontal and vertical) variations in tracer bed concentrations can be predicted. The bed model can also simulate the effects of bioturbation on tracer mixing in the surficial layer of the bed.

2.4 Dissolved Tracer Transport

Simulation of the transport of a dissolved tracer can be accomplished using ECOMSED, with the tracer being either conservative or having a first-order decay rate. This type of calculation can be useful for determining the fate of a water-borne contaminant released from a particular location, e.g., river discharge, offshore diffuser or open boundary. Temporally varying tracer concentrations can be specified for all three types of boundary conditions.

2.5 Particle Tracking

This option allows the tracking of discrete particles that can be released into the aquatic system at various locations. These particles are neutrally-buoyant and conservative. A Lagrangian technique is used to advect the particles and a random-walk procedure is employed to simulate the effects of turbulent diffusion. A complete description of the theory and numerical methods used in the particle tracking module can be found in Zhang (1995).

The particle tracking module can be useful for the simulation of oil spills or studying the trajectories of floating objects. Particles can be released from multiple locations at variable rates. In addition, each released particle has associated with the time and location of its release, which has been helpful information in previous analyses.

2.6 Wind Waves

Resuspension of sediments due to wind-generated waves is an important source of sediment to the water column in many coastal ocean systems. The effects of wind waves on bottom shear stress, which controls sediment resuspension, can be accounted for by ECOMSED. Temporally and spatially variable wind wave parameters, i.e., mean period, significant wave height and direction, can be calculated using an external wave model (e.g., WAM or HISWA), stored in a computer file and then input to ECOMSED. If wind wave information from an external model is unavailable, an internal wave sub-model, which is based upon shallow water SMB theory (USCOE, 1984), can be used to calculate wave parameters. The internal wave sub-model utilizes empirical formulations which provide approximate estimates of significant wave height and period; this module does not account for spatially-varying wind fields, refraction or wave breaking effects.

Once the wave parameters are specified, the Grant-Madsen wave-current model (Grant and Madsen, 1979) is used to calculate bottom shear stresses due to the interaction of waves and currents. A modified version of the Grant-Madsen model which was developed by Scott Glenn (Glenn and Grant, 1987) is incorporated into this version of ECOMSED. If the internal hydrodynamic option is used, the effect of the wave-current interaction on the bottom roughness coefficient can be calculated by the Grant-Madsen model and then included in the hydrodynamic simulation.

3.0 Hydrodynamic Module

3.1 Introduction

This section of the user manual provides a relatively detailed description of a numerical circulation module. The module belongs to that class of models where model realism is an important goal and addresses mesoscale phenomena, that is activity characterized by 1-100 km length and tidal-30 day time scales commonly observed in estuaries and the coastal ocean [Beardsley and Boicourt, 1981]. The module is a three-dimensional coastal ocean model, incorporating a turbulence closure model to provide a realistic parameterization of the vertical mixing processes. The prognostic variables are the three components of velocity, temperature, salinity, turbulence kinetic energy, and turbulence macroscale. The momentum equations are nonlinear and incorporate a variable Coriolis parameter. Prognostic equations governing the thermodynamic quantities, temperature, and salinity account for water mass variations brought about by highly time-dependent coastal upwelling/downwelling processes as well as horizontal advective processes. Free surface elevation is also calculated prognostically, with only some sacrifice in computational time so that tides and storm surge events can also be simulated. This is accomplished by use of a mode splitting technique whereby the volume transport and vertical velocity shear are solved separately. Other computing variables include density, vertical eddy viscosity, and vertical eddy diffusivity. The module also accommodates realistic coastline geometry and bottom topography.

The hydrodynamic module, ECOM described here is a three-dimensional, time-dependent model developed by Blumberg and Mellor (1980, 1987). This module of ECOMSED, has a long history of successful applications to oceanic, coastal and estuarine waters. Some recent applications of the module include Chesapeake Bay (Blumberg and Goodrich, 1990), New York Bight (Blumberg and Galperin, 1990), Delaware Bay and Delaware River (Galperin and Mellor, 1990a, b), the Gulf Stream Region (Ezer and Mellor, 1992), Massachusetts Bay (Blumberg et al., 1993), Georges Bank (Chen et al., 1995), the Oregon Continental Shelf (Allen et al., 1995), and more recently in New York Bight and New York Harbor (Blumberg et al., 1999) and in Onondaga Lake (Ahsan and Blumburg, 1999). In all of these studies, the predictive capabilities of the module were assessed via extensive comparisons with data and a confidence has been established that the predominant physics is realistically reproduced by the module. A detailed description of the module can be found in the above referenced works.

3.2 The Governing Equations

3.2.1 Dynamic and Thermodynamic Equations

The equations which form the basis of the circulation model describe the velocity and surface elevation fields, and the temperature and salinity fields. Two simplifying approximations are used [Bryan, 1969]; first, it is assumed that the weight of the fluid identically balances the pressure (hydrostatic assumption), and second, density differences are neglected unless the differences are multiplied by gravity (Boussinesq approximation).

Consider a system of orthogonal Cartesian coordinates with x increasing eastward, y increasing northward, and z increasing vertically upwards. The free surface is located at $z = \eta(x,y,t)$ and the bottom is at $z = -H(x,y)$. If $\vec{V}$ is the horizontal velocity vector with components (U,V) and ∇ the horizontal gradient operator, the continuity equation is:

$$\nabla \cdot \overline{V} + \frac{\partial W}{\partial Z} = 0 \tag{3-1}$$

The Reynolds momentum equations are

$$\frac{\partial U}{\partial t} + \overline{V} \cdot \nabla U + W \frac{\partial U}{\partial z} - fV = -\frac{1}{\rho_o} \frac{\partial P}{\partial x} + \frac{\partial}{\partial z}\left(K_M \frac{\partial U}{\partial z}\right) + F_X \tag{3-2}$$

$$\frac{\partial V}{\partial t} + \overline{V} \cdot \nabla V + W \frac{\partial V}{\partial z} + fU = -\frac{1}{\rho_o} \frac{\partial P}{\partial y} + \frac{\partial}{\partial z}\left(K_M \frac{\partial V}{\partial z}\right) + F_Y \tag{3-3}$$

$$\rho \mathbf{g} = -\frac{\partial P}{\partial z} \tag{3-4}$$

with ρ_o the reference density, ρ the in situ density, g the gravitational acceleration, P the pressure, K_M the vertical eddy diffusivity of turbulent momentum mixing. A latitudinal variation of the Coriolis parameter, f, is introduced by use of the β plane approximation.

The pressure at depth z can be obtained by integrating the vertical component of the equation of motion, (3), from z to the free surface η, and is

$$P(x,y,z,t) = P_{atm} + g\rho_o\eta + g\int_z^0 \rho(x,y,z',t)dz' \qquad (3\text{-}5)$$

Henceforth, the atmospheric pressure, P_{atm} is assumed constant.

The conservation equations for temperature and salinity may be written as

$$\frac{\partial\theta}{\partial t} + \vec{V}\cdot\Delta\theta + W\frac{\partial\theta}{\partial z} = \frac{\partial}{\partial z}[K_H\frac{\partial\theta}{\partial z}] + F_\theta \qquad (3\text{-}6)$$

$$\frac{\partial S}{\partial t} + \vec{V}\cdot\Delta S + W\frac{\partial S}{\partial z} = \frac{\partial}{\partial z}\left[K_H\frac{\partial S}{\partial z}\right] + F_s \qquad (3\text{-}7)$$

where θ is the potential temperature (or in situ temperature for shallow water applications) and S is the salinity. The vertical eddy diffusivity for turbulent mixing of heat and salt is denoted as $K_{H.}$. Using the temperature and salinity, the density is computed according to an equation of state of the form

$$\rho = \rho(\theta, \mathbf{S}) \qquad (3\text{-}8)$$

given by Fofonoff [1962]. The potential density is ρ, that is, the density evaluated as a function of potential temperature and salinity but at atmospheric pressure; it provides accurate density information to calculate horizontal baroclinic gradients which enter in the pressure gradient terms and the vertical stability of the water column which enters into the turbulence closure module even in deep water when pressure effects become important.

All of the motions induced by small-scale processes not directly resolved by the model grid (subgrid scale) is parameterized in terms of horizontal mixing processes. The terms F_x, F_y, F_θ and F_S found in (3-2), (3-3), (3-6) and (3-7) represent these unresolved processes and in analogy to molecular diffusion can be written as

$$F_x = \frac{\partial}{\partial x}\left[2A_M\frac{\partial U}{\partial x}\right] + \frac{\partial}{\partial y}\left[A_M\left(\frac{\partial U}{\partial y} + \frac{\partial V}{\partial x}\right)\right] \qquad (3\text{-}9a)$$

$$F_y = \frac{\partial}{\partial x}\left[2A_M\frac{\partial V}{\partial y}\right] + \frac{\partial}{\partial x}\left[A_M\left(\frac{\partial U}{\partial y} + \frac{\partial V}{\partial x}\right)\right] \qquad (3\text{-}9b)$$

and

$$F_{\theta,s} = \frac{\partial}{\partial x}\left[A_H\frac{\partial(\theta,S)}{\partial x}\right] + \frac{\partial}{\partial y}\left[A_H\frac{\partial(\theta,S)}{\partial y}\right] \qquad (3\text{-}10)$$

One should note that F_x and F_y are invariant to coordinate rotation. While these horizontal diffusive terms are meant to parameterize subgrid scale processes, in practice the horizontal diffusivities, A_M and A_H, are usually required to damp small-scale computational noise. The form of F_x, F_y and $F_{\theta,S}$ allows for variable A_M and A_H but thus far they have been held constant. The diffusivities are chosen so that they do not produce excessive smoothing of real features. Values as low as 10 m^2/s have been used successfully in various applications. The relatively fine vertical resolution used in the applications resulted in a reduced need for horizontal diffusion because horizontal advection followed by vertical mixing effectively acts like horizontal diffusion in a real physical sense. An enhancement, now in progress, is to relate A_M and A_H to the scales of motion being resolved in the model to the local deformation field as suggested by Smagorinsky [1963].

3.2.2 Turbulence Closure

The governing equations contain parameterized Reynolds stress and flux terms which account for the turbulent diffusion of momentum, heat, and salt. The parameterization of turbulence in the module described here is based on the work of Mellor and Yamada [1974].

The vertical mixing coefficients, K_M and K_H, in (3-2), (3-3), (3-6) and (3-7) are obtained by appealing to a second order turbulence closure scheme [Mellor and Yamada, 1982] which characterizes the turbulence by equations for the turbulence kinetic energy, $q^2/2$, and a turbulence macroscale, ℓ, according to,

$$\frac{\partial q^2}{\partial t} + \tilde{V}\cdot\nabla q^2 + W\frac{\partial q^2}{\partial z} = \frac{\partial}{\partial z}\left(K_q\frac{\partial q^2}{\partial z}\right) + 2K_M\left[\left(\frac{\partial U}{\partial z}\right)^2 + \left(\frac{\partial V}{\partial z}\right)^2\right] + \frac{2g}{\rho_o}K_H\frac{\partial \rho}{\partial z} - \frac{2q^3}{B_1\ell} + F_q \tag{3-11}$$

and

$$\frac{\partial(q^2\ell)}{\partial t} + \tilde{V}\cdot\nabla(q^2\ell) + W\frac{\partial(q^2\ell)}{\partial z} = \frac{\partial}{\partial z}\left[K_q\frac{\partial}{\partial z}(q^2\ell)\right] + \ell E_1 K_M\left[\left(\frac{\partial U}{\partial z}\right)^2 + \left(\frac{\partial V}{\partial z}\right)^2\right] + \frac{\ell E_1 g}{\rho_o}K_H\frac{\partial \rho}{\partial z} - \frac{q^3}{B_1}\tilde{W} + F_\ell \tag{3-12}$$

where ∇ is the horizontal gradient operator and a wall proximity function is defined as

$$\tilde{W} \equiv 1 + E_2 \left(\frac{\ell}{\kappa L} \right)^2 \tag{3-13}$$

and where

$$(L)^{-1} \equiv (\eta - z)^{-1} + (H + z)^{-1} \tag{3-14}$$

Near surfaces it may be shown that both ℓ/κ and L are equal to the distance from the surface (κ = 0.4 is the von Karman constant) so that $\tilde{W} = 1 + E_2$. Far from the surfaces where $\ell << L, \tilde{W} \simeq 1$. The length scale provided by (3-12) is a characteristic length of the turbulent motion at any point in space or time. An alternative to (3-12) is to use a transport equation for the dissipation rate [Hanjalic and Launder, 1972]. The former approach according to Mellor and Yamada [1982] is more consistent since it uses an equation which describes large-scale turbulence to determine the turbulent macroscale. The terms F_q and F_ℓ in (3-11) and (3-12) are the horizontal mixing and are parameterized analogously to temperature and salinity by using (3-9).

While details of the closure module are rather involved, it is possible to reduce the prescription of the mixing coefficients K_M, K_H, and K_q to the following expressions,

$$K_M \equiv \ell q S_M \tag{3-15a}$$

$$K_H \equiv \ell q S_H \tag{3-15b}$$

$$K_q \equiv \ell q S q \tag{3-15c}$$

The stability functions, S_M, S_H, and S_q are analytically derived, algebraic relations functionally dependent upon ∂U/∂z, ∂V/∂z, $g\rho_o^{-1} \partial\rho / \partial z$, q and ℓ. These relations derive from closure hypotheses described by Mellor [1973] and summarized by Mellor and Yamada [1982]. Following Galperin et al. [1988] the stability functions are:

$$S_M = \frac{B_1^{-1/3} - 3A_1A_2G_H\left[(B_2 - 3A_2)\left(1 - \frac{6A_1}{B_1}\right) - 3C_1(B_2 + 6A_1)\right]}{\left[1 - 3A_2G_H(6A_1 + B_2)\right](1 - 9A_1A_2G_H)} \tag{3-16}$$

$$S_H = \frac{A_2\left(1 - \frac{6A_1}{B_2}\right)}{1 - 3A_2G_H(6A_1 + B_2)} \tag{3-17}$$

and

$$G_H = -\left(\frac{Nl}{q}\right)^2 \tag{3-18a}$$

where

$$N = \left(-\frac{g}{\rho_o}\frac{\partial\rho}{\partial z}\right)^{1/2} \tag{3-18b}$$

is the Brunt-Vaisala frequency. The empirical constants given n Mellor and Yamada (1982) are: (A1, A2, B1, B2, C1, E1, E2, Sq) = (0.92, 0.74, 16.6, 10.1, 0.08, 1.8, 1.33, 0.2), respectively. In stably stratified flows, the turbulence macroscale is limited (see Galperin et al. [1988]) according to:

$$l \le \frac{0.53q}{N} \tag{3-19}$$

3.2.3 Boundary Conditions

The boundary conditions at the free surface, $z = \eta(x,y)$, are

$$\rho_o K_M\left(\frac{\partial U}{\partial z}, \frac{\partial V}{\partial z}\right) = (\tau_{ox}, \tau_{oy}) \tag{3-20a}$$

$$\rho_o K_H\left(\frac{\partial \theta}{\partial z}, \frac{\partial S}{\partial z}\right) = (\dot{H}, \dot{S}) \tag{3-20b}$$

$$q^2 = B_1^{2/3} u_{\tau s}^2 \tag{3-20c}$$

$$q^2 \ell = 0 \tag{3-20d}$$

$$W = U \frac{\partial \eta}{\partial x} + V \frac{\partial \eta}{\partial y} + \frac{\partial \eta}{\partial t} \tag{3-20e}$$

where $(\tau_{ox}, \tau_{oy})$is the surface wind stress vector with the friction velocity, $u_{\tau s}$, the magnitude of the vector. It is doubtful that the mixing length goes to zero at a surface containing wind induced waves as suggested by (3-20d). The error is incurred in the near surface layers of thickness of order of the wave height. This is an area where further improvement is necessary. The quantity $B_1^{2/3}$ is an empirical constant (6.51) arising from the turbulence closure relations. The net ocean heat flux is $\dot{H}$ and here $\dot{S} \equiv S(0)[\dot{E} - \dot{P}]/\rho_o$ where $(\dot{E} - \dot{P})$ is the net evaporation-precipitation fresh water surface mass flux rate and S(0) is the surface salinity. On the side walls and bottom of the basin, the normal gradients of θ and S are zero so that there are no advective and diffusive heat and salt fluxes across these boundaries. At the lower boundary (b),

$$\rho_o K_M \left(\frac{\partial U}{\partial z}, \frac{\partial V}{\partial z} \right) = \left(\tau_{bx}, \tau_{by} \right) \tag{3-21a}$$

$$q^2 = B_1^{2/3} u_{\tau b}^2 \tag{3-21b}$$

$$q^2 \ell = 0 \tag{3-21c}$$

$$W_b = -U_b \frac{\partial H}{\partial x} - V_b \frac{\partial H}{\partial y} \tag{3-21d}$$

where H(x,y) is the bottom topography and $u_{\tau b}$ is the friction velocity associated with the bottom frictional stress (τ_{bx}, τ_{by}). The bottom stress is determined by matching velocities with the logarithmic law of the wall. Specifically,

$$\vec{\tau}_b = \rho_o \mathbf{C}_D |\mathbf{V}_b| \mathbf{V}_b \tag{3-22}$$

With value of the drag coefficient C_D given by

$$\mathbf{C}_D = \left[\frac{1}{\kappa} \ln\left(\mathbf{H} + z_b \right) / z_o \right]^{-2} \tag{3-23a}$$

where z_b and V_b are the grid point and corresponding velocity in the grid point nearest the bottom and κ is the von Karman constant. The final result of (3-22) and (3-23) in conjunction with the turbulent closure derived K_M is that the calculations will yield

$$V = \left(\vec{\tau}_b / \kappa u_{*b}\right) \ln\left(z / z_o\right) \tag{3-23b}$$

in the lower boundary region if enough resolution is provided. In those instances where the bottom boundary layer is not well resolved, it is more appropriate to specify $C_D = 0.0025$. The actual algorithm is to set C_D to the larger of the two values given by (3-23a) and 0.0025. The parameter z_o depends on the local bottom roughness; in the absence of specific information $z_o = 1$ cm is used as suggested by Weatherly and Martin [1978].

3.2.4 Open Lateral Boundary Condition

3.2.4.1 Temperature and Salinity

Open lateral boundary conditions are problematic since one must parameterize the environment exterior to the relevant domain. Two types of open boundaries exist, inflow and outflow. Temperature and salinity are prescribed from data at an inflowing boundary, whereas at outflow boundaries,

$$\frac{\partial}{\partial t}(\theta, S) + U_n \frac{\partial}{\partial n}(\theta, S) = 0 \tag{3-23c}$$

is solved where the subscript n is the coordinate normal to the boundary. Turbulence kinetic energy and the macroscale quantity ($q^2\ell$) are calculated with sufficient accuracy at the boundaries by neglecting the advection in comparison with other terms in their respective equations.

The open lateral velocity boundary conditions in some of the applications are computed by using the available hydrographic data in conjunction with a simplified diagnostic model. This type of model uses only geostrophic plus Ekman dynamics and therefore solves a simplified form of the full equations of motion. It does not require a velocity at a reference level but only along a single transect crossing f/H contours. A detailed description of this module can be found in the work by Kantha et al. [1982]. While the normal component of velocity is specified, a free slip condition is used for the tangential component.

3.2.4.2 Water Level Boundary Condition

In developing the ocean circulation module, open boundary conditions that allow long-wave energy (e.g., tides) to enter the open boundaries as well as a means of radiating out longwave energy that impacts the open boundary from the interior of the model domain must be provided. There are a number of radiation boundary conditions that can be utilized to achieve these goals. ECOMSED modeling framework adopts several types of boundary conditions that are discussed below.

3.2.4.2.1 Clamped Boundary Condition

In this type of boundary condition the module uses water level along the boundary grids assigned by the users either from observed data or tidal harmonics. However, this kind of boundary condition is considered rigid and does not allow long wave energy (tides or storm surges) to enter or radiate out of the model domain. For a smaller model domain where wind induced long wave is important to pass through the model boundary, the clamped boundary condition could be problematic.

3.2.4.2.2 Reid and Bodine Boundary Condition

For longwave to radiate through the boundaries, ECOMSED model utilizes an open boundary condition developed by Reid and Bodine (1968). This condition has the form of

$$\eta = \eta_o + \lambda_t \, u_n \, [\, g / D]^{-½} \qquad (3\text{-}24a)$$

where h is the sea level at the open boundary, h_o is the known (assigned) tidal and perhaps low frequency sea level variation at the grid cell, u_n is the model-predicted velocity perpendicular to the open boundary, g is the acceleration due to gravity, and D is the depth of the grid cell. The LaGrange multiplier λ_t is calculated each time step to allow modification of the sea level due to longwave radiation. For Reid and Bodine type of boundary condition, λ_t and therefore the specified h_o at an open boundary grid cell are somewhat modified by the quantity $u_n [\, g / D]^{-1/2}$. Please note for $\lambda_t = 0$ the formulation provided by Equation (3-24a) gives rise to a condition which is strictly clamped.

3.2.4.2.3 Optimized Clamped Boundary Condition

The optimized clamped bounary condition can be defined by Equation (3-24a). Here the LaGrange multiplier is computed with time based on solving optimization problems that minimize the difference between the model computed values and the “reference” boundary values under certain integral constraints on the open boundary. These constraints represent the energy, momentum, and mass fluxes through the open boundary. Detailed discussion on the optimized boundary conditions can be found in Shulman (1995) and Shulman and Lewis (1994).

3.3 Vertical Coordinate Representation

It has often been noted that the ordinary x,y,z coordinate system has certain disadvantages in the vicinity of large bathymetric irregularities. It is desirable to introduce a new set of independent variables that transforms both the surface and the bottom into coordinate surfaces [Phillips, 1957] called σ-coordinate system which is illustrated in Figure 3-1. The governing external and internal mode equations are transformed from (x,y,z,t) to (x*,y*,σ,t*) coordinates, where

$$x^* = x \quad y^* = y \quad \sigma = \frac{z - \eta}{H + \eta} \qquad t^* = t \tag{3-25}$$

Now let D ≡ H + η and apply the chain rule; the following relationships linking derivatives in the old system to those in the new system are obtained:

$$\frac{\partial G}{\partial x} = \frac{\partial G}{\partial x^*} - \frac{\partial G}{\partial \sigma}\left(\frac{\sigma}{D}\frac{\partial D}{\partial x^*} + \frac{1}{D}\frac{\partial \eta}{\partial x^*}\right) \tag{3-26a}$$

$$\frac{\partial G}{\partial y} = \frac{\partial G}{\partial y^*} - \frac{\partial G}{\partial \sigma}\left(\frac{\sigma}{D}\frac{\partial D}{\partial y^*} + \frac{1}{D}\frac{\partial \eta}{\partial y^*}\right) \tag{3-26b}$$

$$\frac{\partial G}{\partial z} = \frac{1}{D}\frac{\partial G}{\partial \sigma} \tag{3-26c}$$

$$\frac{\partial G}{\partial t} = \frac{\partial G}{\partial t^*} - \frac{\partial G}{\partial \sigma}\left(\frac{\sigma}{D}\frac{\partial D}{\partial t^*} + \frac{1}{D}\frac{\partial \eta}{\partial t^*}\right) \tag{3-26d}$$

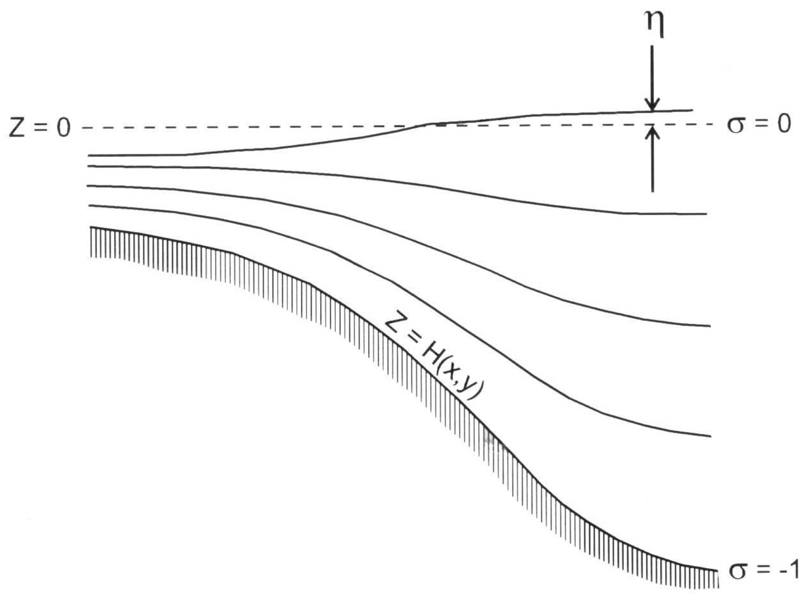
where G is an arbitrary field available, and σ ranges from σ = 0 at z = η to σ = -1 at z = -H. A new vertical velocity can now be defined

$$\omega \equiv W - U\omega\ \sigma \frac{\partial D}{\partial x^*} + \frac{\partial \eta}{\partial x^*} - V\sigma \frac{\partial D}{\partial y^*} + \frac{\partial \eta}{\partial y^*} - \left(\sigma \frac{\partial D}{\partial t^*} + \frac{\partial \eta}{\partial t^*}\right) \tag{3-27}$$

which transforms the boundary conditions, (3-20e) and (3-21d), into

$$\omega\left(x^*, y^*, 0, t^*\right) = 0 \tag{3-28a}$$

$$\omega\left(x^*, y^*, -1, t^*\right) = 0 \tag{3-28b}$$



The sigma coordinate system.

FIGURE 3-1

Also, any vertically integrated quantity, G, for example, now appears as

$$\overline{G} = \int_{-1}^{0} G \, d\sigma \tag{3-29}$$

Equations (3-1), (3-2), (3-3), (3-6), (3-7), (3-11) and (3-12) may now be written as (all asterisks will be dropped for notational convenience)

$$\frac{\partial \eta}{\partial t} + \frac{\partial UD}{\partial x} + \frac{\partial VD}{\partial y} + \frac{\partial \omega}{\partial \sigma} = 0 \tag{3-30}$$

$$\frac{\partial UD}{\partial t} + \frac{\partial U^2 D}{\partial x} + \frac{\partial UVD}{\partial y} + \frac{\partial U\omega}{\partial \sigma} - fVD + gD\frac{\partial \eta}{\partial x}$$
$$= \frac{\partial}{\partial \sigma}\left(\frac{K_M}{D}\frac{\partial U}{\partial \sigma}\right) \frac{gD^2}{\rho_o}\frac{\partial}{\partial x}\int_{\sigma}^{0} \rho \, d\sigma$$
$$+ \frac{gD}{\rho_o}\frac{\partial D}{\partial x}\int_{\sigma}^{0} \sigma \frac{\partial \rho}{\partial \sigma} d\sigma + F_x \tag{3-31}$$

$$\frac{\partial VD}{\partial t} + \frac{\partial UVD}{\partial x} + \frac{\partial V^2 D}{\partial y} + \frac{\partial V\omega}{\partial \sigma} + fUD + gD\frac{\partial \eta}{\partial y}$$
$$= \frac{\partial}{\partial \sigma}\left(\frac{K_M}{D}\frac{\partial V}{\partial \sigma}\right) \frac{gD^2}{\rho_o}\frac{\partial}{\partial y}\int_{\sigma}^{0} \rho \, d\sigma$$
$$+ \frac{gD}{\rho_o}\frac{\partial D}{\partial y}\int_{\sigma}^{0} \sigma \frac{\partial \rho}{\partial \sigma} d\sigma + F_y \tag{3-32}$$

$$\frac{\partial \Theta D}{\partial t} + \frac{\partial \Theta UD}{\partial x} + \frac{\partial \Theta VD}{\partial y} + \frac{\partial \Theta \omega}{\partial \sigma} = \frac{\partial}{\partial \sigma}\left(\frac{K_H}{D}\frac{\partial \Theta}{\partial \sigma}\right) + F_\Theta \tag{3-33}$$

$$\frac{\partial SD}{\partial t} + \frac{\partial SUD}{\partial x} + \frac{\partial SVD}{\partial y} + \frac{\partial S\omega}{\partial \sigma} = \frac{\partial}{\partial \sigma}\left(\frac{K_H}{D}\frac{\partial S}{\partial \sigma}\right) + F_S \tag{3-34}$$

$$\frac{\partial q^2 D}{\partial t} + \frac{\partial U q^2 D}{\partial x} + \frac{\partial V q^2 D}{\partial y} + \frac{\partial \omega q^2}{\partial \sigma} = \frac{\partial}{\partial \sigma}\left(\frac{K_q}{D}\frac{\partial q^2}{\partial \sigma}\right) + \frac{2 K_M}{D}\left[\left(\frac{\partial U}{\partial \sigma}\right)^2 + \left(\frac{\partial V}{\partial \sigma}\right)^2\right] + \frac{2g}{\rho_o} K_H \frac{\partial \rho}{\partial \sigma} \; 2 D q sup \frac{3}{B_1 \ell} + F_q \tag{3-35}$$

$$\frac{2 q^2 \ell D}{\partial t} + \frac{\partial U q^2 \ell D}{\partial x} + \frac{\partial V q^2 \ell D}{\partial y} + \frac{\partial \omega q^2 \ell}{\partial \sigma} = \frac{\partial}{\partial \sigma}\left(\frac{K_q}{D}\frac{\partial q^2 \ell}{\partial \sigma}\right) + E_1 \ell \left\{ \frac{K_M}{D}\left[\left(\frac{\partial U}{\partial \sigma}\right)^2 + \left(\frac{\partial V}{\partial \sigma}\right)^2\right] + \frac{q D^3}{\rho_o} K_H \frac{\partial \rho}{\partial \sigma} \right\} \frac{D q^3}{B_1} \tilde{W} + F_\ell \tag{3-36}$$

The horizontal viscosity and diffusion terms are defined according to:

$$\mathbf{F}_x \equiv \frac{\partial \mathbf{D} \hat{\mathbf{t}}_{xx}}{\partial \mathbf{x}} + \frac{\partial}{\partial \mathbf{y}}\left(\mathbf{D} \hat{\tau}_{yx}\right) \tag{3-37}$$

$$F_y \equiv \frac{\partial D \hat{\tau}_{yy}}{\partial y} + \frac{\partial}{\partial x}\left(D \hat{\tau}_{xy}\right) \tag{3-38}$$

with

$$\hat{\tau}_{xx} = 2 A_M \left[\frac{\partial U}{\partial x}\right] \tag{3-39}$$

$$\hat{\tau}_{xy} = \hat{\tau}_{yx} = A_M \left[\frac{\partial U}{\partial y} + \frac{\partial V}{\partial y}\right] \tag{3-40}$$

$$\hat{\tau}_{yy} = 2 A_M \left[\frac{\partial V}{\partial y}\right] \tag{3-41}$$

Also,

$$F_{\theta_i} \equiv \frac{\partial D \hat{q}_x}{\partial x} + \frac{\partial D \hat{q}_y}{\partial y} \tag{3-42}$$

$$\hat{q}_x = A_H \left[\frac{\partial \theta_i}{\partial x} \right] \tag{3-43}$$

00

$$\hat{q}_y = A_H \left[\frac{\partial \theta_i}{\partial y} \right] \tag{3-44}$$

where θ_i now represents θ, S, q^2 and $q^2\ell$.

Mellor and Blumberg [1985] have shown that the conventional model for horizontal diffusion is incorrect when bottom topographical slopes are large. Horizontal mixing coefficient A_m and A_H for both momentum and heat/salinity are parameterized suggested by Smagorinsky (963) as described in Section 3.5.2.

3.4 Mode Splitting Technique

The equations governing the dynamics of coastal, estuarine and lake circulation contain propagation of fast moving external gravity waves and slow moving internal gravity waves. It is desirable in terms of computer economy to separate out vertically integrated equations (external mode) from the vertical structure equations (internal mode). This technique, known as mode splitting [see Simons, 1974; Madala and Piacsek, 1977] permits the calculation of the free surface elevation with little sacrifice in computational time by solving the volume transport separately from the vertical velocity shear.

The volume transport, external mode equations are obtained by integrating the internal mode equations over the depth, thereby eliminating all vertical structure. By integrating (3-30) from σ = -1 to σ = 0 and using the boundary conditions (3-28a,b) an equation for the surface elevation can be written as

$$\frac{\partial \eta}{\partial t} + \frac{\partial \overline{U} D}{\partial x} + \frac{\partial \overline{V} D}{\partial y} = 0 \tag{3-45}$$

and the momentum equations become upon vertical integration

$$\frac{\partial \overline{U}D}{\partial t}+\frac{\partial \overline{U}^2 D}{\partial x}+\frac{\partial \overline{U}\overline{V}D}{\partial y}-f\overline{V}D+gD\frac{\partial \eta}{\partial x}-D\overline{F}_x=-\overline{wu}(0)$$
$$+\overline{wu}(-1)-\frac{\partial D\overline{U'^2}}{\partial x}-\frac{\partial D\overline{U'V'}}{\partial y}-\frac{gD^2}{\rho_o}\frac{\partial}{\partial x}\int_{-1}^{0}\int_{\sigma}^{0}\rho\, d\sigma' d\sigma \tag{3-46}$$
$$+\frac{gD}{\rho_o}\frac{\partial D}{\partial x}\int_{-1}^{0}\int_{\sigma}^{0}\sigma'\frac{\partial \rho}{\partial \sigma}d\sigma' d\sigma$$

$$\frac{\partial \overline{V}D}{\partial t}+\frac{\partial \overline{U}\overline{V}D}{\partial x}+\frac{\partial \overline{V}^2 D}{\partial y}+f\overline{U}D+gD\frac{\partial \eta}{\partial y}-D\overline{F}_y=-\overline{wv}(0)$$
$$+\overline{wv}(-1)-\frac{\partial D\overline{U'V'}}{\partial x}-\frac{\partial D\overline{V'^2}}{\partial y}-\frac{gD^2}{\rho_o}\frac{\partial}{\partial y}\int_{-1}^{0}\int_{\sigma}^{0}\rho\, d\sigma' d\sigma \tag{3-47}$$
$$+\frac{gD}{\rho_o}\frac{\partial D}{\partial y}\int_{-1}^{0}\int_{\sigma}^{0}\sigma'\frac{\partial \rho}{\partial \sigma'}d\sigma' d\sigma$$

where the pressure has been obtained from (3-5) and the vertically integrated velocities are defined as

$$\left(\overline{U},\overline{V}\right)\equiv\int_{-1}^{0}(U,V)\,d\sigma \tag{3-48}$$

The wind stress components are $-\overline{wu}(0)$, and $-\overline{wv}(0)$, and the bottom stress components are $-\overline{wu}(-1)$ and $-\overline{wv}(-1)$. The terms in (3-46) and (3-47) involving U'^2, $U'V'$, and V'^2 represent vertical averages of the cross-products of the velocity departures from the vertically integrated (average) velocity and are often denoted as the dispersion terms. Thus

$$\left(\overline{U'^2},\overline{V'^2},\overline{U'V'}\right)=\int_{-1}^{0}\left(U'^2,V'^2,U'V'\right)d\sigma \tag{3-49}$$

where $(U',V')=(U-\overline{U},V-\overline{V})$. The quantities $\overline{F}_x$ and $\overline{F}_y$ are vertical integrals of the horizontal momentum diffusion and are defined according to

$$D\overline{F}_x=\frac{\partial}{\partial x}\left(2A_M\frac{\partial \overline{U}D}{\partial x}\right)+\frac{\partial}{\partial y}A_M\left(\frac{\partial \overline{U}D}{\partial y}+\frac{\partial \overline{V}D}{\partial x}\right) \tag{3-50}$$

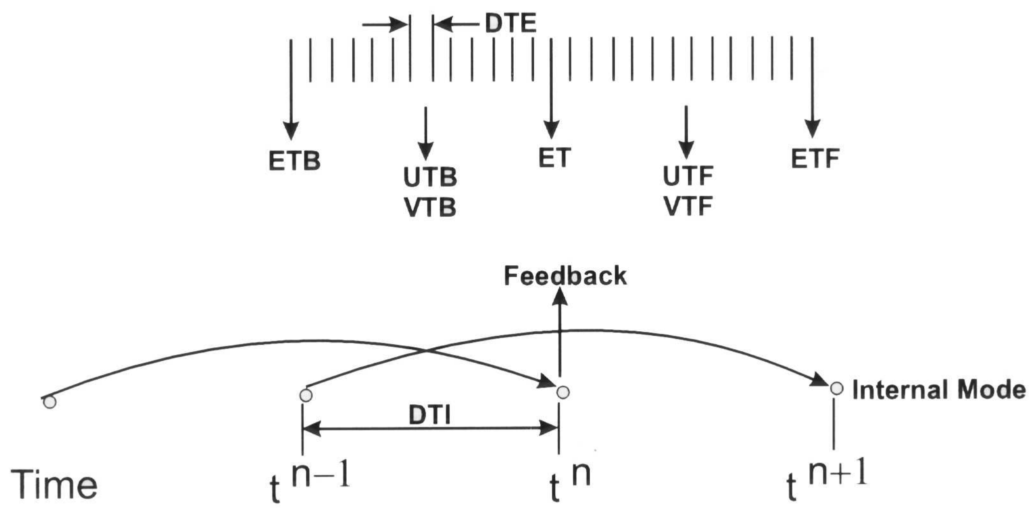
$$D\overline{F}_y = \frac{\partial}{\partial y}\left(2A_M \frac{\partial \overline{V}D}{\partial y}\right) + \frac{\partial}{\partial x}A_M\left(\frac{\partial \overline{U}D}{\partial y} + \frac{\partial \overline{V}D}{\partial x}\right) \qquad (3\text{-}51)$$

The computational strategy is to solve equations for the external mode, the shallow water wave equations (3-45), (3-46), and (3-47), with a short time step to resolve tidal motions. The external mode solutions are obtained with the terms on the right-hand side of (3-46) and (3-47) held fixed in time and after a large number of time steps, of the order of 100, an internal mode calculation is carried out. The external mode provides $\partial\eta/\partial x$ and $\partial\eta/\partial y$ for insertion into the internal mode equations, (3-30) through (3-36), which are then solved with a much longer time step. Once the vertical structure has been determined, the terms on the right-hand side (3-46) and (3-47) are updated and another external mode solution begins. In future simulations, the advective and diffusive terms in (3-46) and (3-47) will be supplied by the internal mode. Figure 3-2 illustrates the time stepping process for the external and internal mode.

The external mode equations have not been subtracted from the original equations (3-30) and (3-32) to form the more conventional internal mode set as, for example, in Bryan [1969] and Wang [1982]. Consequently there may be a slow tendency for the vertical integral of the internal mode velocities to differ from the external mode velocities. This arises because of different truncation errors in each mode. To insure against accumulated mismatch, the vertical mean of the internal velocity is replaced at every time step by the external mode velocity.

3.5 Orthogonal Curvilinear Coordinate System Transformation

An important advantage of the present model over that used earlier is the use of a horizontal, orthogonal, curvilinear coordinate system. The full set of the equations in given in Blumberg and Herring (1987); for the present version of the primer only the internal mode equations are given. These equations in the mass flux conservative form are:



A simplified illustration of the interaction of the
External Mode and the Internal Mode

FIGURE 3-2

The Continuity Equation

$$h_1 h_2 \frac{\partial \eta}{\partial t} + \frac{\partial}{\partial \xi_1}(h_2 U_1 D) + \frac{\partial}{\partial \xi_2}(h_1 U_2 D) + h_1 h_2 \frac{\partial \omega}{\partial \sigma} = 0 \qquad \text{(3-52a)}$$

where:

$$\omega = W - \frac{1}{h_1 h_2}\left[h_2 U_1 \left(\sigma \frac{\partial D}{\partial \xi_1} + \frac{\partial \eta}{\partial \xi_1} \right) + h_1 U_2 \left(\sigma \frac{\partial D}{\partial \xi_2} + \frac{\partial \eta}{\partial \xi_2} \right) \right]$$

$$- \left(\sigma \frac{\partial D}{\partial t} + \frac{\partial \eta}{\partial t} \right) \qquad \text{(3-52b)}$$

The Reynolds Equations

$$\frac{\partial (h_1 h_2 D U_1)}{\partial t} + \frac{\partial}{\partial \xi_1}(h_2 D U_1^2) + \frac{\partial}{\partial \xi_2}(h_1 D U_1 U_2) + h_1 h_2 \frac{\partial (\omega U_1)}{\partial \sigma}$$

$$+ D U_2 \left(- U_2 \frac{\partial h_2}{\partial \xi_1} + U_1 \frac{\partial h_1}{\partial \xi_2} - h_1 h_2 f \right)$$

$$= - g D h_2 \left(\frac{\partial \eta}{\partial \xi_1} + \frac{\partial H_o}{\partial \xi_1} \right) - \frac{g D^2 h_2}{\rho_o} \int_\sigma^0 \left[\frac{\partial \rho}{\partial \xi_1} - \frac{\sigma}{D} \frac{\partial D}{\partial \xi_1} \frac{\partial \rho}{\partial \sigma} \right] d\sigma$$

$$- D \frac{h_2}{\rho_o} \frac{\partial P_a}{\partial \xi_1} + \frac{\partial}{\partial \xi_1}\left(2 A_M \frac{h_2}{h_1} D \frac{\partial U_1}{\partial \xi_1} \right) + \frac{\partial}{\partial \xi_2}\left(A_M \frac{h_1}{h_2} D \frac{\partial U_1}{\partial \xi_2} \right)$$

$$+ \frac{\partial}{\partial \xi_2}\left(A_M D \frac{\partial U_2}{\partial \xi_1} \right) + \frac{h_1 h_2}{D} \frac{\partial}{\partial \sigma}\left(K_M \frac{\partial U_1}{\partial \sigma} \right)$$

(3-53)

$$\frac{\partial(h_1 h_2 D U_2)}{\partial t} + \frac{\partial}{\partial \xi_1}(h_2 D U_1 U_2) + \frac{\partial}{\partial \xi_2}(h_1 D U_2^2) + h_1 h_2 \frac{\partial(\omega U_2)}{\partial \sigma}$$

$$+ D U_1 \left(- U_1 \frac{\partial h_1}{\partial \xi_2} + U_2 \frac{\partial h_2}{\partial \xi_1} + h_1 h_2 f \right)$$

$$= - g D h_1 \left(\frac{\partial \eta}{\partial \xi_2} + \frac{\partial H_o}{\partial \xi_2} \right) - \frac{g D^2 h_1}{\rho_o} \int_\sigma^0 \left[\frac{\partial \rho}{\partial \xi_2} - \frac{\sigma}{D} \frac{\partial D}{\partial \xi_2} \frac{\partial \rho}{\partial \sigma} \right] d\sigma$$

$$- D \frac{h_1}{\rho_o} \frac{\partial P_a}{\partial \xi_2} + \frac{\partial}{\partial \xi_2}\left(2 A_M \frac{h_1}{h_2} D \frac{\partial U_2}{\partial \xi_2}\right) + \frac{\partial}{\partial \xi_1}\left(A_M \frac{h_2}{h_1} D \frac{\partial U_2}{\partial \xi_1}\right)$$

$$+ \frac{\partial}{\partial \xi_1}\left(A_M D \frac{\partial U_1}{\partial \xi_2}\right) + \frac{h_1 h_2}{D} \frac{\partial}{\partial \sigma}\left(K_M \frac{\partial U_2}{\partial \sigma}\right)$$

(3-54)

<u>Transport of Temperature</u>

$$h_1 h_2 \frac{\partial(\theta D)}{\partial t} + \frac{\partial}{\partial \xi_1}(h_2 U_1 \theta D) + \frac{\partial}{\partial \xi_2}(h_1 U_2 \theta D) + h_1 h_2 \frac{\partial(\omega \theta)}{\partial \sigma}$$

$$= \frac{\partial}{\partial \xi_1}\left(\frac{h_2}{h_1} A_H D \frac{\partial \theta}{\partial \xi_1}\right) + \frac{\partial}{\partial \xi_2}\left(\frac{h_1}{h_2} A_H D \frac{\partial \theta}{\partial \xi_2}\right) + \frac{h_1 h_2}{D} \frac{\partial}{\partial \sigma}\left(K_H \frac{\partial \theta}{\partial \sigma}\right)$$

(3-55)

Transport of Salinity

$$h_1h_2 \frac{\partial(SD)}{\partial t} + \frac{\partial}{\partial \xi_1}(h_2U_1SD) + \frac{\partial}{\partial \xi_2}(h_1h_2SD) + h_1h_2 \frac{\partial(\omega S)}{\partial \sigma}$$

$$= \frac{\partial}{\partial \xi_1}\left(\frac{h_2}{h_1} A_H D \frac{\partial S}{\partial \xi_1}\right) + \frac{\partial}{\partial \xi_2}\left(\frac{h_1}{h_2} A_H D \frac{\partial S}{\partial \xi_2}\right) + \frac{h_1h_2}{D} \frac{\partial}{\partial \sigma}\left(K_H \frac{\partial S}{\partial \sigma}\right)$$

(3-56)

Transport of Turbulent Kinetic Energy

$$h_1h_2 \frac{\partial(q^2D)}{\partial t} + \frac{\partial}{\partial \xi_1}(h_2U_1Dq^2) + \frac{\partial}{\partial \xi_2}(h_1U_2Dq^2)\ h_1h_2\frac{\partial(\omega q^2)}{\partial \sigma}$$

$$= h_1h_2\left\{\frac{2K_M}{D}\left[\left(\frac{\partial U_1}{\partial \sigma}\right)^2 + \left(\frac{\partial U_2}{\partial \sigma}\right)^2\right] + \frac{2g}{\rho_o} K_H \frac{\partial \rho}{\partial \sigma} - \frac{2q^3D}{\Lambda_1}\right\}$$

$$+ \frac{\partial}{\partial \xi_1}\left(\frac{h_2}{h_1} A_H D \frac{\partial q^2}{\partial \xi_1}\right) + \frac{\partial}{\partial \xi_2}\left(\frac{h_1}{h_2} A_H D \frac{\partial q^2}{\partial \xi_2}\right) + \frac{h_1h_2}{D} \frac{\partial}{\partial \sigma}\left(K_q \frac{\partial q^2}{\partial \sigma}\right)$$

(3-57)

Turbulent Macroscale

$$h_1h_2 \frac{\partial(q^2\lambda D)}{\partial t} + \frac{\partial}{\partial \xi_1}(h_2U_1Dq^2\lambda) + \frac{\partial}{\partial \xi_2}(h_1U_2Dq^2\lambda) + h_1h_2 \frac{\partial(\omega q^2\lambda)}{\partial \sigma}$$

$$= h_1h_2\left\{\frac{\lambda E_1K_M}{D}\left[\left(\frac{\partial U_1}{\partial \sigma}\right)^2 + \left(\frac{\partial U_2}{\partial \sigma}\right)^2\right] + \frac{\lambda E_1 g}{\rho_o} K_H \frac{\partial \rho}{\partial \sigma} - \frac{q^3D}{B_1}\tilde{w}\right\}$$

$$+ \frac{\partial}{\partial \xi_1}\left(\frac{h_2}{h_1} A_H D \frac{\partial(q^2\lambda)}{\partial \xi_1}\right) + \frac{\partial}{\partial \xi_2}\left(\frac{h_1}{h_2} A_H D \frac{\partial(q^2\lambda)}{\partial \xi_2}\right)$$

$$+ \frac{h_1 h_2}{D} \frac{\partial}{\partial \sigma} \left(K_q \frac{\partial (q^2 \lambda)}{\partial \sigma} \right) \qquad (3\text{-}58)$$

where ξ_1 and ξ_2 are arbitrary horizontal curvilinear orthogonal coordinates.

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4.0 Surface Heat Flux Module

The energy content in lakes, reservoirs, estuaries, and coastal and oceanic water bodies is primarily governed by the surface heat energy exchanges. Measurements of heat fluxes such as solar radiations, atmospheric radiation, sensible heat and latent heat fluxes are very difficult and costly to make and are often parameterized to obtain the fluxes, using the most commonly available meteorological data. The processes that control the heat exchange between the water and atmosphere are well documented (Large and Pond, 1982; Rosati and Miyakoda, 1988; Cole and Buchak, 1994; Ahsan and Blumberg, 1999). All of these works relied mostly on the bulk formulae to evaluate the components of the heat budget. It is important to note here that most of bulk formulae, available in literature, for calculations of radiative fluxes are based on basically the same principles and generally agree with one another in general patterns of temporal and spatial variations of fluxes. However, significant differences in their magnitudes exist depending on the time period of the year and latitudinal position of the study area.

Estimation of net heat flux requires a great deal of judgement in choosing the bulk formulae which are dependent on meteorological parameters like cloud cover, relative humidity, air temperature, winds, water surface temperature etc. Computations of four major heat flux components such as short wave solar radiations, longwave atmospheric radiations, sensible heat and latent heat fluxes have been introduced in ECOM code using three formulations based on the works of Ahsan and Blumberg (1999), Rosati and Miyakoda (1988) and Large and Pond (1982). Users may choose either of these three formulations by choosing heat flux options A&BFLX, R&BFLX, and L&PFLX respectively (see data entry section). Table 4-1 describes the equations to compute the individual heat flux component using these three options. It has been demonstrated in literature that option A&BFLX has more success in simulating heat budget in inland lakes, reservoirs and estuarine systems. The latter two options are described as more appropriate for oceanic environments. The users may apply their judgement to choose these options depending on the nature of their applications.

Table 4-1. Healthflux Formulations in Ecom Model

	A and BFLX	R and MFLX	L and PFLX
Solar Radiation* (H_s)	users measured data	users measured data	users measured data
Atmospheric Radiation (H_a)	$\varepsilon\sigma\left\{\begin{matrix}(9.37\times10^{-6}T_a^6) \\ (1+0.17C^2)-T_s^4\end{matrix}\right\}$	$\varepsilon\sigma T_s^4(0.39-0.05e_a^{1/2})(1-0.8C)+4\varepsilon\sigma T_s^3(T_s-T_a)$	$\left\{\begin{matrix}\varepsilon\sigma T_s^4(0.39-0.05e_a^{1/2}) \\ +4\varepsilon\sigma T_s^3(T_s-T_a)\end{matrix}\right\}(1-0.62C^2)$
Sensible Heatflux (H_c)	$C_t f(w)(T_s - T_a)$	$C_T W(T_s - T_a)$	$C_T U_a(T_s - \theta_a)$
Evaporative Heatflux (H_e)	$f(w)(e_s - e_a)$	$C_E W(e_s - re_a)0.621/P$	$C_E U_a(\theta_s - \theta_a)$
References	Ahsan & Blumberg (1999) (Cole & Buchak (1994))	Rosati & Miyakoda (1988)	Large & Pond (1982)

*In case field measurements are not available, the model computes solar radiation based on:

$H_s = Q_{TOT}(1\text{-}0.62C + 0.001\partial\beta)(1\text{-}\alpha)$; $Q_{TOT} = Q_{DIR} + Q_{DIFF}$; $Q_{DIR} = Q_oT^{secz}$;

$Q_{DIFF} = [(1 - A_a)Q_o - Q_{DIR}]/2$; $Q_o = \frac{J_o}{a^2} CsozD_F(\phi,\lambda)$

(See Rosati and Miyakoda (1988) for definition of parameters.)

Definition of Parameters

ϵ	Emmissivity of water (0.97)	CT	Bulk transfer coefficient for conductive heat flux
σ	Stephen-Boltzman Constant ($5.67 * 10^{-8}$) ($WM^{-2}K^{-4}$)	CE	Bulk transfer coefficient for evaporative heat flux
T_s	Water surface temperature in °K	W	Windspeed in m/s
T_a	Air temperature in °K	θ	Virtual air temperature
e_s(Ta,Ts)	Saturated vapor pressure in mbar at air temperature T_a and sea surface temperature T_s	f(w)	Windspeed function ($6.9 + 0.34\ W^2$) in w m^{-2} $mbar^{-1}$
		P	Barometric pressure in mbar
		R	relative humidity
C	Cloud cover fraction (0 - 1.0)		

5.0 Particle Tracking Module

The movement of particles can be determined by exploiting the equivalency between tracking particles and solving a mass transport equation for a conservative substance (Thompson and Gelhar 1990). Following Dimou and Adams (1993), a random-walk particle tracking scheme has been designed which calculates the displacement of particles as the sum of an advective deterministic component and an independent, random Markovian component which statistically approximates the dispersion characteristics of the environment. By relating the advective and Markovian components to the appropriate terms in a conservation equation, a technique has been designed where a distribution of particles will turn out to be the same as that concentration resulting from the solution of the conservation equation.

In a three dimensional environment, a conservative substance is transported under the influence of advection and dispersion processes. The solution for this transport problem is commonly based on the mass balance equation. Introducing the σ transformation in the vertical:

$$\sigma = \frac{z - \eta}{H + \eta} \tag{5-1}$$

where H(x,y) is the water depth, η(x,y) is the surface elevation and D = H η, the transport equation for a conservative tracer in an orthogonal curvilinear coordinate system (ξ_1, ξ_2, σ) can be written as (Zhang, 1995),

$$h_1 h_2 \frac{\partial(DC)}{\partial t} + \frac{\partial}{\partial \xi_1}(h_2 U_1 DC) + \frac{\partial}{\partial \xi_2}(h_1 U_2 DC) + h_1 h_2 \frac{\partial(\omega C)}{\partial \sigma}$$
$$= \frac{\partial}{\partial \xi_1}\left(\frac{h_2}{h_1} A_H D \frac{\partial C}{\partial \xi_1}\right) + \frac{\partial}{\partial \xi_2}\left(\frac{h_1}{h_2} A_H D \frac{\partial C}{\partial \xi_2}\right) + \frac{h_1 h_2}{D}\frac{\partial}{\partial \sigma}\left(K_H \frac{\partial C}{\partial \sigma}\right) \tag{5-2}$$

where

$$\omega = W - \frac{1}{h_1 h_2}\left[h_2 U_1\left(\sigma \frac{\partial D}{\partial \xi_1} + \frac{\partial \eta}{\partial \xi_1}\right) + h_1 U_2\left(\sigma \frac{\partial D}{\partial \xi_2} + \frac{\partial \eta}{\partial \xi_2}\right)\right]$$
$$-\left(\sigma \frac{\partial D}{\partial t} + \frac{\partial \eta}{\partial t}\right) \tag{5-3}$$

C is the concentration, h_1 and h_2 are the metrics of the unit grid cell in the ξ_1 and ξ_2 directions, and U1 and U2 are the velocity components along the ξ_1 and $\xi_2$directions. Adding:

$$\frac{\partial}{\partial\xi_1}\left[\frac{\partial}{\partial\xi_1}\left(\frac{A_H}{h_1^2}h_1h_2D\right)C\right]+\frac{\partial}{\partial\xi_2}\left[\frac{\partial}{\partial\xi_2}\left(\frac{A_H}{h_2^2}h_1h_2D\right)C\right]$$
$$+\frac{\partial}{\partial\sigma}\left[\frac{\partial}{\partial\sigma}\left(\frac{K_H}{D^2}h_1h_2D\right)C\right] \tag{5-4}$$

on both sides of Equation (5-2) and rearranging it, the transport equation becomes,

$$\frac{\partial}{\partial t}(h_1h_2DC)+\frac{\partial}{\partial\xi_1}\left\{\left[\frac{U_1}{h_1}+\frac{1}{h_1h_2D}\frac{\partial}{\partial\xi_1}\left(\frac{A_H}{h_2^2}h_1h_2D\right)\right]h_1h_2DC\right\}$$
$$+\frac{\partial}{\partial\xi_2}\left\{\left[\frac{U_2}{h_2}+\frac{1}{h_1h_2D}\frac{\partial}{\partial\xi_2}\left(\frac{A_H}{h_2^2}h_1h_2D\right)\right]h_1h_2DC\right\}$$
$$+\frac{\partial}{\partial\sigma}\left\{\left[\frac{\omega}{D}+\frac{1}{h_1h_2D}\frac{\partial}{\partial\sigma}\left(\frac{K_H}{D_2}h_1h_2D\right)\right]h_1h_2DC\right\} \tag{5-5}$$
$$=\frac{\partial}{\partial\xi_1^2}\left(\frac{A_H}{h_1^2}h_1h_2DC\right)+\frac{\partial}{\partial\xi_2^2}\left(\frac{A_H}{h_1^2}h_1h_2DC\right)+\frac{\partial^2}{\partial\sigma^2}\left(\frac{K_H}{D^2}h_1h_2DC\right)$$

Representing the conservative tracer concentration by a collection of particles, the transport problem can also be solved by particle tracking models (Dimou, 1989; Dimou and Admas 1993; Tompson and Gelhar, 1990). As described by those previous studies, the displacement of a particle in a random-walk model is governed by the non-linear Langevin equation (Gardinar, 1985)

$$\frac{d\vec{X}}{dt} = A(\vec{X}t) + B\left(\vec{X},t\right) Z_n \tag{5-6}$$

where $\vec{X}(t)$, $A(\vec{X},t)$ *and* $B(\vec{X}t)$ are vectors, $\vec{X}(t)$ defines the position of a particle, $A(\vec{X},t)$ is the deterministic forces that advect particles, $B(\vec{X},t)$ represents the random forces that lead to particle diffusion (Solomon et al 1994), and Z(t) is a vector of the independent random numbers with zero mean and unit variance.

If $f = f\left(\vec{X},t|\vec{X}_0t_0\right)$ is defined as the conditional probability density function for $\vec{X}(t)$ of particles whose initial position at t_0 is $\vec{X}_0$, the number density will satisfy the Ito-Fokker-Planck equation (Kinzelbach, 1988; Tompson and Gelhar, 1990) in the limit as the number of particles gets very large and the time step used to solve the conservation equation gets very small.

$$\frac{\partial f}{\partial t} + \frac{\partial}{\partial \vec{X}}(Af) = \nabla^2\left(\frac{1}{2}BB^T f\right) \tag{5-7}$$

Therefore, the transport equation (5-5) is equivalent to the Ito-Fokker-Planck equation (5-7) if $f = h_1 h_2 DC$,

$$A \equiv \begin{bmatrix} \frac{U_1}{h_1} + \frac{1}{h_1 h_2 D}\frac{\partial}{\partial \xi_1}\left(\frac{A_H}{h_1^2} h_1 h_2 D\right) \\ \frac{U2}{h_2} + \frac{1}{h_1 h_2 D}\frac{\partial}{\partial \xi_2}\left(\frac{A_H}{h_2^2} h_1 h_2 D\right) \\ \frac{\omega}{D} + \frac{1}{h_1 h_2 D}\frac{\partial}{\partial \sigma}\left(\frac{K_H}{D^2} h_1 h_2 D\right) \end{bmatrix} \tag{5-8}$$

and

$$\frac{1}{2}BB^T \equiv \begin{bmatrix} \frac{A_H}{h_1^2} & 0 & 0 \\ 0 & \frac{A_H}{h_2^2} & 0 \\ 0 & 0 & \frac{K_H}{D^2} \end{bmatrix} \tag{5-9}$$

Thus, $A(\vec{X},t)$, $B(\vec{X},t)$ in Equation (5-6) can be determined and the position $\vec{X}(t)$ of each particle can be calculated.

The numerical algorithm used in the solution of Equation (5-6) is based on the same grid structure and interpolation schemes that are built into ECOMSED. To ensure that the tracking methodology is correct, tests comparing the methodology with analytical solutions were conducted (Zhang 1995). The tests involve long straight channels, with flat and sloping bottoms and circular channels with open and closed lateral boundaries. The methodology was able to obtain the correct answer for all of these test cases.

6.0 Sediment Transport Module

6.1 Introduction

The SED module is HydroQual's state-of-the-art three-dimensional sediment transport model. It realistically simulates cohesive and noncohesive sediments in a variety of aquatic systems (e.g., lakes, rivers, estuaries, bays and coastal waters). In the mid 1990s, concepts of cohesive sediment resuspension, settling and consolidation (Lick et al., 1984) were incorporated within the ECOM modeling framework to create ECOMSED. Over a period of several years, significant modifications were made to ECOMSED to include generalized open boundary conditions, tracers, better bottom shear stresses through a submodel for bottom boundary layer physics, surface wind-wave models, noncohesive sediment transport, and dissolved and sediment-bound tracer capabilities. ECOMSED have been used in a number of sediment transport studies, including: Pawtuxet River in Rhode Island (Ziegler and Nisbet, 1994), Watts Bar Reservoir in Tennessee (Ziegler and Nisbet, 1995), Lavaca Bay in Texas (HydroQual, 1998), Tannery Bay in Michigan (Cannelton Industries, 1998), and Green Bay in Wisconsin (Shrestha et al., 2000).

The SED module is configured to run in conjunction with the hydrodynamic model and a wave model (if waves are included). SED uses the same numerical grid, structure and computational framework as the hydrodynamic model. Sediment dynamics inherent in the model includes sediment resuspension, transport and deposition of cohesive and noncohesive sediments. Cohesive sediments, as referred to herein, represent fine-grained sediments and tailings of particle diameters less than 75 µm (clay-silt range), while noncohesive sediments are coarser particles with diameters between 75 - 500 µm (fine-medium sand range). Coarse sand and gravel, with particle diameters greater than 500 µm, are moved as bed load transport, which is not considered in this model because coarse-grained sediments normally comprise a small fraction of the bed in estuarine and ocean systems. Neglecting bed load will thus have negligible effect on the model results.

Both resuspension and deposition mechanisms depend upon the shear stress induced at the sediment-water interface. Computation of bottom shear stresses is an integral part of the sediment transport processes. The resuspension of sediments from the cohesive bed follows the characteristic equation for resuspension of cohesive sediments, resulting in a certain mass flux of sediments into the water column. Resuspension of sediments from a noncohesive sediment bed, on the other hand, is based on the suspended load theory of van Rijn (1984; 1993). In both cases, the total mass of sediments resuspended into the water column is then apportioned between the fraction of cohesive and noncohesive sediments based on the respective fractions in the bed. Settling of cohesive sediments in the water column is modeled as a function of aggregation (flocculation) and settling. The effect of internal shear rates and water column concentrations on particle aggregation is implicitly defined in the settling velocity formulation. Noncohesive sediments, on the other hand, are

HydroQual Environmental Engineers & Scientists assumed to settle discretely, without interaction with other particles. A unique characteristic of the model is its ability to use experimental results to describe parameters in the formulations of resuspension and deposition, including the effects of aggregation of cohesive sediment particles.

Sediments forming a cohesive sediment bed consolidate with time. A vertically segmented bed model incorporates the effect of consolidation on the sediment bed properties. Forcing functions such as time-varying sediment loads from river inflows, and concentrations of solids at open boundaries can be easily specified. Output from SED includes the spatial and temporal distribution of total suspended solids, water column concentrations of cohesive and noncohesive sediments, bed fractions of cohesive and noncohesive sediments, the mass of sediment deposited/eroded, and subsequent change in bed elevations.

6.2 Governing Equation

The three-dimensional advection-dispersion equation for transport of sediment of size class k (k =1,2) is:

$$\frac{\partial C_k}{\partial t} + \frac{\partial UC_k}{\partial x} + \frac{\partial VC_k}{\partial y} + \frac{\partial (W - W_{s,k})C_k}{\partial z}$$

$$= \frac{\partial}{\partial x}\left(A_H \frac{\partial C_k}{\partial x}\right) + \frac{\partial}{\partial y}\left(A_H \frac{\partial C_k}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_H \frac{\partial C_k}{\partial z}\right) \tag{6-1}$$

Boundary conditions:

$$K_H \frac{\partial C_k}{\partial z} = 0,\ z \to \eta \tag{6-2a}$$

$$K_H \frac{\partial C_k}{\partial z} = E_k - D_k,\ z \to -H \tag{6-2b}$$

where C_k = suspended sediment concentration of size class k (represented by 1 and 2, for cohesive and noncohesive sediments, respectively; u,v,w = velocity in the x, y and z-direction; A_H = horizontal diffusivity; K_H = vertical eddy diffusivity; E_k, D_k = resuspension and deposition flux of size class k; η = water surface elevation above a specified datum; and H = bathymetric depth below the datum. Equation 6-1 is easily transformed to orthogonal curvilinear and sigma coordinates. When so done, it appears similar to Equation (3-55 and 3-56).

6.3 Bottom Shear Stress Computations

The bed shear stress is computed as follows:

$$\tau = \rho u_*^2 \tag{6-3}$$

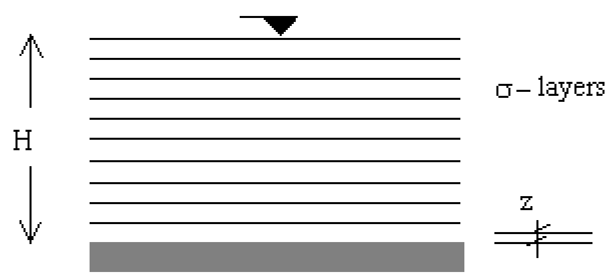
where ρ = density of the suspending medium; and u_* = shear velocity.

For currents only, the shear velocity is defined by the Prandtl-von Karman logarithmic velocity profile

$$u_* = \frac{ku}{\ln\left(\frac{z}{z_0}\right)} \tag{6-4}$$

where k = von Karman constant ≅ 0.40; u = resultant near-bed velocity; z = depth at the center of the bottommost layer; and z_0 = bottom friction specified as input to the model.

For wave-current induced bottom shear stress computations, the reader is referred to Section 7.2.



6.4 Resuspension of Cohesive Sediments

Laboratory experiments (Parchure and Mehta, 1985; Tsai and Lick, 1987; Graham et al., 1992) and field studies (Hawley, 1991; Amos et al., 1992) have revealed that only a finite amount of sediment can be resuspended from a cohesive sediment bed exposed to a constant shear stress as a result of armoring. The amount of fine-grained sediment resuspended from a cohesive sediment bed is given by Gailani et al. (1991) as:

$$\varepsilon = \frac{a_0}{T_d^m}\left(\frac{\tau_b - \tau_c}{\tau_c}\right)^n \tag{6-5}$$

where ε= resuspension potential (mg cm^{-2}); a_0= constant depending upon the bed properties; T_d = time after deposition (days); τ_b= bed shear stress (dynes cm^{-2}); τ_c = critical shear stress for erosion (dynes cm^{-2}); and m, n = constants dependent upon the depositional environment.

The parameters in the above equation are generally determined from shaker studies (Tsai and Lick, 1987). Shaker studies have been conducted in at least twelve aquatic systems (Figure 6-1) and the data obtained from those studies have been used in a number of sediment transport modeling efforts (e.g., Ziegler and Nisbet, 1994; Lick et al., 1995; HydroQual, 1998).

Experimental results show that the total amount of sediment flux into the water column is not resuspended instantaneously but over a time period of approximately one hour (Tsai and Lick, 1987; MacIntyre et al., 1990). The resuspension rate is thus given by

$$E_{tot} = \frac{\varepsilon}{3600 \text{ seconds}} \tag{6-6}$$

where E_{tot} is assumed to be constant until all available sediment is eroded. Once the amount ε has been resuspended, E_{tot} is set to zero until additional sediment is deposited and available for resuspension or until the shear stress increases (Gailani et al., 1991). The resuspension rate of sediments of class k (E_k), which is needed in the governing equation, is then given by

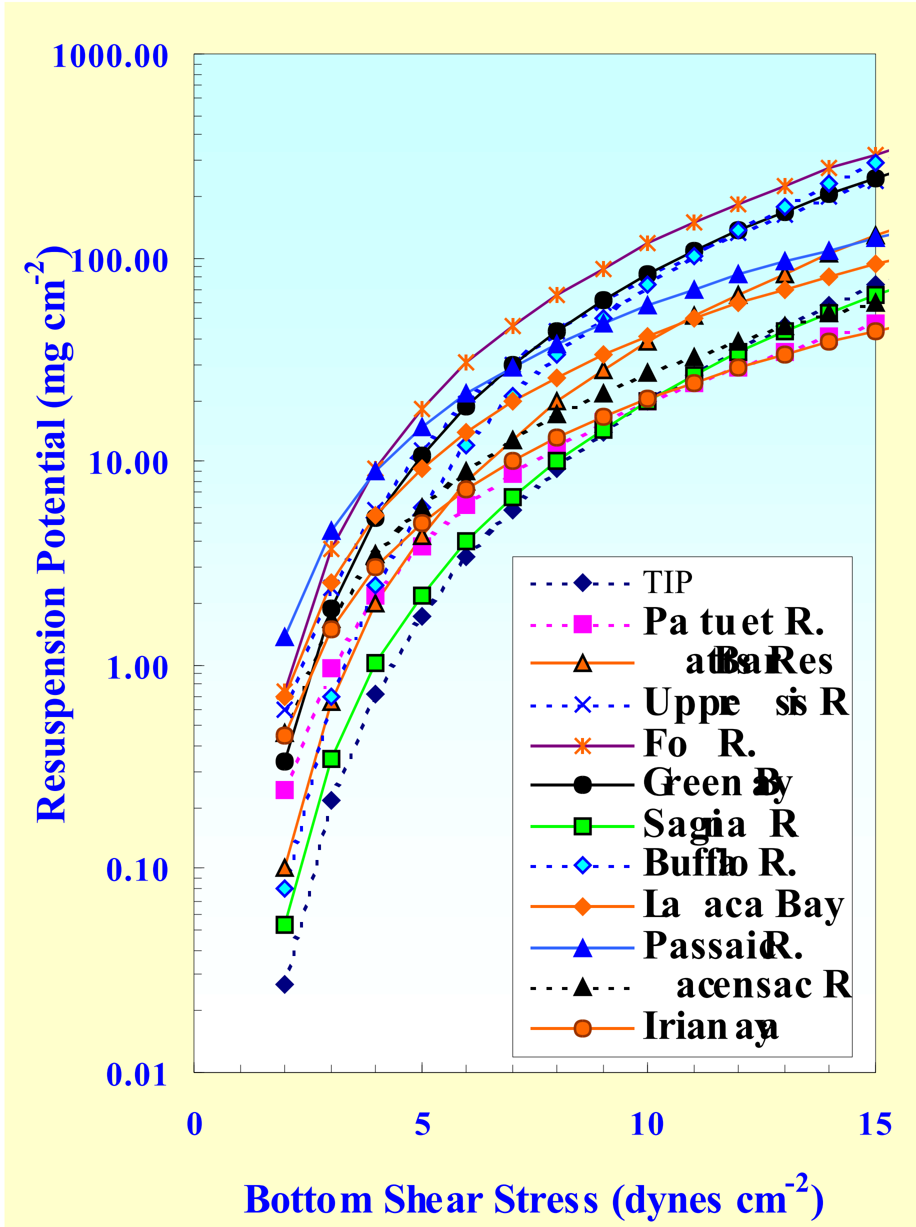
$$E_k = f_k E_{tot} \tag{6-7}$$

where f_k = fraction of class k sediment in the cohesive bed.

6.5 Deposition of Cohesive Sediments

The cohesive nature of particles in suspension causes discrete particles to aggregate, forming flocs that vary in size and settling velocities. Variation in concentration and internal shear stress affects both the size and settling speed of the floc (Burban et al., 1990). Characterization of depositional fluxes in natural water systems can thus be difficult. In SED, the deposition rate for cohesive sediments depends directly upon the sediment flux approaching the bed and the probability of the flocs sticking to the bed, according to the formulation of Krone (1962) as follows:

$$D_1 = -W_{s,1} C_1 P_1 \tag{6-8}$$



Resuspension potential as a function of bed shear stress
for twelve different aquatic systems (based on shaker studies).

FIGURE 6-1

in which D_1 = depositional flux (g cm^{-2} s^{-1}); $W_{s,1}$ = settling velocity of the cohesive sediment flocs (cm s^{-1}); C_1 = cohesive suspended sediment concentration (g cm^{-3}) near the sediment-water interface; and P_1 = probability of deposition.

Settling speeds of cohesive flocs have been measured over a large range of concentrations and shear stresses (Burban et al., 1990). Experimental results show that the settling speed of cohesive flocs is dependent on the product of concentration and the water column shear stress at which the flocs are formed, resulting in the following relationship:

$$W_{s,1} = \alpha \left(C_1 G \right)^{\beta} \tag{6-9}$$

in which $W_{s,1}$, C_1, and G are expressed in m day^{-1}, mg L^{-1}, and dynes cm^{-2}, respectively. The above equation implicitly incorporates the effect of internal shear stress (G) on aggregation and settling. For saltwater suspensions, analysis of Burban et al. (1990) data revealed values of α and β of 2.42 and 0.22, respectively. Figure 6-2 shows a comparison of Equation 6-9 using the above parametric values and Burban et al. data.

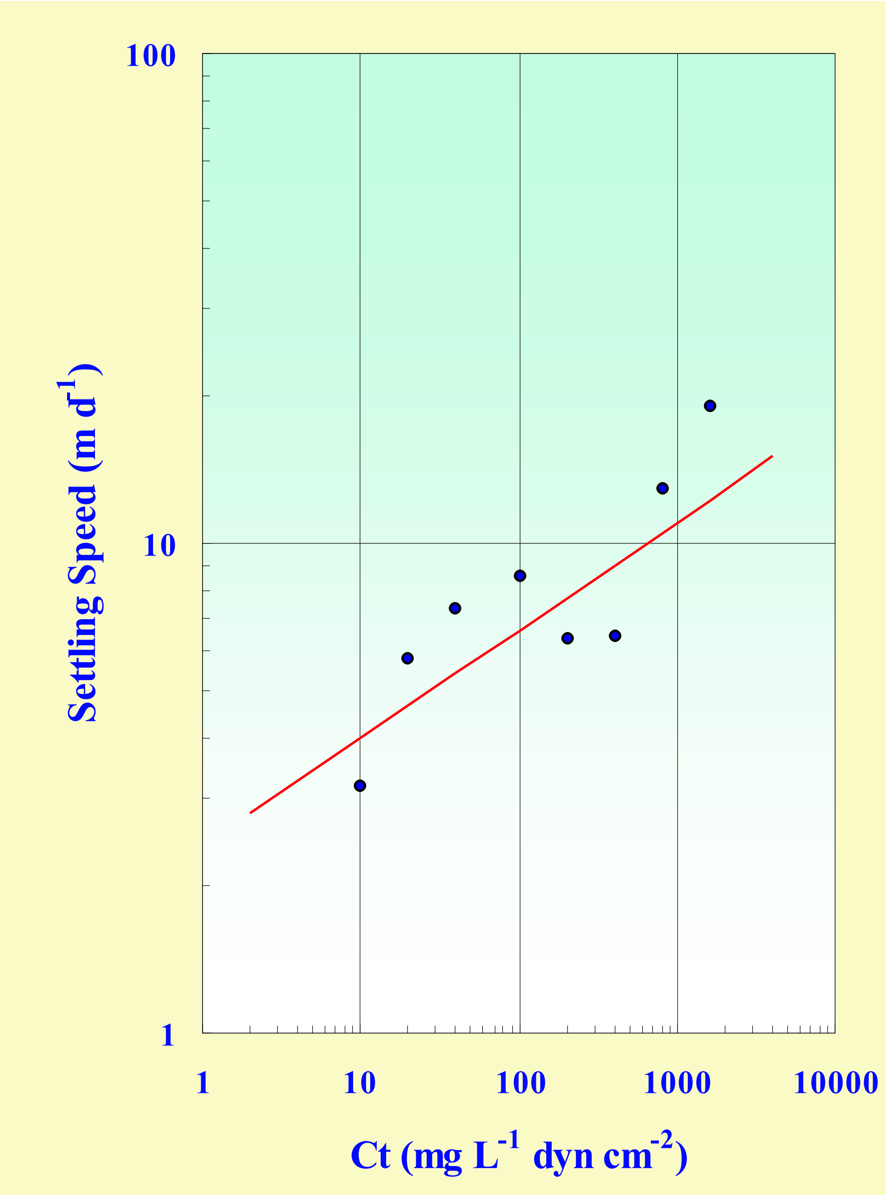
The water column shear stress (G) is computed from the hydrodynamic output (i.e., current velocity and vertical eddy viscosity) as follows:

$$G = \rho K_M \left[\left(\frac{\partial u}{\partial z} \right)^2 + \left(\frac{\partial v}{\partial z} \right)^2 \right]^{1/2} \tag{6-10}$$

where K_M = vertical eddy viscosity, and ρ = density of the suspending medium.

The probability of deposition (P_1) parameterizes the effects of floc size heterogeneity and near-bed turbulence on the deposition rate. The complex interactions occurring at the vicinity of the sediment-water interface cause only a certain fraction of settling sediments to actually become incorporated into the bed (Krone, 1962; Partheniades, 1992). Krone (1962) was the first to develop a relationship for the probability of deposition

$$P_1 = \begin{cases} 1 - \dfrac{\tau_b}{\tau_d}, & \tau_b \le \tau_d \\ 0, & \tau_b > \tau_d \end{cases} \tag{6-11}$$



Settling speed function for cohesive sediments settling in saltwater compared to mean values of Burban et al., (1990) data.

FIGURE 6-2

where τ_b = bottom shear stress (dynes cm^{-2}), and τ_d = critical shear stress for deposition (dynes cm^{-2}). The above formulation has been incorporated into several cohesive sediment transport models including: STUDH (Ariathurai and Krone, 1976); TSEDH (Shrestha and Orlob, 1994); CSTM-H (Hayter and Mehta, 1986); and SEDZL (Ziegler and Nisbet, 1996). The critical shear stress for deposition (τ_d) is typically used as a calibration parameter in modeling studies because it is not well known. Limited experimental data indicate τ_d ranges between 0.6 and 1.1 dynes cm^{-2}, depending upon sediment concentration and type (Krone, 1962; Mehta and Partheniades, 1975). Partheniades (1992) developed an empirically based formulation that realistically represents the effects of variable floc size on probability of deposition. This can be expressed as:

$$P_1 = 1 - \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Y} e^{-\frac{\omega^2}{2}} d\omega \tag{6-12}$$

where ω = dummy variable, and

$$Y = 2.04 \log\left[0.25\left(\frac{\tau_b}{\tau_{b,min}} - 1\right) e^{1.27 \tau_{b,min}}\right] \tag{6-13}$$

where $\tau_{b,min}$ = bottom shear stress below which P_1 = 1 (dynes cm^{-2}).

The probability integral in Equation (6-12) can be accurately approximated by a cubic equation, yielding (for $0 \le Y < \infty$).

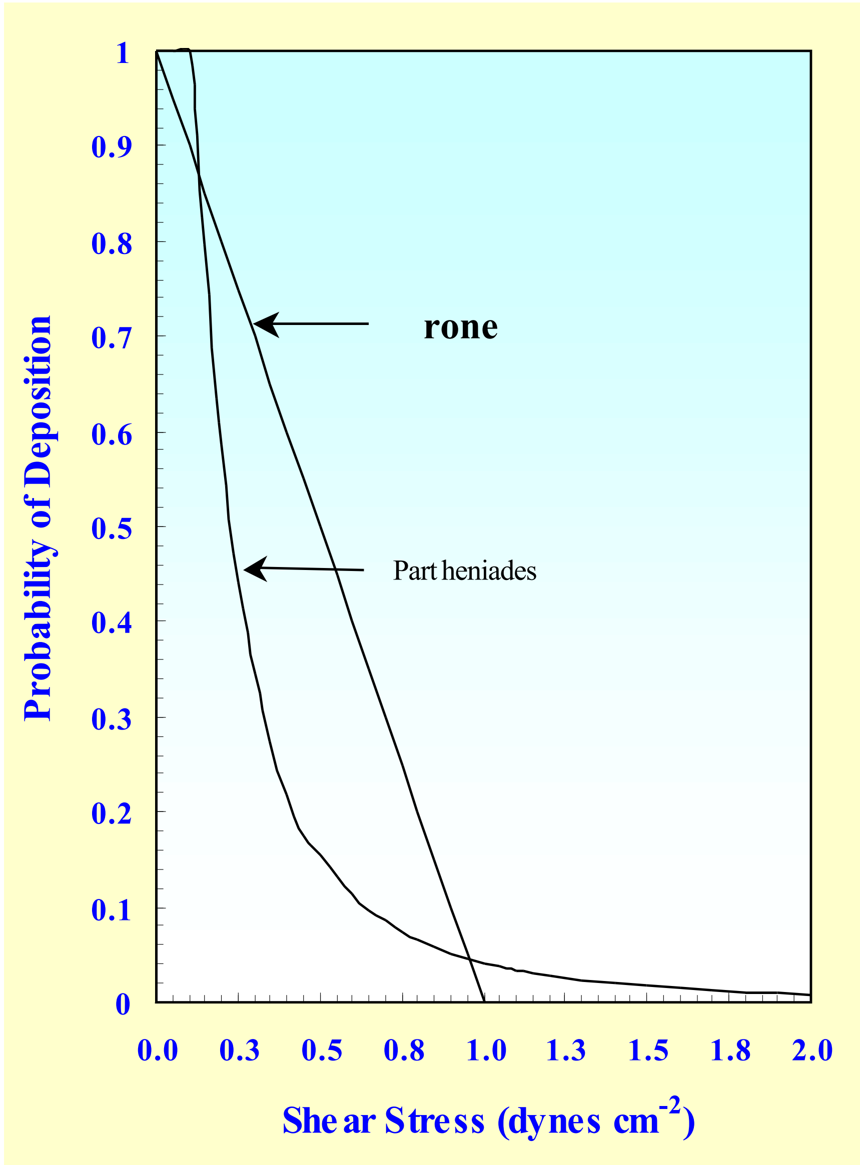
$$P_1 = \frac{1}{\sqrt{2\pi}} e^{-\frac{Y^2}{2}} \left(0.4362z - 0.1202z^2 + 0.9373z^3\right) \tag{6-14}$$

where:

$$z = \left(1 + 0.3327Y\right)^{-1} \tag{6-15}$$

for $\quad Y < 0, P_1(-Y) = 1 - P_1(Y)$

There are two primary differences between the Krone and Partheniades probability of deposition formulations as shown in Figure 6-3. First, the Partheniades approach results in significantly higher deposition than Krone's method in the low shear stress region, with P_1 = 1 for shear stresses up $\tau_{b,min}$. Secondly, Partheniades' formulation allows finite deposition to occur, even for higher shear stresses.



Comparison of Krone (1962) and Parpheniades (1992) formulations for the probabilities of deposition of cohesive sediments.

FIGURE 6-3

6.6 Cohesive Sediment Bed Model

To realistically simulate the effects of sequential deposition and erosion, and the subsequent change in bed properties such as thickness and erodibility characteristics, a vertically segmented model of the cohesive sediment bed is constructed as shown in Figure 6-4. This is achieved by discretizing the sediment bed into seven layers. Each layer of the bed is characterized by a dry density (ρ_d), a critical shear stress for erosion (τ_{cr}), and an initial thickness. The "time after deposition" for each layer increases linearly from one day at the surface, which is composed of freshly deposited material, to seven days in the bottom layer. Previous laboratory results (Tsai and Lick, 1987; MacIntyre et al., 1990) have indicated that consolidation effects on resuspension are minimal after seven days of deposition, hence deposited sediments aged seven days or more are assumed to be seven days old. The resuspension potential equation shows that each layer decreases with time of consolidation (T_d), in accordance with the $(T_d)^{-m}$ term. The layered bed model conserves mass, with resuspension and deposition fluxes occurring only at the bed level. During the course of a simulation, the bed model accounts for changes in thickness, the mass of cohesive and noncohesive sediments in each layer, resulting from resuspension and deposition at the sediment-water interface.

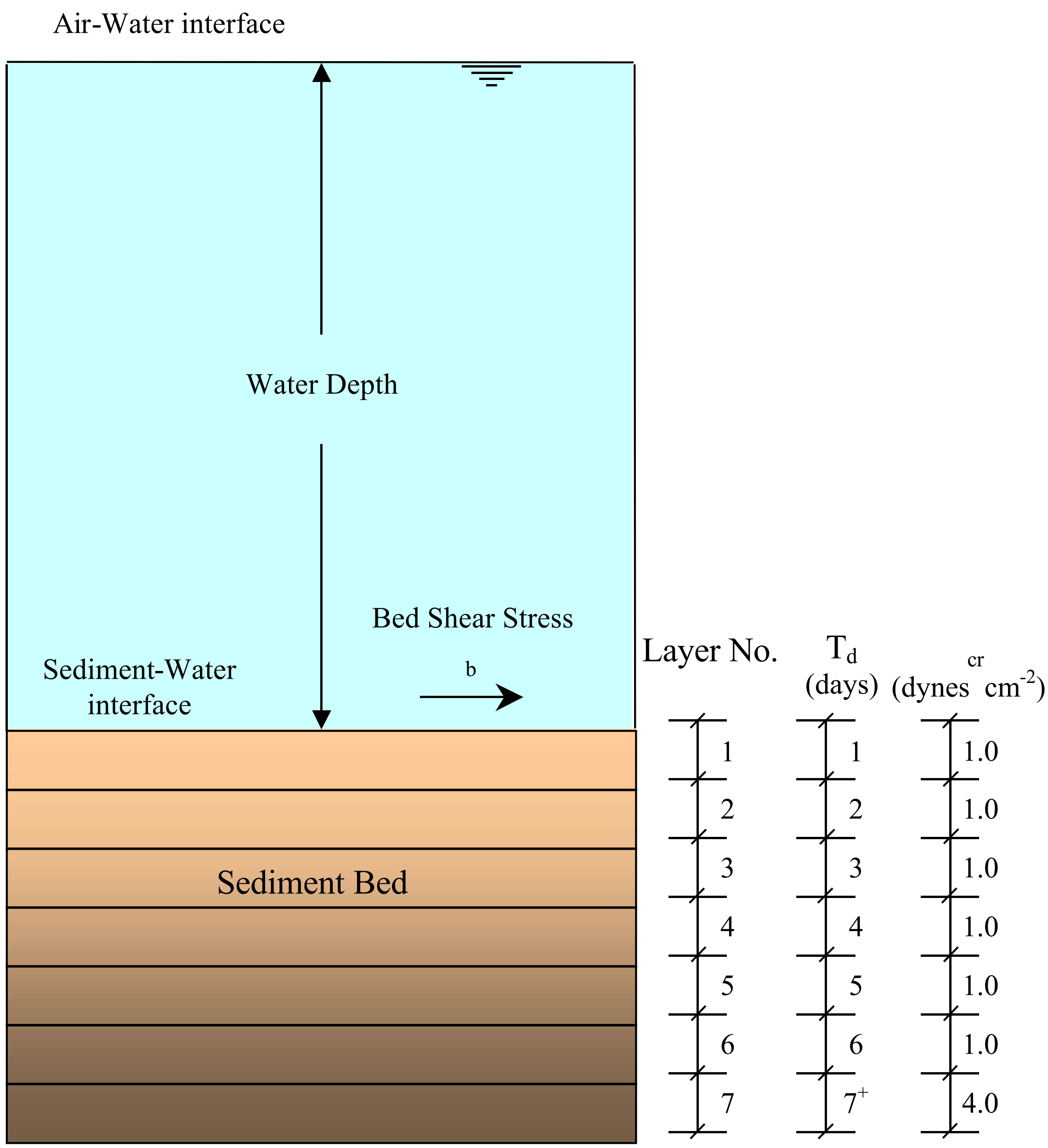
6.7 Resuspension of Noncohesive Sediments

The resuspension of sediment from a non-cohesive sediment bed is calculated using a procedure developed by van Rijn (1984). The van Rijn method has been shown to yield good results for predicting suspended load of fine sands (van Rijn, 1984; Garcia and Parker, 1991; van Rijn et al., 1993; Ziegler and Nisbet, 1994). Only a brief overview of the van Rijn method will be presented here, for details of the calculation procedure see van Rijn (1984). The first step in the procedure is to compare the bed-shear velocity u_* with the critical bed-shear velocity, $u_{*,\,crbed}$ based on the local D_{50} (Figure 5-16), according to Shields criterion for initiation of motion. Suspended transport will only occur if the bed-shear velocity exceeds both the Shields criterion for bed load movement and the critical bed-shear velocity for suspension, $u_{*,\,crs}$. If resuspension does occur, the local D_{50} and bed-shear velocity, u_*, are used to determine the reference concentration at a height of z = a above the sediment bed, C_a. Finally, the local values of u_*, D_{50} and C_a are used to calculate the suspended load transport rate.

Using the van Rijn method, the following procedure is adopted to calculate the suspended load transport.

1. Compute the critical bed shear velocity for initiation of motion

A non-dimensional particle parameter is first introduced:



Schematic of the sediment bed model.

FIGURE 6-4

$$D_* + \left[\frac{(s-1)g}{\upsilon^2}\right]^{1/3} D_{50} \tag{6-16}$$

where s = specific gravity of the particles; g = gravitational acceleration; υ = kinematic viscosity; and D_{50} = representative particle diameter in the bed.

The critical bed shear velocity for initiation of bed motion is then computed using the Shields criteria as

$$u_{*,crbed} = \left[(s-1)gD_{50}\theta_{cr}\right]^{1/2} \tag{6-17}$$

where θ_{cr} = critical mobility parameter which is defined as

$$\begin{array}{ll} \theta = 0.24\, D_*^{-1} & D_* \le 4 \\ \theta_{cr} = 0.14\, D_*^{-0.64} & 40 < D_* \le 10 \\ \theta_{cr} = 0.04\, D_*^{-0.10} & 10 < D_* \le 20 \\ \theta_{cr} = 0.013\, D_*^{-0.29} & 20 < D_* \le 150 \\ \theta_{cr} = 0.055 & D_* > 150 \end{array} \tag{6-18}$$

2. Compute the critical shear velocity for resuspension

The critical shear velocity for resuspension is given by

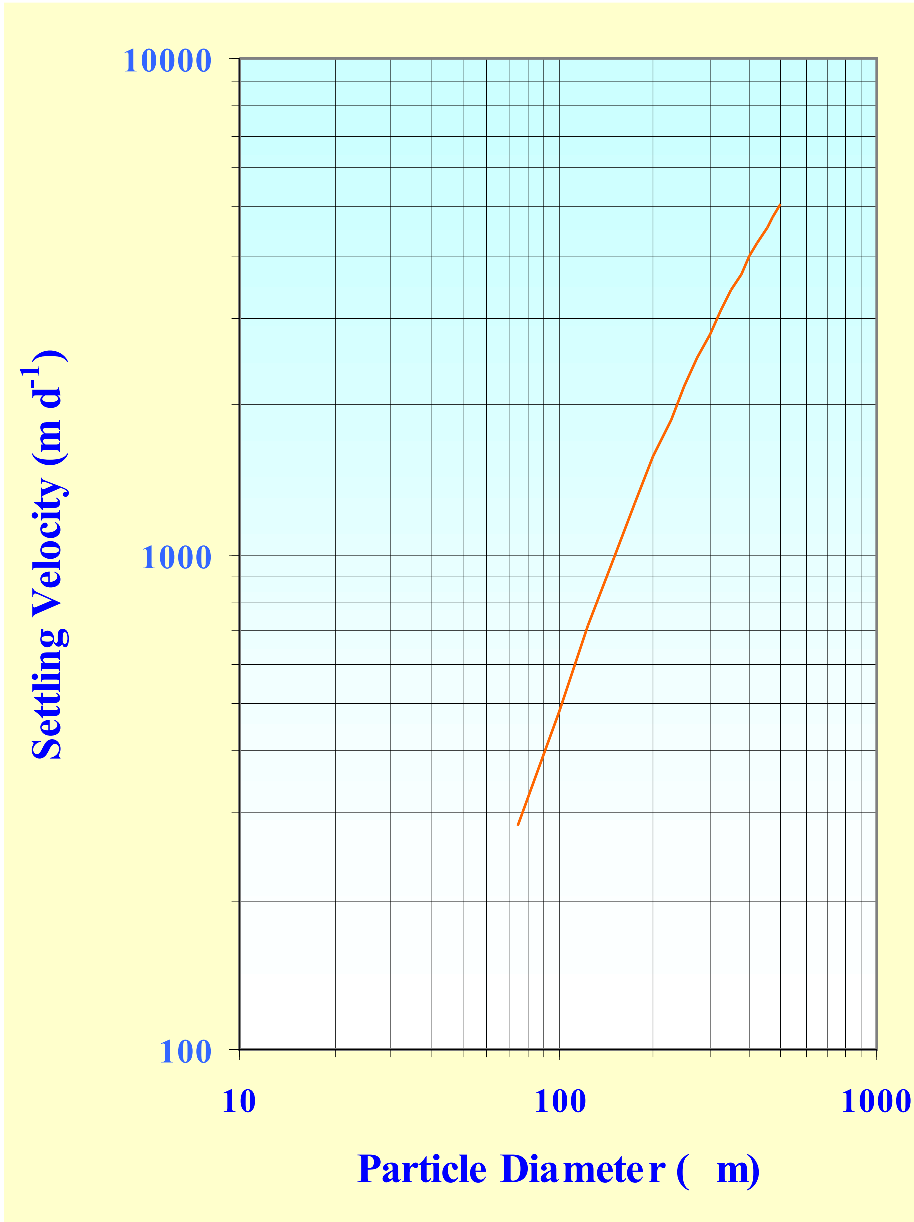
$$u_{*,crsus} = W_{s,2} \tag{6-19}$$

where $W_{s,2}$ = settling velocity of the noncohesive suspended sediment. The settling velocity is specified as input to the model and is computed from the effective particle diameter (D_k) of the suspended sediment using the formulation of Cheng (1997).

$$W_{s,2} = \frac{\upsilon}{D_k}\left[\left(25 + 1.2D_*^2\right)^{0.5} - 5\right]^{1.5} \tag{6-20}$$

where D_* = non-dimensional particle parameter as shown in Eq.(5-16) with effective particle diameter D_k.

The dependence of $W_{s,2}$ on D_k is illustrated in Figure 6-5, which shows that the settling speeds of suspended sand particles (i.e., $75<D_k<500\mu m$) range from about 3,300 – 59,000 μms^{-1} (i.e., ~ 280 to 5,000 md^{-1}).



Settling velocity as a function of particle diameter for noncohesive sediments (based on Cheng, 1997 formulation).

FIGURE 6-5

3. Compute the bed shear velocity

The near-bed shear velocity due to the flow is computed as in Eq. (5-4).

$$u_* = \frac{ku}{\ln\left(\frac{z}{z_0}\right)} \tag{6-21}$$

4. Suspended Load Transport

If the bed shear velocity (u_*) is less than the threshold for motion ($u_{*,crbed}$) or less than the critical shear velocity for resuspension then deposition occurs . If u_* exceeds $u_{*,crbed}$ and $u_{*,crsus}$, the sediment flux is from the bed to the lower layer of the water column. The suspended load transport is then computed as follows:

<u>Compute the transport stage parameter</u>

$$T = \frac{u_*^2}{u_{*,crbed}^2} - 1 \tag{6-22}$$

<u>Compute the reference level above bed</u>

$$a = \max\ (\ 0.01h,\ k_s) \tag{6-23}$$

where h = water depth, and k_s = Nikuradse roughness height.

$$C_a = \frac{0.015 D_k T^{1.5}}{a D_*^{0.3}} \tag{6-24}$$

<u>Compute the β-factor</u>

$$\beta = 1 + 2\left(\frac{W_s}{u_*}\right)^2 \quad \text{for } 0.1 < \frac{W_s}{u_*} < 1 \tag{6-25}$$

<u>Compute the ϕ-factor</u>

$$\phi = 2.5\left(\frac{W_s}{u_*}\right)^{0.8}\left(\frac{C_a}{C_0}\right)^{0.4} \text{ for } 0.01 < \frac{W_s}{u_*} \leq 1 \tag{6-26}$$

where C_o = maximum volumetric bed concentration = 0.65.

<u>Compute the suspension parameter</u>

$$Z' = Z + \phi = \frac{W_s}{\beta k u_*} + \phi \tag{6-27}$$

<u>Compute the F-factor</u>

$$F = \frac{\left(\frac{a}{h}\right)^{Z'} - \left(\frac{a}{h}\right)^{1.2}}{\left(1 - \frac{a}{h}\right)^{Z'}(1.2 - Z')} \tag{6-28}$$

<u>Compute the suspended load transport</u>

$$q_s = F\,z\,u\,C_a \tag{6-29}$$

where z = depth of the lowest σ-layer

<u>Compute resuspension flux from the bed</u>

The resuspension flux is calculated as the difference between the total suspended load transport (or the carrying capacity of the flow) and the existing horizontal sediment flux in the lowest σ-layer. If this difference is greater than zero, erosion occurs, whereas if the difference is less than zero, deposition occurs. It is therefore possible to have deposition even if u_* exceeds $u_{*,crbed}$ and $u_{*,crsus}$.

In the model, resuspension is computed as

$$E = \frac{(s q_s - q z C_z)\Delta t}{\Delta x \Delta y} \tag{6-30}$$

where C_z = concentration of suspended sediment in the lowest σ layer; Δt = time step; and Δx Δy = surface area of bottom.

6.8 Deposition of Noncohesive Sediments

When the bed shear velocity (u_*) is less than the critical value ($u_{*,crbed}$ or $u_{*,crsus}$), then the sediments in the water column deposit to the bed according to the formula:

$$D_2 = W_{s,2} C_2 \tag{6-31}$$

where D_2 = noncohesive sediment depositional flux; $W_{S,2}$ = settling velocity; and C_2 = near-bed suspended sediment concentration.

6.9 Noncohesive Sediment Bed Armoring

An important assumption in the van Rijn procedure is that the bed sediments are homogeneous. A non-cohesive sediment bed is generally comprised of a wide range of particle sizes, from fine sands that are suspendable to coarse sands and gravels that are only transported as bed load. Bed armoring occurs when fine sands are eroded from a heterogeneous sediment bed and the coarser material that cannot be resuspended remains on the bed surface. During erosion, the suspendable sediments in the near-surface layer (referred to as the active layer) are depleted and a layer of coarse, non-suspendable sediments forms. Continuous depletion of suspendable sediments in the active layer will eventually reduce the erosion rate to zero, at which point the active layer is composed entirely of non-suspendable sediments, i.e., coarse sand and gravel. The sediment bed then becomes armored (Shen and Lu, 1983; Karim and Holly, 1986; van Niekerk et al., 1992).

The bed armoring process can be modeled by assuming that the sediment bed is composed of an active layer, which interacts with the water column, and a parent bed layer, which is below the active layer (Karim and Holly, 1986; van Niekerk et al., 1992). Resuspension of bed sediments is assumed to occur only from the active layer such that

$$E_2 = f_a E \tag{6-32}$$

where f_a = fraction of sediment in the active layer that is resuspendable; and E = resuspension rate for a homogeneous bed calculated using the van Rijn method. The fraction of resuspendable sediment in the parent bed (f_p) is determined from the initial grain size distribution data. The active layer thickness is determined using a modified form of the equation proposed by van Niekerk et al., (1992).

$$T_a = \frac{D_{50}\tau}{5\tau_{c50}} \tag{6-33}$$

where τ = bed shear stress; and τ_{c50} = critical shear stress necessary to initiate bed load motion for sediment with bed D_{50} and is calculated using Shields criteria.

Changes in the composition of the active layer are made following the method of Karim and Holly (1986).

7.0 Wave Module

7.1 Introduction

Prediction of the wave dynamics is based on a parametric type wave model developed for this study in an orthogonal curvilinear coordinate system. The model is based on a Great Lakes Environmental Research Laboratory (GLERL) wave model developed by Donelan (1977) and modified by Schwab et al. (1984). This is a parametric type model based on the conservation of momentum applied to deep water waves (ratio of water depth to wave length greater than 0.5). The governing equations describe the local momentum balance rather than the transport of energy. The momentum input to the model results from drag on the waves, which depends on the wave height and the differential speeds between the wave and the wind. An important feature of this model is the provision for a "fossil" wave field that may be left behind by a rapidly changing wind (Schwab et al., 1984). The model determines its computational time step dynamically based on the maximum winds for each hour. Given a description of the coastal bathymetry and a two dimensional, time-dependent wind field, the model predicts significant wave heights, wave periods, and wave directions.

The original GLERL model has successfully been applied to Lake Michigan (Liu et al., 1984) and Lake Erie (Schwab et al., 1984). It is also being used in the Great Lakes Coast Watch program. Additional application of the model in an estuarine environment includes the study on the prediction of waves in Chesapeake Bay (Lin et al. 1999). The model has also been compared against four currently available and well-recognized wave models (ACES, HISWA, WAVD and SWAN described by Leenknecht et al. (1992), Booij and Holthuijsen (1995), Resio and Perrie (1989) and Holthuijsen et al. (1993), respectively. The GLERL model performed quite well in simulating the wave field generated by tropical storm Danielle over northern Chesapeake Bay in September 1992. It gave the best prediction of significant wave height and showed a good response to a sharply turning wind.

The current wave model differs from the original GLERL model in two ways. First, the wave model is transformed to a curvilinear coordinate system to take advantage of the orthogonal curvilinear grid of the ECOM hydrodynamic model used in the present study. Second, it incorporates the frictional effect on the wave as it moves into shallower water.

The formulation of the wave prediction model is based on the assumption that the potential and kinetic energies are equally partitioned and that the deep water linear wave theory applies such that the group velocity is one half the phase speed. The transformation of the wave momentum equation into an orthogonal curvilinear coordinate system ($_1$, $_2$, z) as shown in Figure 6-1, yields the following momentum conservation equations:

$$\frac{\partial M_{\xi_1}}{\partial t} + \frac{1}{h_1 h_2}\left[\frac{\partial (h_2 T_{\xi_1 \xi_1})}{\partial \xi_1} + \frac{\partial (h_1 T_{\xi_1 \xi_2})}{\partial \xi_2}\right] = \frac{\tau^w_{\xi_1}}{\rho_w} \tag{7-1}$$

$$\frac{\partial M_{\xi_2}}{\partial t} + \frac{1}{h_1 h_2}\left[\frac{\partial (h_2 T_{\xi_1 \xi_2})}{\partial \xi_1} + \frac{\partial (h_1 T_{\xi_2 \xi_2})}{\partial \xi_2}\right] = \frac{\tau^w_{\xi_2}}{\rho_w} \tag{7-2}$$

The momentum components M $_1$ and M $_2$ are defined as

$$M_{\xi 1} = g \int_0^\infty \int_0^{2\pi} \frac{F(f, \theta)}{C(f)} \cos\theta \, d\theta \, df \tag{7-3}$$

and

$$M_{\xi 2} = g \int_0^\infty \int_0^{2\pi} \frac{F(f, \theta)}{C(f)} \sin\theta \, d\theta \, df \tag{7-4}$$

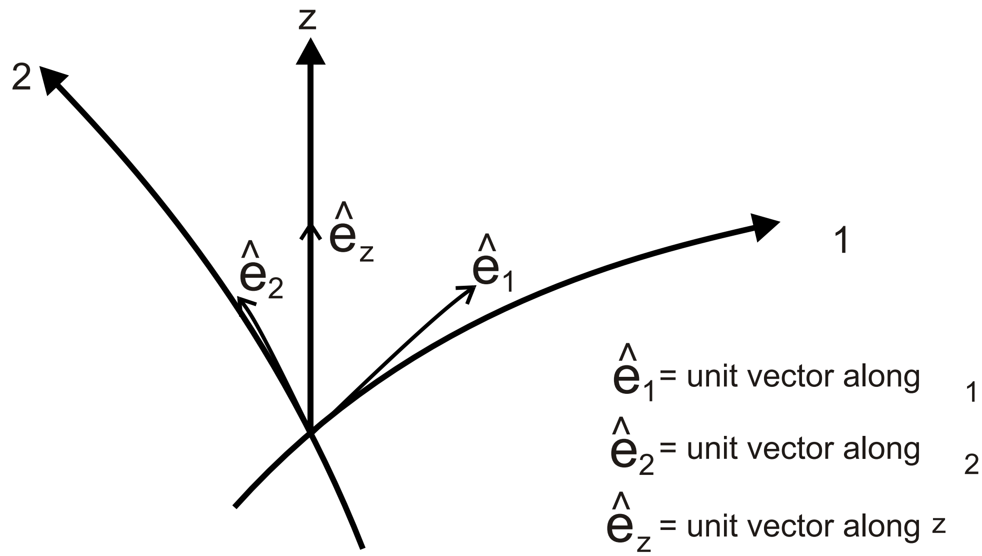
Here F(*f*, θ) is the wave energy spectrum as a function of frequency (*f*) and direction (θ) and *C(f)* is the phase speed. τ_{ξ_1} and τ_{ξ_2} are wind stress along ξ_1 and ξ_2 directions, ρ_w is the density of air.

The wave momentum flux $T_{\xi_1\xi_1}$, $T_{\xi_1\xi_2}$, and $T_{\xi_2\xi_2}$, are defined as follows:

$$T_{\xi_1\xi_1} = \frac{g}{2} \int_0^\infty \int_0^{2\pi} F(f, \theta) \cos^2\theta \, d\theta \, df \tag{7-5}$$

$$T_{\xi_1\xi_2} = T_{\xi_2\xi_1} = \frac{g}{2} \int_0^\infty \int_0^{2\pi} F(f, \theta) \sin\theta \cos\theta \, d\theta \, df \tag{7-6}$$

$$T_{\xi_2\xi_2} = \frac{g}{2} \int_0^\infty \int_0^{2\pi} F(f, \theta) \sin^2\theta \, d\theta \, df \tag{7-7}$$



Curvilinear coordinate system.

FIGURE 7-1

Considering the wave energy is distributed about the mean angle θ_0 as cosine square and there is no energy for $|\theta-\theta_0|>\pi/2$,

$$F(f,\theta)=\frac{2}{\Pi}E(f)\cos^2(\theta-\theta_0) \tag{7-8}$$

Here E(f) is the spectral wave energy.

If θ_0 is independent of frequency, the momentum fluxes may be expressed in terms of θ_0 and the variance as:

$$\sigma^2=\int_0^\infty E(f)\,df \tag{7-9}$$

Integration of Equations 7-5 to 7-7 results

$$T_{\xi_1\xi_1}=g\left(\frac{\sigma^2}{4}\cos^2\theta_0+\frac{\sigma^2}{8}\right) \tag{7-10}$$

$$T_{\xi_1\xi_2}=T_{\xi_2\xi_1}=g\left(\frac{\sigma^2}{4}\cos\theta_0\sin\theta_0\right) \tag{7-11}$$

$$T_{\xi_2\xi_2}=\left(g\frac{\sigma^2}{4}\sin\theta_0+\frac{\sigma^2}{8}\right) \tag{7-12}$$

It is interesting to note here that Equations 7-10 to 7-12 expressing the momentum flux are independent of the spectral shape. Moreover, $\sigma^2/8$ in Equations 7-10 and 7-12 represents an isotropic term, which causes a wave pressure gradient from areas of high waves toward areas of low waves.

The relation between the variance σ^2 and the momentum components in Equations 7-1 and 7-2 can be obtained by fitting all fetch-limited frequency spectra to JONSWAP function (Hasselmann et al., 1975):

$$E(f)=\alpha g^2(2\Pi)^{-4}f^{-5}\exp\left\{-\frac{5}{4}\left(\frac{f}{f_p}\right)^{-4}\right\}\cdot\left\{3.3^{\exp\left[-\frac{(f-f_p)^2}{2\beta^2 f_p^2}\right]}\right. \tag{7-13}$$

= 0.07, for f f_p
= 0.09, for $f > f_p$

Two scale parameters f_p and are peak frequency and the Phillips constant respectively. Donelan (1977) suggested an empirical relation between these two parameters which successfully eliminates the dependency on the fetch length described in the original JONSWAP formula. This relations is as follows:

$$\alpha = 0.0097 \left(\frac{U}{C_p} \right)^{2/3} \tag{7-14}$$

Here $C_p = g/2\pi f_p$ and U is wind speed 10 m above sea level.

Integrating equation 7-13 and 7-14 yields

$$\frac{\sigma^2}{|M|} = \frac{C_p}{g} \tag{7-15}$$

and

$$\sigma^2 = 0.30 \alpha g^2 (2\pi)^{-4} f_p^{-4} \tag{7-16}$$

Here |M| is the magnitude of momentum vectors M_{ξ_1} and M_{ξ_2}.

Now the numerical solution is sought to solve equations 7-1, 7-2 (substituting equation 7-10 to 7-12) for variance (σ^2), wave period $(T = \frac{2\pi}{f_p})$ and direction θ. The significant wave height, H_s, is then computed using the following relation.

$$H_s = 4\sigma \tag{7-17}$$

7.2 Wave Induced Bottom Shear Stress

Bed shear stresses due to currents and waves are crucial for calculating sediment resuspension and deposition fluxes (Fredsoe and Deigaard, 1991; van Rijn, 1993). This stress is generally higher than that induced by currents computed by hydrodynamic processes (Grant and Madsen, 1979; Glenn and Grant, 1987). Hydrodynamic models are based on processes with much longer time scales. Wind waves, on the other hand, are high frequency short waves. These waves are generally considered deep water waves, represented as governing equations (USCOE, 1984; Fredsoe and Deigaard, 1991) which are different than the shallow water wave equations. The computation of bottom shear stress due to wave induced currents is presented below.

The hydrodynamic model provides the near bottom current velocity (U), direction of current (θ_c), and the total water depth (h). The wave model predicts the significant wave height (H_s), period (T) and direction (θ). Linear wave theory is used to translate the wave parameters (H_s and T) into a near-bed peak orbital velocity (U_p) and peak orbital amplitude (A_p) as follows

$$U_p = \frac{\pi H_s}{T \sinh\left(2\pi \frac{h}{L}\right)} \tag{7-18}$$

$$A_p = \frac{H_s}{2 \sinh\left(2\pi \frac{h}{L}\right)} \tag{7-19}$$

where the wave length (L) is given by

$$L = C_o T \tag{7-20}$$

and the shallow water wave speed (C_o) is

$$C_o = \sqrt{g h} \tag{7-21}$$

in which g is the gravitational acceleration.

The Grant-Madsen wave-current model (Grant and Madsen, 1979; Glenn and Grant, 1987) is then used to calculate bottom shear stresses due to currents and waves. Inputs to the model are:

U	=	magnitude of the near bottom current velocity
Φ	=	θ - θ_c, the difference between wave and current direction
U_p	=	near-bed peak orbital velocity
A_p	=	near-bed peak orbital amplitude
z_0	=	effective bottom roughness height

Output from the model is the bottom shear velocity (u_*). The bed shear stress (τ_b) is then computed as

$$\tau_b = \rho\, u_*^2 \tag{7-22}$$

where ρ = density of water. In the absence of wave, u_* is a function of U only. The details of bed shear stress computations without wave and current interaction can be found in Blumberg and Mellor (1987).

Surface wind waves can significantly increase bed shear stresses as pointed out in previous studies (Fredsoe and Deigaard, 1991; van Rijn, 1993). The magnitude of the bed shear stress is a function of the characteristics of wind wave field, which is highly variable in time. Bed shear stresses due to the combined effects of waves and currents can result in stresses that are two orders of magnitude higher than stresses resulting from currents alone. These higher stresses may result in significantly different bed erosion and sediment transport. Therefore, effects of wind generated waves may be an important mechanism that should be included in the current modeling framework.

8.1 Finite Difference Formulation

The governing equations form a set of simultaneous partial differential equations which cannot be solved using known analytic methods. The equations require numerical computational methods using discretized equations on a grid. In anticipation of constructing the finite differencing scheme, the governing equations have been cast into their flux form. This is to insure that certain integral constraints are maintained by the differencing.

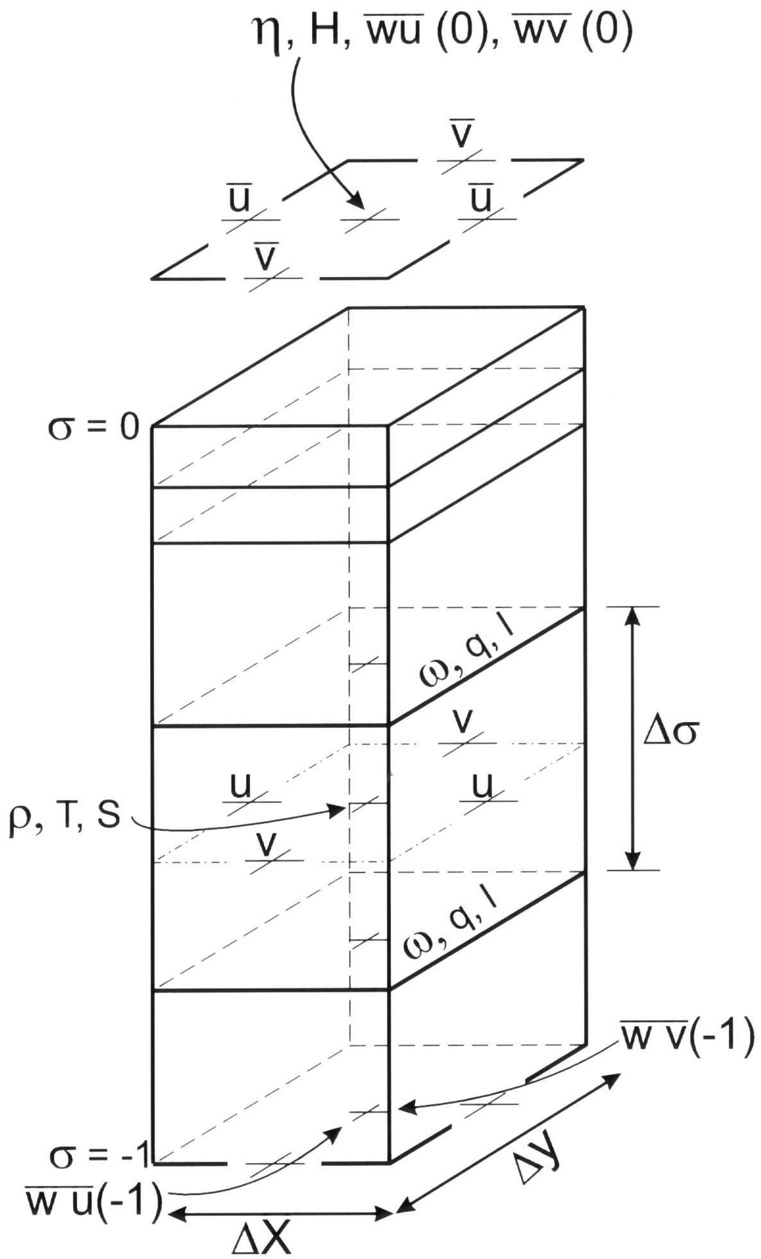
8.1.1 Finite Differencing

The relative positions of the variables on the staggered computation "C" grid are shown in Figure 3-3. The staggered arrangement uses U at points to the east and west of the point where η and H are defined and V at points to the north and south of the η and H points. This type of grid has been shown by Batteen and Han [1981] to be the most effective grid for high resolution models. The Δx and Δy are the constant horizontal grid spacings and $\Delta\sigma$ is the vertical increment which varies in thickness to accommodate more resolution near the surface and bottom.

The finite difference equations used in ECOM can be demonstrated to be of second order accuracy in space and time and to conserve energy, temperature, salinity, mass, and momentum. Finally, the model's computer code has been deliberately designed to be economical on modern array processing computers.

8.1.2 Subgrid Scale Parameterizaton

Horizontal mixing coefficients for both momentum and heat/salinity are used to parameterize all processes which are not resolved on the numerical grid. Typically, these mixing coefficients are chosen such that they are sufficient to provide minimal smoothing without excessive damping of real oceanographic processes. Since the numerical grid can be non-uniform, the mixing coefficients must vary proportionally in order to maintain a uniform grid Reynolds number. The parameterization suggested by Smagorinsky (1963), which also depends on the horizontal grid sacing, has been used in the model.



The locations of the variables on the finite difference grid.

FIGURE 8-1

The terms related to small-scale mixing processes not directly resolved by the model are parameterized as horizontal diffusion as described in Equations (3-39) and (3-44) and calculated according to Smagorinsky 91963):

$$A_M = \alpha \, \Delta x \, \Delta y \left[\left(\frac{\partial U}{\partial x} \right)^2 + \left(\frac{\partial V}{\partial y} \right)^2 + \frac{1}{2} \left(\frac{\partial U}{\partial y} \right) + \left(\frac{\partial V}{\partial x} \right)^2 \right]^{1/2} \qquad (8\text{-}1)$$

and where the notation is based upon Cartesian coordinates and variable names are those used conventionally. The parameter α is typically equal to 0.10 and has ranged from 0.01 to 0.5 in various applications. Here $A_H = A_M$, but the code has provisions to relax this constraint

8.1.3 Stability Constraints

The leap-frog differencing used for the time stepping introduces a tendency for the solution at even and odd time steps to split. This time splitting is removed by a weak filter [Asselin, 1972] where the solution is smoothed at each time step according to

$$F_s^n = F^n + \frac{\alpha}{2}\left(F^{n+1} - 2F^n + F_s^{n-1}\right) \qquad (8\text{-}2)$$

where $\alpha = 0.05$ and F_s is a smoothed solution.

This technique introduces less damping than either the Euler-backward or forward stepping techniques.

The Courant-Friedrichs-Levy (CFL) computational stability condition on the vertically integrated, external mode, transport equations limits the time step as shown by Blumberg and Mellor [1981a] according to

$$\Delta t \le \frac{1}{C_t}\left(\frac{1}{\Delta x^2} + \frac{1}{\Delta y^2}\right)^{-1/2} \qquad (8\text{-}3a)$$

where

$$C_t = 2(gH)^{1/2} + \overline{U}_{max} \qquad (8\text{-}3b)$$

$\overline{U}max$ is the maximum average velocity expected. There are other restrictions but in practice the CFL limit is the most stringent. The model time step is usually 90% of this limit. The internal mode has a much less stringent time step since the fast moving external mode effects have been removed. The time step criteria is analogous to the one for the external mode given above and is

$$\Delta T \le \frac{1}{C_T}\left(\frac{1}{\Delta x^2}+\frac{1}{\Delta y^2}\right)^{-1/2} \tag{8-4}$$

where $C_T = 2C + U_{max}$, with C being the maximum internal gravity wave speed commonly of order 2 m/s and U_{max} is the maximum advective speed. For typical coastal ocean conditions the ratio of the time steps, $\Delta T/\Delta t$, is often a factor of 80-100.

Diffusion is important in the internal mode but does not affect the overall choice of time step, unless the grid Reynolds number is of order 1, in which case

$$\Delta T < \frac{1}{4A_H}\left(\frac{1}{\Delta x^2}+\frac{1}{\Delta y^2}\right)^{-1} \tag{8-5}$$

must be used.

A rotational condition is

$$\Delta t < \frac{1}{f} = \frac{1}{2\Omega \sin\theta} \tag{8-6}$$

where Ω is the angular velocity of the earth and θ is the latitude. However, even for high latitudes the rotational condition is not a limiting factor.

8.2 ADVECTION ALGORITHMS

Accurately simulating the transport of salinity, temperature, sediment and tracers can be difficult, particularly in hydrodynamic and sediment transport problems involving the propagation of steep gradients, or fronts. In estuarine and coastal problems, the propagation of fronts is important, particularly in the zone where freshwater and saltwater mix. Three algorithms, each of which may provide distinct advantages for a particular problem, are available for use in ECOMSED: central difference, upwind difference and the Multidimensional Positive Definite Advection Transport Algorithm (MPDATA).

The central difference algorithm is second-order accurate, generates no numerical diffusion and is computationally efficient. However, this method is not positive definite and negative salinities/ temperatures/sediment concentrations, which are physically impossible, may be generated in certain types of hydrodynamic and sediment transport problems. In addition, numerical ripples may be generated ahead of and behind fronts. Upwind differences are only first-order accurate and may introduce significant numerical diffusion into a solution depending upon typical current speeds and grid sizes. An advantage of upwind transport is that the algorithm is positive definite and the most computationally efficient of any of the advective schemes.

An improvement over both the central and upwind methods, particularly with regard to the transport of fronts, is MPDATA, which is described in detail by Smolarkiewicz (1984), Smolarkiewicz and Clark (1986) and Smolarkiewicz and Grabowski (1990). The general concept used in MPDATA is the successive application of an upwind transport algorithm, which is first-order accurate and positive definite, such that numerical diffusion, generated by a first-order truncation error, is minimized. A correction to the first-order truncation error is made by reapplying the upwind algorithm, after the initial upwind step, using an "anti-diffusion" velocity that is based on the local first-order truncation error. The corrective step may be applied an arbitrary number of times, resulting in a successive reduction in the numerical diffusion generated by the initial upwind step. This procedure yields an advection algorithm that is second-order accurate, and positive definite. Furthermore, MPDATA preserves the local monotone character of the advection field, such that, the field is free of numerically-generated ripples, provided that the anti-diffusion velocities are property bounded. The greatest drawback to routine use of MPDATA is its large demand for computational resources. The execution time for a typical simulation can double the time required for a case involving central or upwind differences. On vector computers this factor is even larger because of the unavoidable many "IF" statements needed in the computer code.

9.0 Structure of Computer Code

9.1 Fortran Symbols

The FORTRAN symbols followed by their corresponding analytical symbols in parentheses and a brief description of the symbols are listed in Table 8-1.

Table 9-1. Fortran Symbols

Indices	Description
I, J (i,j)	horizontal grid indexes
IM, JM	outer limits of I and J
K (k)	vertical grid index; K = 1 at the top and K = KB at the bottom
INT	internal mode time step index
IEXT	external mode time step index
Constants	
DTE (Δt_E)	external mode time step, (s)
DTI (Δt_I)	internal mode time step, (s)
EXTINC	short wave radiation extinction coefficient, (m^{-1})
HORCON(C)	the coefficient of the Smagorinsky diffusivity
IEND	total internal model time steps
IPRINT	the interval in IINT at which variables are printed
ISPLIT	DTI/DTE
MODE	if MODE =2, a 2-D calculation is performed if MODE =3, a 3-D prognostic calculation is performed if MODE =4, a 3-D diagnostic calculation is performed
RFE, RFW, RFN, RFS	1 or 0 on the four open boundaries; for use in BCOND
SMOTH (α)	parameter in the temporal smoother
TPRNI (A_H/A_M)	inverse, horizontal, turbulence Prandtl number
TR	short wave surface transmission coefficient
UMOL	background vertical diffusivity
One-dimensional Arrays	
Z(σ)	sigma coordinate which spans the domain, Z = 0 (surface) to Z = -1 (bottom)
ZZ	sigma coordinate, intermediate between Z
DZ($\delta\sigma$)	= Z(K)-Z(K+1)
DZZ	= ZZ(K)-ZZ(K+1)
Two-dimensional Arrays	
AAM2D	vertical average of AAM (m^2s^{-1})
ART, ARU, ARV	cell areas centered on the variables, T, U and V respectively (m^2)
ADVUA, ADVVA	sum of second, third and sixth terms in equations (3-46, 3-47)
ADX2D, ADY2D	vertical integrals of ADVX, ADVY
COR(f)	the Coriolis parameter (s^{-1})
CURV2D	the vertical average of CURV

Table 9-1. Fortran Symbols (Cont.)

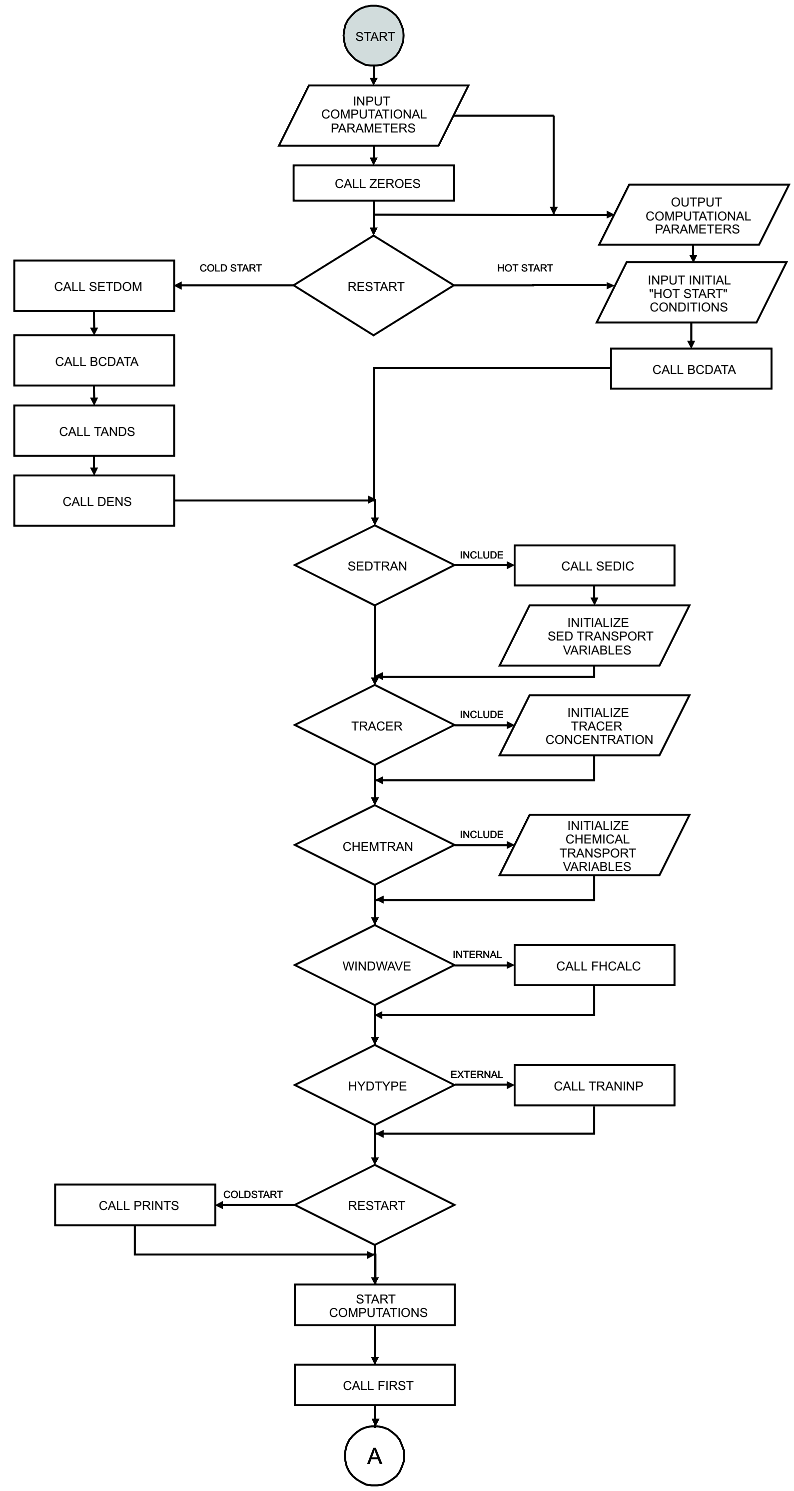
Indices	Description
DUM	Mask for the *u* component of velocity; = 0 over land; =1 over water
DVM	Mask for the v component of velocity; = 0 over land; =1 over water
FSM	Mask for scalar variables; = 0 over land; =1 over water
DX(h_x or δ_x)	grid spacing (m)
DY(h_y or δ_y)	grid spacing (m)
EL (η)	the surface elevation as used in the external mode (m)
ET (η)	the surface elevation as used in the internal mode and derived from EL (m)
EG (η)	the surface elevation also used in the internal mode for the pressure gradient and derived from EL (m)
D (D)	= H + EL (m)
DT (D)	= H + ET (m)
DRX2D, DRY2D	vertical integrals of DRHOX and DRHOY
H (H)	the bottom depth (m)
SWRAD	short wave radiation incident on the ocean surface (m s^{-1}K)
UA, VA, $(\overline{U},\overline{V})$	vertical mean of U, V (m s^{-1})
UT, VT, $(\overline{U},\overline{V})$	UA, VA time averaged over the interval, DT = DTI (m s^{-1})
WUSURF, WVSURF	(<wu(0)>,<wv(0)>) momentum fluxes at the surface (m^2s^{-2})
WUBOT, WUBOT	(<wu(-1)>,<wv(-1)>) momentum fluxes at the bottom (m^2s^{-2})
WTSURF, WSSURF	(<wθ(0)>,<ws(0)>) temperature and salinity fluxes at the surface (ms^{-1} K, ms^{-1} psu)
Three-Dimensonal Arrays	
ADVX, ADVY	horizontal advection and diffusion terms in equations (3-2) and (3-3)
AAM (A_M)	horizontal kinematic viscosity ($m^2\,s^{-1}$)
AAH (A_H)	horizontal heat diffusivity = TPRNI*AAM
CURV $(\tilde{f})$	curvature terms
L (ℓ)	turbulence length scale
KM (K_M)	vertical kinematic viscosity ($m^2\,s^{-1}$)
KH (K_H)	vertical diffusivity ($m^2\,s^{-1}$)
DRHOX	x-component of the internal baroclinic pressure gradient
$\left(gDh_y\rho_0^{-1}\left[-D\int_\sigma^0 \delta_x\rho'\delta\sigma' + \delta_x D\int_\sigma^0 \sigma'\delta\rho'\right]\right)$	subtract RMEAN from density before integrating
DRHOY	*y*-component of the internal baroclinic pressure gradient
$\left(gDh_x\rho_0^{-1}\left[-D\int_\sigma^0 \delta_y\rho'\delta\sigma' + \delta_y D\int_\sigma^0 \sigma'\delta\rho'\right]\right)$	subtract RMEAN from density before integrating
RAD (R)	short wave radiation flux (ms^{-1}K). Sign is the same as WTSURF

Table 9-1. Fortran Symbols (Cont.)

Indices	Description
Q2 (q^2)	twice the turbulence kinetic energy (m^2s^{-2})
QL ($q^2\ell$)	Q2 × the turbulence length scale (m^3s^{-2})
T (T)	potential temperature (K)
S (S)	salinity (psu)
RHO (ρ/ρ_o-1.025)	density (non-dimensional)
U, V (U, V)	horizontal velocities (m s^{-1})
W (ω)	sigma coordinate vertical velocity (m s^{-1})
RMEAN	density field which is horizontally averaged before transfer to sigma coordinates.
TCLIM	a stationary temperature field which approximately has the same vertical structure as T.
SCLIM	a stationary salinity field which approximately has the same vertical structure as S.

9.2 Program Structure

The ECOMSED computer programs consist of a main program and a set of subroutines. The main program and subroutines contain approximately 15,000 lines of code and they share a common file of some 100 or so records. The file "comdeck" must be edited for new values of IM, JM, KB or KSL (number of standard level). The various components of the computer programs are listed in Table 7-2. Figure 7-1 is the flow chart for the programs in simplified form. The code is written in a modular fashion so that various "physics" packages can be inserted easily. For example, SUBROUTINE PROFQ solves for the vertical mixing coefficients (eddy viscosity and eddy diffusivity). If forms other than the presently implemented level 2-1/2 turbulence closure model are desired, they can be incorporated in a new subroutine and PROFQ discarded. Much care has gone into the design of a code that is fully vectorizable. The use of "IF" statements has been greatly minimized. The code has a five fold increase in speed when running with vectorization "on" on a Cray X-MP/48 supercomputer.



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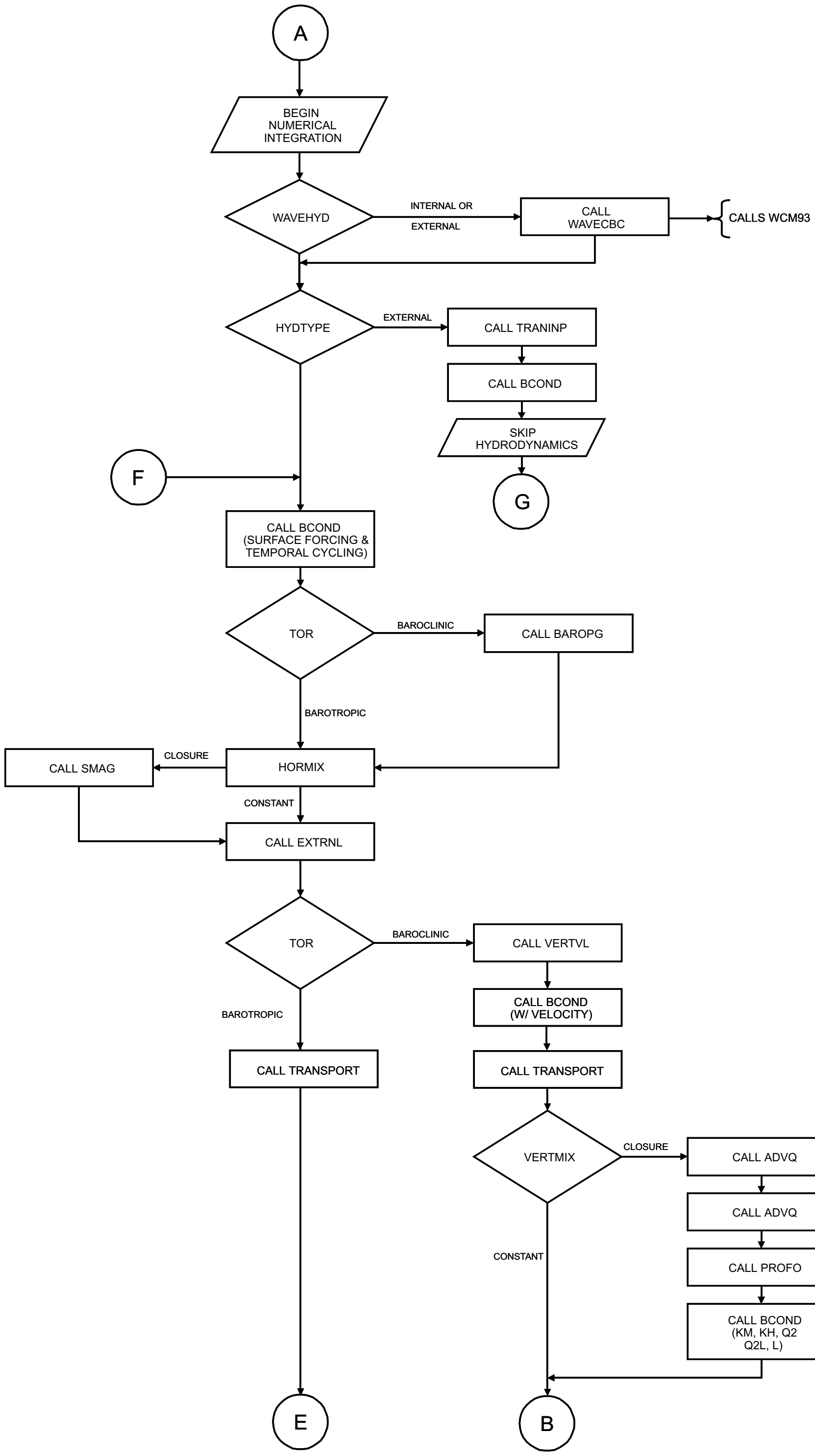
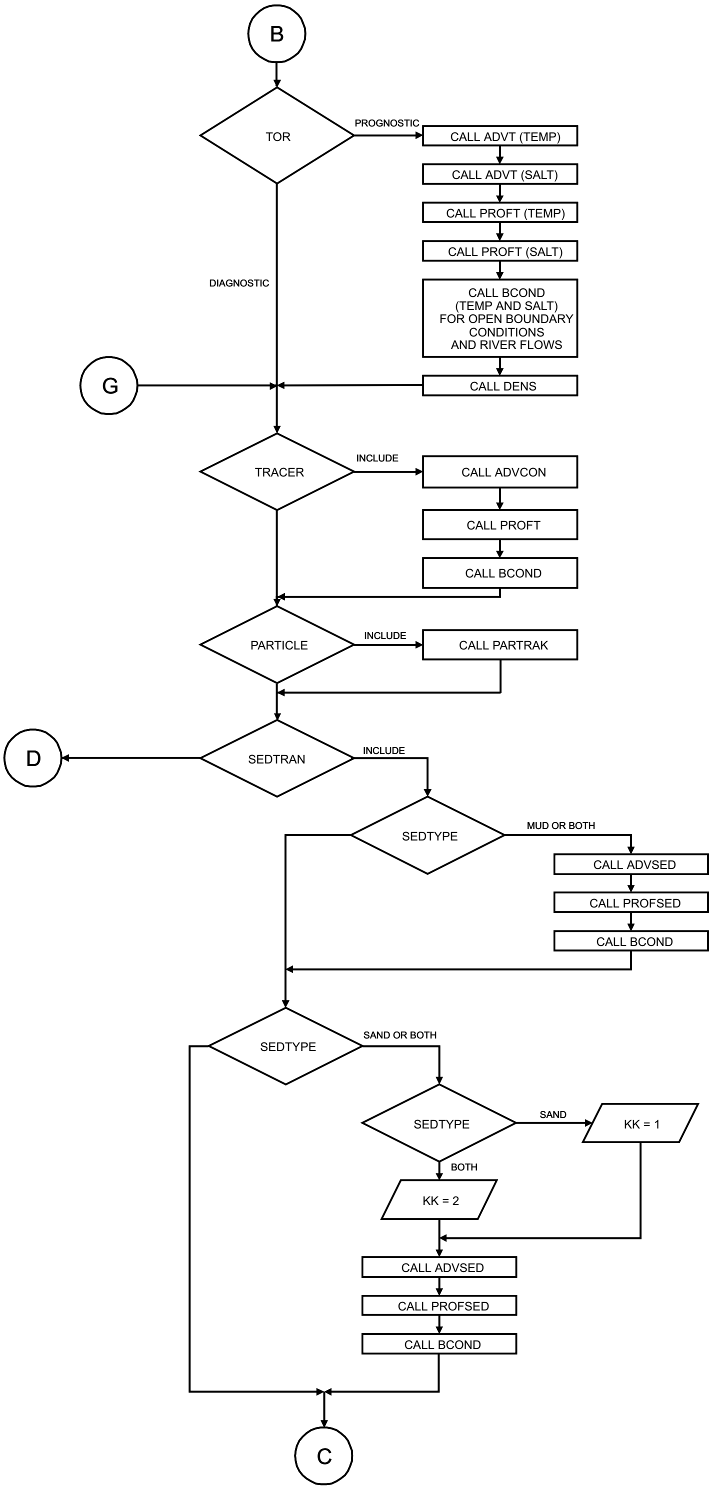
ECOMSED flowchart.

FIGURE 9-1



ECOMSED flowchart.

FIGURE 9-1 (continued)



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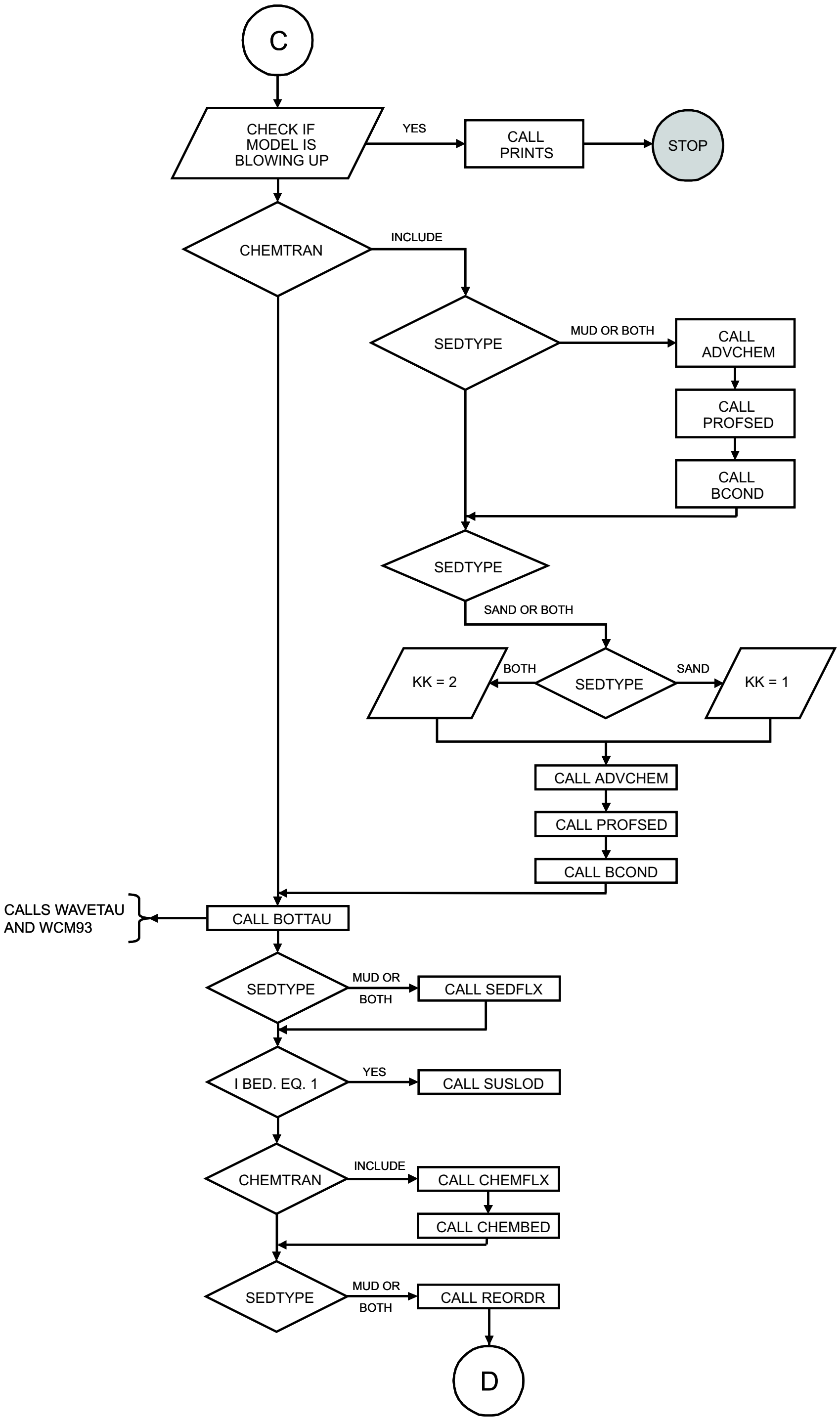
ECOMSED flowchart.

FIGURE 9-1 (continued)



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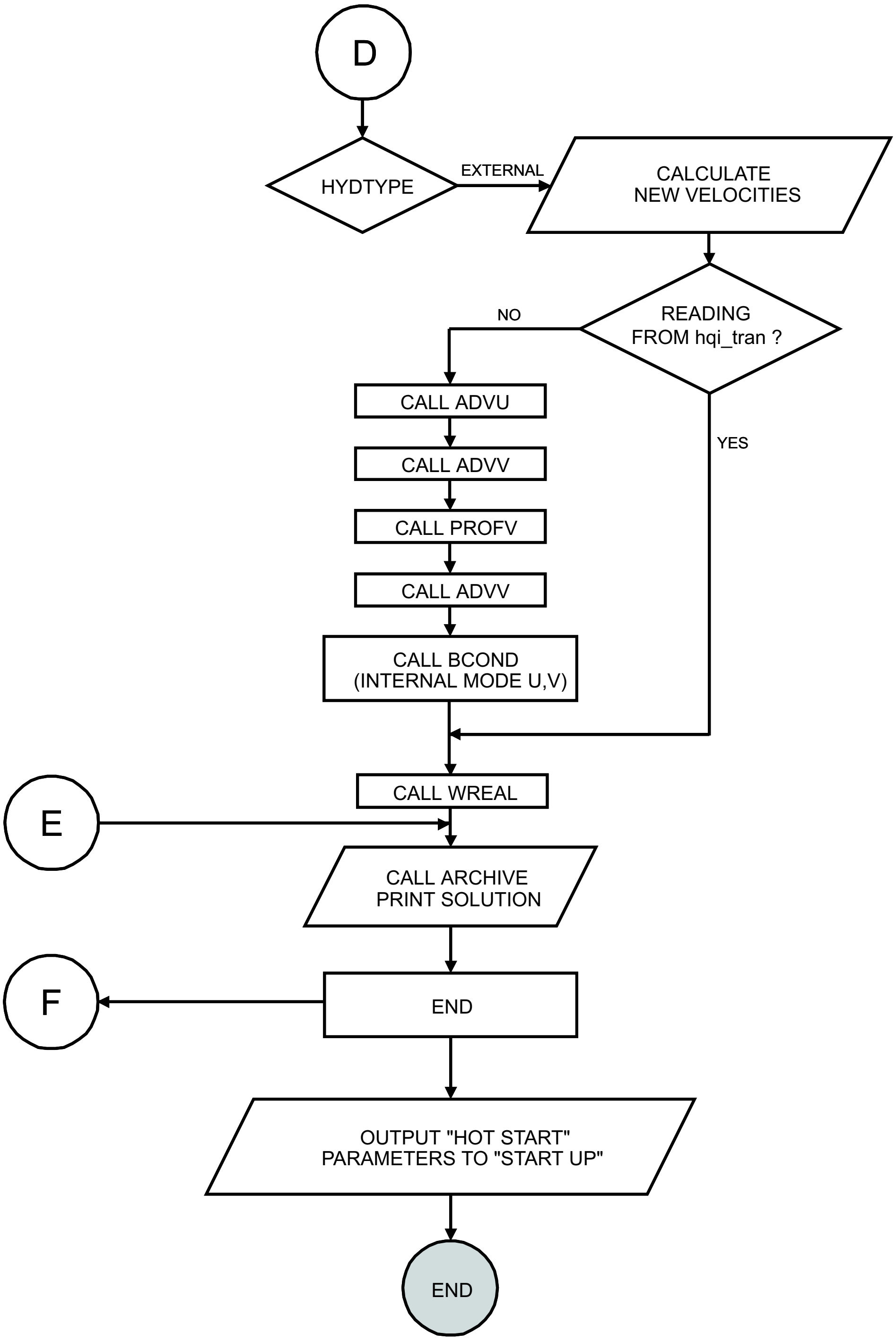
ECOMSED flowchart.

FIGURE 9-1 (continued)



ECOMSED flowchart.

FIGURE 9-1 (continued)

Table 9-2. Components of the Computer Programs

Subroutines	Description
ADVAVE	Computes the advective and dispersive terms in the ξ_1 and ξ_2 components of the vertically integrated momentum equation
ADVCHEM	Computes advective and dispersive terms in sediment-bound tracer transport equation
ADVCON	Computes advective and dispersive terms in dissolved tracer transport equation
ADVQ	Computes the advective and dispersive terms in the turbulence kinetic energy and macroscale equations
ADVSED	Computes advective and dispersive terms in sediment transport equation
ADVT	Computes the advective and dispersive terms in the mass transport equation
ADVU	Computes the advective, Coriolis, pressure gradient and dispersive terms in the ξ_1 component of the momentum equation
ADVV	Computes the advective, Coriolis, pressure gradient and dispersive terms in the ξ_2 component of the momentum equation
ANTIDIF	Computes anti-diffusion velocities for use in Smolarkiewicz transport algorithm
ARCHIVE	Time averages and writes to disk various quantities useful for graphical analyses
BAROPG	Computes the baroclinic pressure gradient terms through the vertical integral of the horizontal density gradient
BCDATA	Reads in the boundary condition data and performs the necessary interpolation for the model run
BCOND	Specifies the lateral and surface boundary conditions. Cycles through the input files when necessary
BOTTAU	Computes bottom shear stresses for sediment transport model
BULK	Computes sensible heat and latent heat
CHEMBED	Calculates changes in sediment bed concentrations of sediment-bound tracer
CHEMFLX	Calculates flux of sediment-bound tracer at sediment-water interface
COMDECK	Contains all paramters, type specifications, dimensions and common blocks to be included in the main program and subroutines. COMDECK should be edited for new values of IM, JM, KB and KSL.
DENS	Computes the local density of water from the most recent values of temperature and salinity. The program actually uses ρ-1
DISPLY	Writes a two dimensional array to the "gcmprt" file

Table 9-2. Components of the Computer Programs

Subroutines	Description
ECOM3D	Controls and monitors the flow of the particular simulation. This is the main program
EXTRNL	Solves for the depth integrated U and V velocities
FHCALC	Calculates fetch and mean depth for wind wave model
FIRST	Prepares the first set of data for use in the time variable model run
FZOL	Estimates stability functions for heat flux calculation
JDAY	Gives Julian day number
LONGWAVE	Computes longwave radiation
MAXMIN	Finds the maximum and minimum values of an array
N_CLOUD	Estimates total shortwave radiation reaching the earth surface and cloud cover fraction (0.0 to 1.0)
NCLD	Calculates percent cloud cover based on observed shortwave radiation and day of the year
ONEPART	Particle tracking algorithm
PARTRAK	Controls particle tracking simulations
PRINT	Writes a two dimensional array to the "gcmprt" file in an integer format
PRINTS	Controls the printing of the various model quantities
PROFQ	Solves for turbulence kinetic energy, turbulence macroscale, and the vertical mixing coefficients for momentum, and temperature and salinity
PROFT	Solves for temperature, salinity and conservative tracer
PROFU	Solves for the U velocity
PROFV	Solves for the V velocity
PRTXY	Selects a horizontal field for use in PRINT
QSAT	Calculates saturation humidity
REORDR	Reorders sediment layers due to consolidation
SEDFLX	Calculates sediment flux at sediment-water interface
SEDIC	Initializes sediment transport constants and variables
SETDOM	Defines the physical characteristics of the model domain and the particular run and computes various constants to expedite the computation
SINTER	Interpolates various data profiles to model depths from their observed depth

Table 9-2. Components of the Computer Programs

Subroutines	Description
SLICEXZ	Writes a vertical slice in the x-direction of a three dimensional array to the "gcmprt" file
SLICEYZ	Writes a vertical slice in the y-direction of a three dimensional array to the "gcmprt" file
SMAG	Computes the coefficient of horizontal viscosity
STRESS	Calculates bottom shear stress due to wind induced waves and currents
SUSLOD	Calculates non-cohesive sediment suspended load
TANDS	Prepares the initial temperature and salinity fields for use in the model calculation
TRANINP	Reads external hydrodynamic information from "hqi_geom" and "hqi_tran" files
TRANSPORT	Calculates mean mass transport fields for use with a water quality model
VAPOR	Computes vapor pressure
VERTVL	Solves for the vertical velocity
WAVEDON	Calculates wave parameters based on Donelan (1977)
WAVESMB	Calculates wave parameters based on United States Army Corps of Engineers Shore Protection Manual (1984)
WREAL	Computes the vertical velocity in real x, y, z space
ZEROES	Sets all computational arrays to initial zeroes and values

The information necessary to make a complete ECOMSED model run is contained in 24 files, briefly described in Table 7.3. Also described briefly in Table 7-3 are the model generated output files and are followed by detailed descriptions of the contents of certain output files.

Table 9-3. Mass Storage Files

User Created Files	Description
1. model_grid	Contains the physical information for the model grid (needed if HYDTYPE = "INTERNAL")
2. init_tands	Contains the initial conditions for temperature and salinity in each water grid box at the standard levels noted in run data (needed if HYDTYPE = "INTERNAL")
3. run_data	Contains parameters which control the type and length of the simulation. The frequency of various outputs is also included here, along with some of the important problem constants
4. synop_wind	Contains time variable wind components and atmospheric pressurefor the entire model grid. This file is an unformatted input file
5. synop_hflx	Contains time variable surface heat flux data for the entire model grid. This file is an unformatted input file
6. corner_loc	Contains corner locations of grid elements, used for wind wave simulations when WAVEHYD = "INTERNAL" and needed for particle tracking simulations
NOTE	The following user created file is needed for dissolved tracer transport calculations (TRACER = "INCLUDE")
7. water_tracer.inp	Contains input parameters and boundary condition values for dissolved tracer transport.
NOTE	The following user created files are needed for sediment transport calculations (SEDTRAN = "INCLUDE")
8. coh_sed.inp	Contains input parameters and boundary condition values for cohesive sediment transport (needed if SEDTYPE = "MUD " or "BOTH")
9. noncoh_sed.inp	Contains input parameters and boundary condition values for non-cohesive sediment transport (needed if SEDTYPE = "SAND" or "BOTH"
10. bed_mask	Contains sediment bed map for the entire model grid
11. p0_init	Contains initial values of spatially-variable cohesive bed fractions for the entire model grid
12. a0_init	Contains spatially-variable a_o values for the entire model grid
13. exp_init	Contains spatially-variable values of exponent n for the entire model grid
14. bed_d50	Contains spatially-variable D_{50} values for the entire model grid
15. bed_frac.mud	Contains spatially-variable cohesive composition fractions for the entire model grid, clay/silt fraction
16. bed_frac.sand	Contains spatially-variable cohesive composition fractions for the entire model grid, sand fraction

Table 9-3. Mass Storage Files

User Created Files	Description
17. bed_bulkden	Contains spatially-variable sediment bed bulk density for the entire model grid
NOTE	The following user created files are needed for sediment-bound tracer transport calculations (CHEMTRAN = "INCLUDE" and SEDTRAN = "INCLUDE")
18. coh_trace.inp	Contains input parameters and boundary condition values for cohesive sediment-bound tracer transport (needed if SEDTYPE = "MUD " or "BOTH")
19. noncoh_trace.inp	Contains input parameters and boundary condition values for non-cohesive sediment-bound tracer transport (needed if SEDTYPE = "SAND" or "BOTH")
20. bed_chemic	Contains spatially-variable initial bed concentrations for sediment-bound tracer, for the entire model grid
NOTE:	The following user created file is needed for particle tracking calculations (PARTICLE = "INCLUDE")
21. partrack.inp	Contains input parameters for particle tracking
NOTE:	The following user created files are needed for simulations using externally-calculated hydrodynamics (HYDTYPE = "EXTERNAL")
22. hqi_geom	This file contains grid segmentation information to be used for transport calculations
23. hqi_tran	This file contains the computed results as a time history for surface elevations and hydrodynamic advection/dispersion fields to be used for transport calculations
NOTE	The following user created file is needed for simulations using externally-calculated wind wave fields (WAVEHYD = "EXTERNAL")
24. wave_input	This file contains computed results as a time history for wind wave parameters as calculated using a wind wave model (e.g., WAM or HISWA
Model Generated Files	**Description**
1. gcmprt:	This file is a main output file containing all the input information and all the computed values
2. gcmplt	This file contains the computed results as a time history for all grid elements. It is useful for graphical analyses
3. gcmtsr	This file contains the computed values of elevation, current, temperature and salinity, and cross sectional fluxes for user specified grid elements. This file also contains the run-time global integrals of various parameters to assist in the diagnosis of the model

Table 9-3. Mass Storage Files

User Created Files		Description
4.	gcm_tran	This file contains the computed results as a time history for surface elevations, volume transports and dispersions to be used by a water quality model
5.	gcm_geom	This file contains grid segmentation information to be used by a water quality model
6.	startup	This file contains all the information for the hydrodynamic model run which will become the initial conditions for the "HOT START" runs
7.	restart	This file is similar to the "startup" file. User should move or copy the "startup" file to "restart" before making the next "HOT START" run

10.0 Model Input and Output Data Structure

This section provides a detail description of data structure of 24 input data files and selected output files. The names of the input/output files are listed in Section 7.

10.1 Model Geometry Input Data

The input file name is model_grid. There are three data groups in this input file (Table 10-1A).

Table 10-1A: model_grid data structure

Data Group	Description
A.	Comment for Grid Information
B.	Vertical Segmentation
	Comment
	Number of sigma levels
	Sigma levels
C.	Horizontal Segmentation
	Comment
	I index and J index
	Grid Information

NOTE: The model_grid file is only needed if HYDTYPE = "INTERNAL".

Table 10-1B describes in detail format of the data structure in model_grid.

Table 10-1B: model_grid data format

Data Group A: Comment for Grid Information

80

COM

80A1

COM = user specified comment for grid information

Data Group B: Vertical Segmentation

1. Comment

80

COM

80A1

COM = user specified comment for sigma levels

2. Number of Sigma Levels

5

IKB

I5

IKB = number of sigma levels

3. Sigma Levels

10

Z

F10.5

Z = depth of the interface between sigma levels
$-1.0 \leq Z \leq 0.0$

NOTE: Total number = IKB.

Data Group C: Horizontal Segmentation

1. Comment

80
COM
80A1

COM = user specified comment for horizontal segmentation

2. I Index and J Index

5	10
IIX	IJY
2I5	

IIX = index in the ξ_1 direction
IJY = index in the ξ_2 direction

3. Grid Information

5	10	20	30	40	50	60	70	75	80
I	J	H1	H2	H	ANG	YGRID	XGRID	DATUM	
2I5,4F10.2,2F10.5,F5.1,I5									

I = i number of grid element in the ξ_1 direction
J = j number of grid element in the ξ_2 direction
H1 = distance in meters in the ξ_1 direction at center of grid element
H2 = distance in meters in the ξ_2 direction at center of grid element
H = average depth of grid element in meters (at mean water level)
= MLW + tidal amplitude
ANG = angle in degrees between east and ξ_1 direction measured in a counter-clockwise direction
YGRID = latitude in degrees (positive for northern hemisphere) to compute the Coriolis parameter
XGRID = longitude in degrees (Note: model does not use this ____. Only used for postprocessing purposes)
DATUM = datum of grid element in meters (above some reference elevation)

NOTE: Total number of wet grid ≤ total number of grid elements. Grid information need be specified for wet points only and it is not necessary to specify grid information for other grid elements. H must be sufficiently large in order to remain wet at low tide.

10.2 Initial Condition

The initial condition input file name is "init_tands". There is only one data group. Tables 8-2A and 8-2B describe the data structure and format respectively.

Table 10-2A: Data structure of init_tands

Data Group	Description
A.	Location, Temperature and Salinity at Standard Levels
NOTE:	The init_tands file is only needed if HYDTYPE = "INTERNAL"

Table 10-2B: init_tands data format

Data Group A: Location, Temperature and Salinity at Standard Levels

5	10	15	20	...	260	265	270	...	510
I	J	TS(I,J,1)	TS (I,J,2)	...	TS(I,J,KSL)	SS(I,J,1)	SS(I,J,2)	...	SS(I,J,KSL)

2I5,100F5.0

I = i number of grid element in the ξ_1 direction
J = j number of grid element in the ξ_2 direction
TS = temperature in °C at each standard level
SS = salinity in psu at each standard level

NOTE:

1. KSL = number of standard levels. To ensure proper interpolation of data from standard level to sigma level, each bottom-most sigma level must be bracketed by two standard levels. These standard levels must contain data.

2. Spatially variable inital conditions cannot be specified for conservative tracer concentration. Initial conditions for this constituent are specified using standard levels.

10.3 Model Simulation Input Data

The name of the input file is run_data. This file contains parameters which control the type and length of the simulation. The frequency of various output is included here. The data also contains various modeling contents. There are eight data groups as listed in Tables 8-3A and 8-3B.

Table 10-3A. Data structure of run_data

Data Group	Description
A.	Run Computational, Output and Print Characteristics
	Comment
	Comment-Run options
	Run options
	Comment-Run computational characteristics
	Run computational characteristics
	Comment-Run output characteristics
	Run output characteristics
	Comment-Run print characteristics
	Run print characteristics
B.	Hydrodynamic Characteristics
	Comment-Constants of the model problem
	Constants of the model problem
	Comment-Horizontal mixing characteristics
	Horizontal mixing characteristics
	Comment-Vertical mixing characteristics
	Vertical mixing characteristics
C.	Result Evaluation
	Computational history for plotting
	Comment
	Number and averaging interval of computational history output sets
	Time in number of time steps for writing the output
	Averaging interval for skill assessment
	Comment
	Averaging interval
	Computed time series for elevations
	Comment
	Number of grid elements
	Location of grid elements
	Computed time series for currents, temperature, salinity & transport quantities
	Comment
	Number of grid elements
	Location of grid elements
	Computed time series for cross sectional fluxes
	Comment
	Number of cross sections

Table 10-3A. Data structure of run_data

Data Group	Description
	Location of cross sections
	Computational results for water quality
	Comment
	Number and averaging interval of computational result output sets
	Time in number of time steps for writing the output
D.	Standard Level Declaration
	Comment
	Number of standard levels
	Standard levels
E.	Initial Temperature and Salinity Data
	Comment
	Initial temperature and salinity data option
	Initial temperature data
	Initial salinity data
F.	Open Boundary Condition Information
	Elevation boundary conditions
	Comment
	Number of grid elements and option
	Elevation boundary conditions
Option 1	Time variable data
	Location of grid elements
	Time of observation
	Elevation data
Option 2	Computer generated data from tidal constituents
	Location of grid elements and mean water level
	Amplitudes of the 6 dominant harmonic constituents
	Phases of the 6 dominant harmonic constituents
	Time Variable temperature and salinity boundary conditions
	Comment
	Temperature and salinity boundary conditions
	Time of observation
	Location of grid elements, temperature and salinity data
G.	Discharge Information
	Time variable river/dam and onshore intake/outfall discharges
	Comment
	Number of grid elements
	Location of grid elements/vertical distribution of intake/outfall discharge
	Time of observation
	Discharge data
	Temperature data
	Salinity data
	Time variable offshore intake/outfall (diffuser) discharges
	Comment

Table 10-3A. Data structure of run_data

Data Group	Description
	Number of grid elements
	Location of grid elements/vertical distribution of intake/outfall diffuser discharge
	Time of observation
	Discharge data
	Temperature data
	Salinity data
	Time variable offshore intake/outfall (diffuser) discharges in loops
	Comment
	Number of grid elements
	Location of grid elements/vertical distribution of intake/outfall diffuser discharge
	Time of observation
	Discharge data
	Temperature data
	Time variable offshore intake/outfall discharges in loops
	Comment
	Grid elements (I,J) and distribution of flows
	Discharge data
	Temperature data
	Salinity data
H.	Meteorological Data
	Comment
	Meteorological data option
	Meteorological data
Option 1	Time variable surface heat data, salt flux data and wind data
	Time of observation
	Precipitation, evaporation, heat flux, wind speed and direction data
Option 2	Synoptic time variable surface heat flux data and synoptic wind and atmospheric pressure data
	Wind and pressure data input from file "synop_wind"
	Surface heat flux data input from file "synop_hflx"
Option 3	Time variable surface heat flux parameters, salt flux data and wind data
	Time of observation
	Precipitation, evaporation, heat flux, wind speed and direction data

Table 10-3B: Data format of run_data

DATA GROUP A: Computational and Output Characteristics

1. Comment

80	
COM	
80A1	

COM = user specified comment for run information

2. Comment - Run Options

80	
COM	
80A1	

COM = user specified header for run options

3. Run Options

10	20	30	40	50	60	70
HYDTYPE	WAVEDYN	TRACER	SEDTRAN	CHEMTRAN	SEDTYPE	PARTICLE

2X,A8,2X,A8,3X,A7,3X,A7,3X,A7,6X,A4,3X,A7

HYDTYPE	=	"INTERNAL" - use internal (ECOM) hydrodynamics
	=	"EXTERNAL" - use external hydrodynamics input from 'hqi_tran' file
WAVEDYN	=	"NEGLECT " - no effect of surface waves on bottom friction
	=	"SMBMODEL" - include effects of waves on bottom friction, internal calculation of waves using SMB theory
	=	"DONMODEL" - include effects of waves on bottom friction, internal calculation of waves using Donelan Theory

	=	"EXTERNAL" - include effects of waves on bottom friction, wave parameters input from 'wave_input' file, (external calculation using WAM or HISWA)
TRACER	=	"INCLUDE" - dissolved tracer transport will be simulated
	=	"NEGLECT" - no simulation of dissolved tracer transport
SEDTRAN	=	"INCLUDE" - sediment transport will be simulated
	=	"NEGLECT" - no simulation of sediment transport
CHEMTRAN	=	"INCLUDE" - sediment-bound tracer transport will be simulated
	=	"NEGLECT" - no simulation of sediment-bound transport
SEDTYPE	=	"BOTH" - cohesive and non-cohesive sediment transport
	=	"MUD " - cohesive sediment transport only
	=	"SAND" - non-cohesive sediment transport only
PARTICLE	=	"INCLUDE" - particle tracking will be simulated
	=	"NEGLECT" - no simulation of particle tracking

NOTE: SMBMODEL is not fully operational.

NOTE: CHEMTRAN = "INCLUDE" requires that SEDTRAN = "INCLUDE".

NOTE: CHEMTRAN option is not fully operational.

4. Comment - Run Computational Characteristics

80
COM
80A1

COM = user specified header to identify run computational characteristics

5. Run Computational Characteristics

10	15	20	25	30	35	40	45
DTI	ISPLIT	IRAMP	IYR	IMO	IDA	IHR	NHYD

F10.4,7I5

DTI = time step in seconds of the internal mode (the maximum allowable time step in seconds can be found in "gcmprt")

ISPLIT	=	number of time steps between the internal and external modes
IRAMP	=	number of time steps over which all model forcing functions are ramped from zero to their full values linearly
IYR, IMO, IDA, IHR	=	year, month, day, hour of model start time and IYR should be a 4-digit number
NHYD	=	number of time steps betweeen each hydrodynamic transport field input from "hqi_tran", only used if HYDTYPE = "EXTERNAL"

NOTE: If TOR = "BAROTROPIC", ISPLIT = 1
If TOR = "PROGNOSTIC" or "DIAGNOSTIC", ISPLIT >3

6. Comment - Run Output Characteristics

```
     80
    COM
80A1
```

COM = user specified header to identify NSTEPS, IPRINT, IPRTSTART, RESTAR, TOR, ADVECT output characteristics

7. Run Output Characteristics

10	20	30	41	52	63	75
NSTEPS	IPRINT	IPRTSTART	RESTART	TOR	ADVECT	SCHEME

3I10,1X,A10,1X,A10,1X,A10,1X,A10

NSTEPS	=	number of time steps in the model run
IPRINT	=	print interval in number of time steps
IPRTSTART	=	time in number of time steps at which printing will begin
RESTAR	=	"COLD START" - all initial conditions are set to zero
	=	"HOT START" - all initial conditions are input from file "restart"
TOR	=	"BAROTROPIC" - 2-D calculation (bottom stress calculated in ADVAVE)
	=	"PROGNOSTIC" - 3-D calculation (bottom stress calculated in PROFU & PROFV)

	=	"DIAGNOSTIC" - 3-D calculation with temperature and salinity held fixed
ADVECT	=	"LINEAR" - no momentum advection terms
	=	"NON-LINEAR" - include momentum advection terms
SCHEME	=	"CENTRAL" - central finite difference scheme for advection
	=	"UPWIND" - upwind finite difference scheme for advection
	=	"SMOLAR_R" - finite difference scheme due to Smolarkiewicz and using reclusive formulation for antidiffusive velocities
	=	"SMOLAR_2" - finite difference scheme due to Smolarkiewicz and using two passes for corrections of numercial diffusion

NOTE: If RESTAR = "HOT START", then the user should move or copy "startup" to "restart" before the model run. "startup" is a file containing computed results from the previous model run.
If TOR = "BAROTROPIC", ISPLIT = 1
If TOR = "PROGNOSTIC" or "DIAGNOSTIC", ISPLIT >3

NOTE: HOT START option is not fully operational for Particle Tracking and wave simulations.

8. Comment - Run Print Characteristics

80
COM
80A1

COM = user specified header to identify run print characteristics of variables DEV, VSX, JROW, VSY, IROW, U, V, W, AM, S, T, RHO, Q2, L, KM, KH for output to "gcmprt"

9. Run Print Characteristics

5	10	15	20	25	30	35	40
DEV	VSX	JROW	VSY	IROW	U	V	W

45	50	55	60	65	70	75	80
AM	S	T	RHO	Q2	L	KM	KH

2X,A3,4X,A1,I5,4X,A1,I5,211(4X,A1)

DEV	=	primary output device for viewing "gcmprt"
	=	"SCR" - for 15 columns across the page, suitable for printing on a screen with no wrap around
	=	"LPR" - for 25 columns across the page, suitable for printing on a laser or line printer
VSX	=	vertical slice in the x (ξ_1) direction of various model quantities included in the "gcmprt" file
	=	"Y" - vertical slices
	=	"N" - no vertical slices
JROW	=	j number at which the vertical slice in the x (ξ_1) direction will be taken
	=	0, for VSX="N"
VSY	=	vertical slice in the y (ξ_2) direction of various model quantities included in the "gcmprt" file
	=	"Y" - vertical slices
	=	"N" - no vertical slices
IROW	=	i number at which the vertical slice in the y (ξ_2) direction will be taken
	=	0, for VSY="N"
U	=	U velocity included in "gcmprt"
	=	"Y" - include
	=	"N" - omit
V	=	V velocity included in "gcmprt"
	=	"Y" - include
	=	"N" - omit
W	=	W velocity included in "gcmprt"
	=	"Y" - include
	=	"N" - omit
AM	=	horizontal mixing included in "gcmprt"
	=	"Y" - include
	=	"N" - omit
S	=	salinity and conservative tracer included in "gcmprt"
	=	"Y" - include
	=	"N" - omit
T	=	temperature included in "gcmprt"
	=	"Y" - include
	=	"N" - omit
RHO	=	density included in "gcmprt"
	=	"Y" - include

	=	"N" - omit
Q2	=	turbulent kinetic energy included in "gcmprt" for closure vertical mixing
	=	"Y" - include
	=	"N" - omit
L	=	mixing length included in "gcmprt" for closure vertical mixing
	=	"Y" - include
	=	"N" - omit
KM	=	mixing K_M included in "gcmprt" for closure vertical mixing
	=	"Y" - include
	=	"N" - omit
KH	=	mixing K_H included in "gcmprt" for closure vertical mixing
	=	"Y" - include
	=	"N" - omit

DATA GROUP B: Hydrodynamic Characteristics

1. Comment - Constants of the Model Problem

80
COM
80A1

COM = user specified header for BFRIC, ZOB, NU, ALPHA, TLAG constants

2. Constants of the Model Problem

10	20	30	40	50	60	70	80
BFRIC	ZOB	NU	THETA	ALPHA	TLAG	NWAVE	BCTYPE

6E10.3, I10, 3x,A7

BFRIC	=	bottom friction coefficient (non-dimensional)
ZOB	=	bottom roughness coefficient in meters
NU	=	coefficient in time filter (non-dimensional)
	=	0.1 (recommended value)
THETA	=	weighting factor (0-1); 0 - explicit and 1- implicit scheme
	=	0.225 (recommended value)
ALPHA	=	advection time scale for temperature and salinity at the boundary time “HOURS” over which the boundary values reach their full specified value during the flood cycle from the values exiting at the end of the ebb cycle. *Caution: If the user does not want boundary relaxation (α-folding), specify ALPHA = 0.
TLAG	=	friction time scale (Hours) for barotropic radiation boundary condition (only needed if user selects BCTYPE as PCLAMP
NWAVE	=	number of time steps between each update of bottom friction coefficient, only used if WAVEHYD = "INTERNAL" or "EXTERNAL"
BCTYPE	=	baratropic radiation boundary condition types “CLAMPED” - clamp boundary condition (no radiation) “PCLAMP” - partially clamped. Note: if user selects PCLAMP type B.C., user must provide TLAG in Hours “OCLAMP” - optimized clamp which is same as

RANDB except λt is non unity.
"RANDB" - Reid and Bodine type boundary condition
"IRANDB" - inverted Reid and Bodine type boundary condition
"MIXED" - mixed boundary conditions

3. Comment - Horizontal Mixing Characteristics

```
      80
     COM
80A1
```

COM = user specified header for HORZMIX, HORCON, HPRNU mixing characteristics

4. Horizontal Mixing Characteristics

```
        10         20         30
   HORZMIX     HORCON      HPRNU
A10,2E10.3
```

HORZMIX	=	"CONSTANT" - value given for HORCON is scaled in each grid element relative to the smallest grid element
	=	"CLOSURE" - value given for HORCON is used in Smagorinsky's formula for mixing
HORCON	=	value used as a constant or in Smagorinsky's formula based on HORZMIX (non-dimensional)
HPRNU	=	horizontal Prandtl number - ratio of horizontal viscosity to horizontal diffusivity (momentum mixing/dispersive mixing)
	=	1.0 (recommended value)

5. Comment - Vertical Mixing Characteristics

```
      80
     COM
80A1
```

COM = user specified header for VERTMIX, UMOL, VPRNU mixing characteristics

6. Vertical Mixing Characteristics

10	20	30
VERTMIX	UMOL	VPRNU

A10,2E10.3

VERTMIX	=	"CONSTANT" - value given for UMOL applies everywhere
	=	"CLOSURE" - value given to UMOL is background mixing
UMOL	=	constant or background mixing in m^2/sec
	=	1.0E-06 (recommended value if VERTMIX = "CLOSURE")
VPRNU	=	vertical Prandtl number - ratio of vertical viscosity to vertical diffusivity (momentum mixing/diffusive mixing)
	=	1.0 (recommended value)

DATA GROUP C: Result Evaluation

1. Computational History Output for Plotting

a. Comment

80
COM

80A1

COM = user specified comment for computational history output

b. Number and Averaging Interval of Computational History Output Sets

10	20
JHM	IAVGE

2I10

JHM	=	number of times all information necessary for plotting will be written in "gcmplt" and "part_location"
IAVGE	=	interval in number of time steps for averaging the elevations and currents for all grid elements

NOTE: If JHM = 0, then go to Data Group C.2 (Averaging Interval for Skill Assessment)

c. Time in Number of Time Steps for Writing the Output

8	16	...	80
IHIST(1)	IHIST(2)	...	IHIST(JHM)

10I8

IHIST = time in number of time steps all information will be written in "gcmplt" and "part_location" (for particle tracking output when PARTICLE = "INCLUDE")

NOTE: IHIST relative to start of run (independent of RESTART option specified)

2. Averaging Interval for Skill Assessment

a. Comment

80
COM

80A1

COM = user specified comment for averaging interval for skill assessment

b. Averaging Interval

10
ISKILL

I10

ISKILL = interval in number of time steps for averaging the elevations and currents for user specified grid elements (for example, at the tide gauge locations)
= 0, no element stored in "gcmtsr" for skill assessment

NOTE: If ISKILL=0, then go to Data Group C.6 (Computational Results for Water Quality Model)

3. Computed Time Series for Elevations

a. Comment

80
COM
80A1

COM = user specified comment for computed time series for elevations

b. Number of Grid Elements

5
EPTS
I5

EPTS = number of grid elements for which time series of elevations are to be stored in "gcmtsr"

NOTE: If EPTS=0, then go to Data Group C.4 (Computed Time Series for Currents, Temperature and Salinity)

c. Location of Grid Elements

5	10	...	75	80
INXIE(1)	INXJE(1)	...	INXIE(EPTS)	INXJE(EPTS)
16I5				

INXIE = i number of grid element
INXJE = j number of grid element

4. Computed Time Series for Currents, Temperature, Salinity and Transport Quantities

a. Comment

80
COM
80A1

COM = user specified comment for computed time series for currents

b. Number of Grid Elements

5
VPTS
I5

VPTS = number of grid elements for which time series of currents are to be stored in "gcmtsr"

NOTE: If VPTS=0, then go to Data Group C.5 (Computed Time Series for Cross Sectional Fluxes)

c. Location of Grid Elements

5	10	...	75	80
INXIV(1)	INXJV(1)	...	INXIV(VPTS)	INXJV(VPTS)
16I5				

INXIV = i number of grid element
INXJV = j number of grid element

5. Computed Time Series for Cross Sectional Fluxes

a. Comment

80
COM
80A1

COM = user specified comment for computed time series for cross sectional fluxes

b. Number of Cross Sections

5
FPTS
I5

FPTS = number of cross sections for which time series of fluxes are to be stored in "gcmtsr"

NOTE: If FPTS=0, then go to Data Group C.6 (Computation Results for Water Quality Model)

c. Location of Cross Sections

5	10	15	20	...
ISFLX(1)	JSFLX(1)	DIRFLX(1)	NFLXE(1)	...

4(2I5,1X,A4,I5)

65	70	75	80
ISFLX(FPTS)	JSFLX(FPTS)	DIRFLX(FPTS)	NFLXE(FPTS)

ISFLX = i number of grid element in which cross section begins

JSFLX = j number of grid element in which cross section begins

DIRFLX = direction of cross-section
= "IDIR" - cross-section is in the ξ_1 direction
= "JDIR" - cross-section is in the ξ_2 direction

NFLXE = number of grid elements in the cross-section

6. Computation Results for Water Quality Model

a. Comment

80
COM

80A1

COM = user specified comment for computation results for water quality model

b. Number and Averaging Interval of Computation Result Output Sets

10	20	30	40	50
JTM	NPLPF	ITRNFORM	IZERO	IWET

5I10

JTM	=	number of times all information necessary for the water quality model input is generated
NPLPF	=	interval in number of time steps for averaging the elevations and currents to be used as input in the water quality model
ITRNFORM	=	0 : user specified time steps for writing the output 1: ECOM will generate the writing block (i.e. section 6.c.)
IZERO	=	# of time steps to skip before start to writing 'gcm_tran' information. IZERO should not be '0' if 'COLD START'. If ITRANFORM = 0, IZERO will be ignored.
IWET	=	0 : entire grid output 1 : wet grid only output

NOTE: If JTM = 0, then go to Data Group D (Standard Level Declaration)

c. Time in Number of Time Steps for Writing the Output

IF ITRANFORM = 0
IF ITRANFORM = 1 skip this block

8	16	...	80
ITRAC(1)	ITRAC(2)	...	ITRAC(JTM)

10I8

ITRAC = time in number of time steps at which the information will be output, necessary for water quality model input

NOTE: ITRAC relative to start of run (independent of RESTART option specified)

DATA GROUP D: Standard Level Declaration

1. Comment

80
COM

80A1

COM = user specified comment about the standard levels

2. Number of Standard Levels

	5
	IKSL
I5	

IKSL = number of standard levels (< 50)

NOTE: To reduce the amount of computer storage required, keep the number of standard levels (IKSL) at a minimum, i.e., IKSL < 50.

3. Standard Levels

	10	20	...	80
	DPTHSL(1)	DPTHSL(2)	...	DPTHSL(IKSL)
8F10.5				

DPTHSL = depth of standard level in meters with respect to surface water level

NOTE: It is not necessary to include the surface level, although it may be included. If not, constituent values associated with the first level below the surface will be applied to the depth between the surface and the first standard level. Extrapolation to the surface may cause incorrect representation of the vertical profile. To ensure proper interpolation of data from standard level to sigma level, each bottom-most sigma level must be bracketed by two standard levels. These standard levels must contain data.

DATA GROUP E: Initial Temperature and Salinity

1. Comment

	80
	COM
80A1	

COM = user specified comment for temperature and salinity data

2. Initial Temperature and Salinity Data Option

	10
	OPTTSI
A20	

OPTTSI = "FIXED" - initial temperature and salinity data are constant for each standard level, initial conservative tracer concentrations specified only with this option.
= "DATA" - initial temperature and salinity data vary horizontally and vertically - data read in from data file "init_tands"

If OPTTSI = "DATA", then go to Data Group F (Open Boundary Condition Information)

3. Initial Temperature Data

10	20	30	...	80
TSI(1)	TSI(2)	TSI(3)	...	TSI(IKSL)
8F10.5				

TSI = temperature in °C

4. Initial Salinity Data

10	20	30	...	80
SSI(1)	SSI(2)	SSI(3)	...	SSI(IKSL)
8F10.5				

SSI = salinity in psu

NOTE: IKSL = number of standard levels

DATA GROUP F: Open Boundary Condition Information

1. **Elevation Boundary Conditions**

a. Comment

80
COM
80A1

COM = user specified comment for elevation boundary condition

b. Number of Grid Elements and Option

5	26
NUMEBC	OPTEBC
I5,1X,A20	

NUMEBC = total number of elevation boundary grid elements. If NUMBEC = 0, then go to Data Group G (Discharge Information)

OPTEBC = "DATA" - use Elevation Boundary Conditions OPTION 1 - Time Variable Data

= "TIDAL CONSTITUENT" - use Elevation Boundary Conditions OPTION 2 - Computer Generated Data from Tidal Constituents

c. Elevation Boundary Conditions

OPTION 1 - TIME VARIABLE DATA

i. Location of Grid Elements

5	10	15	20	...
IETA(1)	JETA(1)	ICON(1)	JCON(1)	...
16I5				

65	70	75	80
IETA(NUMEBC)	JETA(NUMEBC)	ICON(NUMEBC)	JCON(NUMEBC)

IETA	=	i number of grid element where elevation is specified
JETA	=	j number of grid element where elevation is specified
ICON	=	i number of connecting grid element (nearest interior non- boundary grid element)
JCON	=	j number of connecting grid element (nearest interior non- boundary grid element)

NOTE: Every boundary element should have a connecting interior grid element.

ii. Time of Observation

10
TIME
F10.5

TIME	=	time in hours
	=	0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

iii. Elevation Data

10	20	30	...	80
EBDRY(1)	EBDRY(2)	EBDRY(3)	...	EBDRY(NUMEBC)
8F10.5				

EBDRY	=	boundary elevation data in meters at time "TIME"

NOTE: Sequence (TIME/EBDRY) repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs.

OPTION 2 - COMPUTER GENERATED DATA FROM TIDAL CONSTITUENTS

i. Location of Grid Elements and Mean Water Level

	5	10	15	20	30
	IETA	JETA	ICON	JCON	EMEAN
4I5,F10.5					

IETA	=	i number of grid element
JETA	=	j number of grid element
ICON	=	i number of connecting grid element (nearest interior non- boundary grid element)
JCON	=	j number of connecting grid element (nearest interior non- boundary grid element)
EMEAN	=	mean water level in meters with reference to the lowest mean water level of entire domain

ii. Amplitudes of the 6 Dominant Harmonic Constituents

	10	20	30	40	50	60
	AMP-S_2	AMP-M_2	AMP-N_2	AMP-K_1	AMP-P_1	AMP-O_1
6F10.5						

AMP-S_2	=	solar semidiurnal amplitude in meters (period = 12.00 hr)
AMP-M_2	=	lunar semidiurnal amplitude in meters (period = 12.42 hr)
AMP-N_2	=	lunar semidiurnal amplitude in meters (period = 12.66 hr)
AMP-K_1	=	lunar diurnal declination amplitude in meters (period = 23.94 hr)
AMP-P_1	=	solar diurnal declination amplitude in meters (period = 24.06 hr)
AMP-O_1	=	lunar diurnal declination amplitude in meters (period = 25.82 hr)

iii. Phases of the 6 Dominant Harmonic Constituents

	10	20	30	40	50	60
	PHASE-S_2	PHASE-M_2	PHASE-N_2	PHASE-K_1	PHASE-P_1	PHASE-O_1
6F10.5						

PHASE-S_2	=	solar semidiurnal phase in degrees (period = 12.00 hr)
PHASE-M_2	=	lunar semidiurnal phase in degrees (period = 12.42 hr)
PHASE-N_2	=	lunar semidiurnal phase in degrees (period = 12.66 hr)
PHASE-K_1	=	lunar diurnal declination phase in degrees (period = 23.94 hr)
PHASE-P_1	=	solar diurnal declination phase in degrees (period = 24.06 hr)
PHASE-O_1	=	lunar diurnal declination phase in degrees (period = 25.82 hr)

NOTE: Every boundary element should have a connecting interior grid element. Sequence i/ii/iii repeated for each boundary element. Total number = NUMEBC (total number of elevation boundary grid elements). Phases of each component are in degrees and are with respect to Greenwich Mean Time.

2. Time Variable Temperature and Salinity Boundary Conditions

a. Comment

```
   80
  COM
80A1
```

COM = user specified comment for temperature and salinity boundary conditions

b. Temperature and Salinity Boundary Conditions

i. Time of Observation

```
   10
  TIME
F10.5
```

TIME	=	time in hours
	=	0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

ii. Location of Grid Elements, Temperature and Salinity Data

5	10	15	20	...
ITAS	JTAS	TBDRYSL(NUMEBC,1)	TBDRYSL(NUMEBC,2)	...
2I5,100F5.0				

260	265	270	...
TBDRSYL(NUMEBC,IKSL)	SBDRYSL(NUMEBC,1)	SBDRYSL(NUMEBC,2)	...

510
SBDRYSL(NUMEBC,IKSL)

ITAS = i number of grid element where temperature and salinity are specified

JTAS = j number of grid element where temperature and salinity are specified

TBDRYSL = temperature in °C at time "TIME" for each standard level (not sigma level)

SBDRYSL = salinity in psu at time "TIME" for each standard level (not sigma level)

NOTE:

1. Sequence (ITAS/JTAS/TBDRYSL/SBDRYSL) repeated for each location. Total number = NUMEBC (total number of boundary grid elements). The sequence (TIME/ TBDRYSL/SBDRYSL) repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. TIME for temperature and salinity observation need not be the same as for elevation observations.

2. The ITAS, JTAS sequence of temperature/salinity boundary conditions must correspond exactly to the IETA, JETA sequence of elevation boundary conditions, i.e., ITAS = IETA and JTAS = JETA for n = 1 to n = NUMEBC.

DATA GROUP G: Discharge Information

1. Time Variable River/Dam and Onshore Intake/Outfall Discharges

a. Comment

80
COM
80A1

COM = user specified comment for discharge

b. Number of Grid Elements

5
NUMQBC
I5

NUMQBC = total number of discharge boundary grid elements. If NUMQBC = 0, then go to Data Group G.2 (Time Variable Offshore Intake/Outfall (Diffuser) Discharges)

c. Location of Grid Elements/Vertical Distribution of Intake/Outfall Discharge

5	10	15	20
IQD(NUMQBC)	JQD(NUMQBC)	IQC(NUMQBC)	JQC(NUMQBC)
4I5,20F5.0			

25	30	35	...	120
VQDIST(1)	VQDIST(2)	VQDIST(3)	...	VQDIST(KBM1)

IQD = i number of grid element discharge enters/leaves
JQD = j number of grid element discharge enters/leaves
IQC = i number of connecting exterior boundary grid element
JQC = j number of connecting exterior boundary grid element
VQDIST = percentage (not fraction) of total discharge QDIS apportioned to each model layer from surface to bottom at location (IQD,JQD)

KBMI = KB-1

NOTE: 1. Sequence (IQD/JQD/IQC/JQC/VQDIST) is repeated for each discharge location.

d. Time of Observation

10
TIME
F10.5

TIME = time in hours
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

e. Discharge Data

10	20	30	...	80
QDIS(1)	QDIS(2)	QDIS(3)	...	QDIS(NUMQBC)
8F10.5				

QDIS = discharge flow in m^3/sec
> 0.0 (positive) for flow into the model domain (river/outfall)
< 0.0 (negative) for flow out of the model domain (intake)

f. Temperature Data

10	20	30	...	80
TDIS(1)	TDIS(2)	TDIS(3)	...	TDIS(NUMQBC)
8F10.5				

TDIS = temperature of discharge in °C

g. Salinity Data

10	20	30	...	80
SDIS(1)	SDIS(2)	SDIS(3)	...	SDIS(NUMQBC)

8F10.5

SDIS = salinity of discharge in psu

NOTE: Sequence (TIME/QDIS/TDIS/SDIS) repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. Discharges leaving the model domain (intakes) do not require associated T and S values. However, a value of zero should be input as the values for T and S of these discharges.

2. Time Variable Offshore Intake/Outfall (Diffuser) Discharges

a. Comment

80
COM

80A1

COM = user specified comment for discharge

b. Number of Grid Elements

5
NUMDBC1

I5

NUMDBC 1 = total number of discharge grid elements. If NUMDBC = 0, then go to Data Group G3 (Time Variable Offshore Intake/Outfall (Diffuser) Discharges in Loops)

c. Location of Grid Elements/Vertical Distribution of Intake/Outfall Diffuser Discharge

5	10	15	20	...	110
IDD(NUMDBC)	JDD(NUMDBC)	VDDIST(1)	VDDIST(2)	...	VDIST(KBM1)

2I5,20F5.0

IDD = i number of grid element diffuser enters/leaves
JDD = j number of grid element diffuser enters/leaves
VDDIST = percentage (not fraction) of total discharge DQDIFF apportioned each model layer from surface to bottom at location (IDD,JDD)
KBM1 = KB-1

NOTE:
1. Sequence (IDD/JDD/VDDIST) is repeated for each diffuser location.
2. More than one diffuser can be specified at the same location (IDD, JDD)

d. Time of Observation

10
TIME

F10.5

TIME = time in hours
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

e. Discharge Data

10	20	...	80
QDIFF(1)	QDIFF(2)	...	QDIFF(NUMDBC1)

8F10.5

QDIFF = diffuser discharge in m^3/sec

f. Temperature Data

10	20	30	...	80
TDIFF(1)	TDIFF(2)	TDIFF(3)	...	TDIFF(NUMDBC)
8F10.5				

TDIFF = temperature of diffuser discharge in °C

g. Salinity Data

10	20	30	...	80
SDIFF(1)	SDIFF(2)	SDIFF(3)	...	SDIFF(NUMDBC)
8F10.5				

SDIFF = salinity of diffuser discharge in psu

NOTE: Sequence (TIME/QDIFF/TDIFF/SDIFF) repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. Discharges leaving the model domain do not require associated T and S values. However, a value of zero should be input as the values for T and S of these discharges.

3. Time Variable Offshore Intake/Outfall (Diffuser) Discharges in Loops

a. Comment

```
  80
COM
 80A1
```

COM = user specified comment for discharge in loops

b. Number of Grid Elements

```
        5
  NUMDBC2
I5
```

NUMDBC2 = total number of discharge grid elements. If NUMDBC2 = 0, then go to Data Group H (Meteorological Data). The NUMDBC2 should be even numbers; intake/outfall diffusers are specified in pairs; diffuser is intake and the other is recirculating discharging outfall (i.e., one diffuser discharges the volume of water withdrawn through the other)

c. Location of Grid Elements/Vertical Distribution of Intake/Outfall Diffuser Discharge

5	10	15	20	...	110
IDD(NUMDBC)	JDD(NUMDBC)	VDDIST(1)	VDDIST(2)	...	VDIST(KBM1)

2I5,20F5.0

IDD = i number of grid element diffuser enters/leaves
JDD = j number of grid element diffuser enters/leaves
VDDIST = percentage (not fraction) of total discharge DQDIFF apportioned each model layer from surface to bottom at location (IDD,JDD)
KBM1 = KB-1

NOTE: Sequence (IDD/JDD/VDDIST) is repeated for each intake/outfall diffuser location.

d. Time of Observation

10
TIME

F10.5

TIME = time in hours
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

e. Discharge Data

10	20	...	80
DQDIFF(1)	DQDIFF(2)	...	DQDIFF(NUMDBC2)

8F10.5

DQDIFF = diffuser discharge in m^3/sec. Even though DQDIFF(N) and DQDIFF(N+1) is a coupling intake/outfall pair, the DQDIFF(N) and DQDIFF(N+1) need not be equal.

f. Temperature Data

10	20	30	...	80
DTDIFF(1)	DTDIFF(2)	DTDIFF(3)	...	DTDIFF(NUMDBC2)

8F10.5

DTDIFF = temperature increase/decrease of diffuser discharge in ºC. Only effective on diffuser having positive values of DQDIFF. This increase/decrease of temperature is with respect to the temperature of corresponding intake.

g. Salinity Data

10	20	30	...	80
DSDIFF(1)	DSDIFF(2)	DSDIFF(3)	...	DSDIFF(NUMDBC2)

8F10.5

DSDIFF = salinity increase/decrease of diffuser discharge in psu. Only effective on diffuser having positive values of DQDIFF.

NOTE: Sequence (TIME/DQDIFF/DTDIFF/DSDIFF) repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. Discharges leaving the model domain do not require associated T and S values. However, a value of zero should be input as the values for T and S of these discharges.

DATA GROUP H: **Meteorological Data**

1. Comment

	80
	COM
80A1	

COM = user specified comment for meteorological data

2. Meteorological Data Option

	10	20	30	40	50
	OPTMBC	ALAT	ALON	TR	WNDSH
A10,4F10.2					

OPTMBC = "AVERAGED" - a single value for each meteorological parameter is used for all grid element at each time - use Meteorological Data OPTION 1 - Time Variable Surface Heat Flux Data, Salt Flux Data and Wind Data

= "SYNOPTIC" - spatially varying meteorological parameter values are specified for every grid element at each time - use Meteorological Data OPTION 2 - Averaged Time Variable Surface Heat Flux Data and Salt Flux Data and Synoptic Time Variable Wind and Atmospheric Pressure Data

= “AANDBFLX” - heat flux sub-model based on the work of Ahsan and Blumberg (1999). The local heat flux is determined from local surface temperature - use Meteorological Data OPTION 3 - Time Variable Surace Heat Flux Parameters, Salt Flux Data and Wind Data

= “LANDPFLX” - heat flux sub-model based on the work of Large and Pond (1982). The local heat flux is determined from local surface temperature - use Meteorological Data OPTION 3 - Time Variable Surface Heat Flux Parameters, Salt Flux Data and Wind Data.

= “RANDMFLX” - heat flux sub-model based on the work of Rosati and Miyakoda (1988). The local heat flux is determined from local surface temperature - use Meteorological Data OPTION 3

- Time Variable Surface Heat Flux Parameters, Salt Flux Data and Wind Data.

ALAT	=	Latitude (in degrees, median of modeling domain)
ALON	=	Longitude (in degrees, median of modeling domain)
TR	=	Fraction of short wave radiation absorbed in surface layer
WNDSH	=	Wind sheltering coefficient

3. Meteorological Data

OPTION 1 - Time Variable Surface Heat Flux Data, Salt Flux Data and Wind Data

i. Time of Observation

10
TIME
F10.5

TIME	=	time in hours
	=	0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

ii. Precipitation, Evaporation, Heat Flux, Wind Speed and Direction Data

10	20	30	40	40
WDS	WDD	HFLUX	QPREC	QEVAP
5F10.5				

WDS	=	wind speed in m/sec
WDD	=	direction of wind in degrees from which the wind blows, measured clockwise from north
HFLUX	=	heat flux in watts/m^2
	>	0, heating of the water
	<	0, cooling of the water
QPREC	=	amount of precipitation in m/year

QEVAP = amount of evaporation in m/year

NOTE: Sequence (TIME/QPREC/QEVAP/HFLUX/WDS/WDD) repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than (IEND + NSTEPS) x DTI/3600 for HOT START runs.

OPTION 2 - Synoptic Time Variable Surface Heat Flux Data, Synoptic Wind, and Atmospheric Pressure Data

i. Wind and atmospheric pressure data input from file "synop_wind" (Table 8-4A)

ii Surface Heat Flux Data Input from File "synop_hflx" (Table 8-4B)

OPTION 3 - Time Variable Surface Heat Flux Parameters, Salt Flux Data and Wind Data

i. Time of Observation

	10
	TIME
F10.5	

TIME = time in hours
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

ii Precipitation, Evaporation, Heat Flux, Wind Speed and Direction Data

10	20	30	40	50
WDS	WDD	SWOBS	AIRTMP	RELHUM
60	70	80	90	100
BAROP	CLD	EXTC	QPREC	QEVAP

10F10.5

WDS	=	wind speed in m/sec
WDD	=	direction of wind in degrees from which the wind blows, measured clockwise from north
SWOBS	=	observed shortwave radiation in watts/m^2
AIRTMP	=	air temperature in °C
RELHUM	=	relative humidity in percent
BAROP	=	barometric pressure in mbar
CLD	=	cloud cover fracton (0.0 to 1.0)
EXTC	=	extinction coefficient
QPREC	=	amount of precipitation in m/year
QEVAP	=	amount of evaporation in m/year

NOTE: Sequence (TIME/QPREC/QEVAP/AIRTMP/RELHUM/BAROP/SWOBS/WDS/WDD) repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run) for COLD START runs, and greater than (IEND + NSTPS) x DTI/3600 for HOT START runs.

Table 10-4A. synop_wind INPUT FILE SUMMARY OF DATA GROUPS

Data Group	Description
A.	Time Variable Synoptic Wind and Atmospheric Pressure Data Time of observation Wind and atmospheric pressure data

synop_wind INPUT FILE (UNFORMATTED)

Data Group A

1. Time

TIME

TIME = time of observation
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

2. Wind and Atmospheric Pressure Data

((TX2D(I,J),TY2D(I,J),PATM(I,J),I=1,IM),J=1,JM)

TX2D = velocity component in m/sec in the east-west direction
TY2D = velocity component in m/sec in the north-south direction
PATM = atmospheric pressure in mb

NOTE: Sequence (TIME/TX2D/TY2D) repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs.

Table 10-4B. synop_hflx INPUT FILE SUMMARY OF DATA GROUPS

Data Groups	Description
A.	Time Variable Synoptic Surface Heat Flux Data Time of observation Surface heat flux data

synop_hflx INPUT FILE (UNFORMATTED)

Data Group A

1. Time

TIME

TIME = time of observation
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

2. Surface Heat Flux Data

((SHFLX(I,J),I=1,IM),J=1,
JM)

SHFLX = surface heat flux in w/m^2

NOTE: Sequence (TIME/SHFLX) repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs.

Table 10-5. corner_loc INPUT FILE

Table 8-5 lists the format of corner_loc that contains corner locations of grid elements for wind, wave and particle tracking simulations. For transport calculations, user created input files are summarized in Table 8-6. Tables 8-7 through 8-24 list the detailed formats of those files. Model generated output files are summarized in Table 8-25. Tables 8-26 through 8-30 list the detailed format of some selected model output files in Table 8-25.

NOTE: PARTICLE = "INCLUDE"

	5	10	20	30
	I	J	XCOR(I,J)	YCOR(I,J)
2I5, 2F10.0				

I = i number of corner location in ζ_1 direction
J = j number of corner location in ζ_2 direction
XCOR(I,J) = corner location in x-direction (East), in meters
YCOR(I,J) = corner location in y-direction (North), in meters

NOTE: Notation convention is XCOR(I,J) = x(i-1/2, j-1/2) and YCOR(I,J) = y(i-1/2, j-1/2) (Lower left hand corner of element)

Table 10-6. Summary of User Created Input Files for Transport Calculations

File	Description
water_tracer.inp	Contains input parameters and boundary condition values for dissolved tracer transport.
coh_sed.inp	Contains input parameters and boundary condition values for cohesive sediment transport.
noncoh_sed.inp	Contains input parameters and boundary condition values for non-cohesive sediment transport.
coh_trace.inp	Contains input parameters and boundary condition values for cohesive sediment-bound tracer transport.
noncoh_trace.inp	Contains input parameters and boundary condition values for non-cohesive sediment-bound tracer transport.
partrack.inp	Contains input parameters for particle tracking.
bed_mask	Contains sediment bed map for the entire model grid.
p0_init	Contains spatially-variable, initial cohesive bed fractions for the entire model grid.
a0_init	Contains spatially-variable a_0 values for the entire model grid.
exp_init	Contains spatially-variable values of exponent n for the entire model grid.
bed_d50	Contains spatially-variable D_{50} values for the entire model grid.
bed_frac.mud	Contains spatially-variable cohesive composition fractions for the entire model grid, clay/silt fraction.
bed_frac.sand	Contains spatially-variable cohesive composition fractions for the entire model grid, sand fraction.
bed_bulkden:	Contains spatially-variable sediment bed bulk density for the entire model grid.
bed_chemic:	Contains spatially-variable initial bed concentrations for sediment-bound tracer for the entire model grid.
NOTE:	All of the above input files are formatted.
hqi_geom:	Contains grid segmentation information to be used for transport calculations.
hqi_tran:	Contains the computed results as a time history for surface elevations and hydrodynamic advection/dispersion fields to be used for transport calculations.
wave_input:	Contains computed results as a time history for wind wave parameters as calculated using a wind wave model (e.g., WAM or HISWA).
NOTE:	These three files are unformatted.

Table 10-7. water_trace.inp INPUT FILE

NOTE: This file must be included for dissolved tracer transport simulations. (TRACER = "INCLUDE")

1. Comment - Dissolved Tracer Input Parameters

80
COM
80A1

COM = user specified comment for dissolved tracer input parameters

2. Dissolved Tracer Input Parameters

10	20
CONDRAT	CONINIT
2F10.2	

CONDRAT = dissolved tracer decay rate (first-order decay) in day^{-1}

CONINIT = initial dissolved tracer concentration in mg/l, assumed spatially constant

3. Comment - Dissolved Tracer Concentrations at Open Boundaries

80
COM
80A1

COM = user specified comment for dissolved tracer concentrations at open boundaries

4. Number of Grid Elements

5
NUMEBCTR
I5

NUMEBCTR = total number of open boundary elements at which dissolved tracer concentrations will be specified

5. Time of Observation

10
TIME
F10.1

TIME = time in hours
= 0.0 for initial time

6. Location of Grid Elements and Dissolved Tracer Data

5	10	15	20	25	
ITRED	JTRED	ITREC	JTREC	CBDRYSL1(1)	... CBDRYSL1(IKSL)
4I5,100F5.0					

ITRED = i number of grid element where dissolved tracer is specified
JTRED = j number of grid element where dissolved tracer is specified
ITREC = i number of connecting grid element (nearest interior non-boundary grid element)
JTREC = j number of connecting grid element (nearest interior non-boundary grid element)
CBDRYSL1 = dissolved tracer concentration in mg/l at "TIME" for each standard level (not sigma level)

NOTE: 1. Sequence (ITRED/JTRED/CBDRYSL1) is repeated for each location. Total number = NUMEBCTR (total number of boundary grid elements). The sequence (TIME/CBDRYSL1) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. "TIME" for dissolved tracer observations need not be the same as for elevation observations in run_data.

2. If HYDTYPE = 'INTERNAL', then NUMEBCTR = NUMEBC (as specified in Data Group F, Table 8-3B: Open Boundary Condition Information in run_data).

3. If HYDTYPE = 'EXTERNAL', then dissolved tracer concentrations **must** be specified at all open boundaries in the domain.

7. Comment - Dissolved Tracer Concentrations at River Discharges

	80
	COM
80A1	

COM = user specified comment for dissolved tracer concentrations at river discharges

8. Number of Grid Elements

	5
	NUMQBCTR
I5	

NUMQBCTR = total number of river discharges at which dissolved tracer concentrations will be specified

9. Location of Grid Elements

	5	10	15	20
	ITRQD	JTRQD	ITRQC	JTRQC
4I5				

ITRQD = i number of grid element discharge enters
JTRQD = j number of grid element discharge enters
ITRQC = i number of connecting exterior boundary grid

		element
JTRQC	=	j number of connecting exterior boundary grid element

NOTE: Sequence ITRQD/JTRQD/ITRQC/JTRQC is repeated for each discharge location.

10. Time of Observation

```
        10
      TIME
F10.1
```

TIME	=	time in hours
	=	0.0 for initial time

11. Dissolved Tracer Data

```
          10         20         30                            80
   CDIS1(1)   CDIS1(2)   CDIS1(3)     ... CDIS1(NUMQBCTR)
8F10.1
```

CDIS1	=	dissolved tracer concentration of river discharge in mg/l

NOTE:

1. The sequence (TIME/CDIS1) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. Discharges leaving the mode domain (shore-based intakes) do not require associated CDIS1 values. However, a value of zero should be input for CDIS1 of these discharges.

2. If HYDTYPE = 'INTERNAL', then NUMQBCTR = NUMQBC (as specified in Data Group G, Table 8-3B: Discharge Information in run_data).

3. If HYDTYPE = 'EXTERNAL', then dissolved tracer concentrations **must** be specified at all river discharges in the domain.

NOTE: Only include the next data group (items 12 -14) if offshore discharges (diffuser outfalls) are specified in run_data (NUMDBC > 0 in Data Group G (Table 8-3B): Discharge Information)

12. Comment - Dissolved Tracer Concentrations at Offshore Discharges

80
COM
80A1

COM = user specified comment for dissolved tracer concentrations at offshore discharges

13. Number of Grid Elements

5
NUMDBCTR1
I5

NUMDBCTR1 = total number of offshore discharges at which dissolved tracer concentraitons will be specified

14. Location of Grid Elements

5	10
ITRDD	JTRDD
2I5	

ITRDD = i number of grid element discharge enters
JTRDD = j number of grid element discharge enters

NOTE: Sequence ITRDD/JTRDD is repeated for each discharge location

15. Time of Observation

10
TIME
F10.1

TIME = time in hours
= 0.0 for initial time

16. Dissolved Tracer Data

10	20	30	80
CDIFF1(1)	CDIFF1(2)	CDIFF1(3)	... CDIFF1(NUMDBCTR1)

8F10.1

CDIFF1 = dissolved tracer concentration of offshore discharge in mg/l

NOTE: The sequence (TIME/CDIFF1) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs.

17. Comment-Dissolved Tracer Concentrations at Offshore Discharges in Loops

80
COM
80A1

COM = user specified comment for dissolved tracer concentrations at offshore discharges in loops

18. Number of Grid Elements

5
NUMDBCTR2
I5

NUMDBCTR2 = total number of offshore discharges in loops at which dissolved tracer concentrations will be specified

19. Time of Observations

10
TIME
F10.1

TIME = time in hours
= 0.0 for initial time

20. Dissolved Tracer Data

10	20	30	80
DCDIFF1(1)	DCDIFF1(2)	DCDIFF1(3)	DCDIFF1(NUMDBCTR2)

8F10.1

DCDIFF1 = dissolved tracer concentrations of offshore discharge in loops in mg/l

NOTE: The sequence (TIME/DCDIFF1) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLDSTART runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOTSTART runs.

21. Comment - Dissolved Tracer Point Source Loads

80
COM

80A1

COM = user specified comment for dissolved tracer point source loads

22. Number of Grid Elements and Point Source Loading Option

5	15
NUMPSTR	OPTPSTR

I5,6X,A4

NUMPSTR = total number of grid elements at which dissolved tracer point source loads will be specified

OPTPSTR = "MASS" - dissolved tracer point sources are specified as a mass loading in kg/s
= "CONC" - dissolved tracer point sources are specified as instantaneous concentrations in mg/l

23. Location of Grid Elements

	5	10	15
	IPSTR	JPSTR	KPSTR
3I5			

IPSTR = i number of grid element where dissolved tracer point source is specified

JPSTR = j number of grid element where dissolved tracer point source is specified

KPSTR = k number of grid element where dissolved tracer point source is specified

NOTE: Sequence IPSTR/JPSTR/KPSTR is repeated for each point source location.

24. Time of Observation

	10
	TIME
F10.1	

TIME = time in hours
= 0.0 for initial time

25. Dissolved Tracer Data

	10	20	80
	PSLOAD(1)	PSLOAD(2)	.... PSLOAD(NUMPSTR)
8F10.1			

PSLOAD = dissolved tracer load in kg/s (OPTPSTR = "MASS")
= dissolved tracer load in mg/l (OPTPSTR = "CONC")

NOTE: 1. If OPTPSTR = "CONC", then the point source load is specified by instantaneously setting the dissolved tracer concentration in grid element (IPSTR, JPSTR,KPSTR) equal to PSLOAD (mg/l) at the specified time whenever PSLOAD > 0. No point source load will be specified at all times that PSLOAD = 0 mg/l.

2. The sequence (TIME/PSLOAD) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run) for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs.

NOTE: "TIME" for all the above boundary conditions is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

Table 10-8. coh_sed.inp INPUT FILE

NOTE: This file must be included for cohesive sediment transport simulations. (SEDTRAN = "INCLUDE" and SEDTYPE = "BOTH" or "MUD ")

1. Comment - Sediment Transport Control Parameters

80
COM
80A1

COM = user specified comment for sediment transport control parameters

2. Sediment Transport Control Parameters

10	20
NSEDBEG	NSBED
2I10	

NSEDBEG = time step at which to start sediment transport calculation

NSBED = frequency, in time steps, at which to calculate deposition/ resuspension fluxes

NOTE: If SEDTYPE = "BOTH", then NSEDBEG and NSBED must have the same values in both coh_sed.inp and noncoh_sed.inp.

3. Comment - Cohesive Sediment Deposition Parameters

80
COM
80A1

COM = user specified comment for cohesive sediment deposition parameters

4. Cohesive Sediment Deposition Parameters

10	20	30	40
ADEP	DEPEXP	TCRDEP	PDEPFORM

3F10.0, 5X,A5

ADEP = A_{set} coefficient for floc settling speeds in µm/s
DEPEXP = b exponent for floc settling speeds
TCRDEP = critical shear stress for deposition of cohesive sediment in dynes/cm^2
PDEPFORM = "KRONE" - Krone formulation for probability of deposition (TCRDEP = τ_d in Eq. 5-11)
"PARTH" - Partheniades formulation for probability of deposition (TCRDEP = $\tau_{b,min}$ in Eq. 5-13)

5. Comment - Cohesive Sediment Resuspension Parameters

80
COM

80A1

COM = user specified comment for cohesive sediment resuspension parameters

6. Cohesive Sediment Resuspension Parameters

10	20	30	40
A0IN	RESEXP	EXPM	VARIA0N

3F10.0, 3X,A7

A0IN = a_o parameter in Eq. (5-5) in mg/cm^2, spatially-constant value when VARIA0N = "NEGLECT"
RESEXP = exponent n in Eq. (5-5), spatially-constant value when VARIA0N = "NEGLECT"
EXPM = exponent m in Eq. (5-5)
VARIA0N = "INCLUDE" - spatially-variable values of a_o and n in Eq. (5-5), input from a0_init and exp_init files
"NEGLECT" - spatially-constant values of a_o and n in Eq. (5-5), input as A0IN and RESEXP

7. Comment - Cohesive Sediment Bed Property Parameters

80
COM
80A1

COM = user specified comment for cohesive sediment bed property parameters

8. Cohesive Sediment Bed Property Parameters

10	20	30	40	50	60
DENCOH	VARIBULK	P0(1)	VARIPO	BFCOH	Z0COH

F10.0, 3X,A7, F10.0,3X,A7,2F10.0

DENCOH = bulk density of cohesive sediment bed in g/cm^3

VARIBULK = "INCLUDE" - spatially-variable sediment bed bulk density (g/cm^3), input from bed_bulkden file
"NEGLECT" - spatially-constant bulk density, input as DENCOH (cohesive bed) and DENNON (non-cohesive bed)

NOTE: If SEDTYPE = "BOTH", then VARIBULK must have same values in both co_sed.inp and non coh_sed.inp.

P0(1) = initial, spatially-constant fraction of fine class sediment in bed

VARIPO = "INCLUDE" - initial, spatially-variable fraction of fine class sediment in bed, input from p0_init file
"NEGLECT" - initial, spatially-constant fraction of fine class sediment in bed , input as P0(1)

BFCOH = bottom friction coefficient for cohesive sediments (non-dimensional)

Z0COH = bottom roughness coefficient for cohesive sediments, in meters

9. Comment - Cohesive Bed Consolidation Parameters

80
COM

80A1

COM = user specified comment for cohesive bed consoldiation parameters

10. Cohesive Bed Consolidation Parameters

10	20	30	40	50	60	70
FTIME(1)	FTIME(2)	FTIME(3)	FTIME(4)	FTIME(5)	FTIME(6)	FTIME(7)

8F10.0

FTIME(1) = time after deposition of sediment layer 1, in days
FTIME(2) = time after deposition of sediment layer 2, in days
FTIME(3) = time after deposition of sediment layer 3, in days
FTIME(4) = time after deposition of sediment layer 4, in days
FTIME(5) = time after deposition of sediment layer 5, in days
FTIME(6) = time after deposition of sediment layer 6, in days
FTIME(7) = time after deposition of sediment layer 7, in days

11. Comment - Initial Cohesive Bed Thickness

80
COM

80A1

COM = user specified comment for cohesive bed thickness

12. Initial Cohesive Bed Thickness

10	20	30	40	50	60	70
TSED0(1)	TSED0(2)	TSED0(3)	TSED0(4)	TSED0(5)	TSED0(6)	TSED0(7)

8F10.0

TSED0(1) = initial thickness of sediment layer 1, in cm
TSED0(2) = initial thickness of sediment layer 2, in cm
TSED0(3) = initial thickness of sediment layer 3, in cm
TSED0(4) = initial thickness of sediment layer 4, in cm

TSED0(5)	=	initial thickness of sediment layer 5, in cm
TSED0(6)	=	initial thickness of sediment layer 6, in cm
TSED0(7)	=	initial thickness of sediment layer 7, in cm

13. Comment - Cohesive Bed Critical Shear Stress

80
COM
80A1

COM = user specified comment for critical shear stress

14. Cohesive Bed Critical Shear Stress

10	20	30	40	50	60	70
TAUCR(1)	TAUCR(2)	TAUCR(3)	TAUCR(4)	TAUCR(5)	TAUCR(6)	TAUCR(7)
8F10.0						

TAUCR(1)	=	critical shear stress of sediment layer 1, in dynes/cm^2
TAUCR(2)	=	critical shear stress of sediment layer 2, in dynes/cm^2
TAUCR(3)	=	critical shear stress of sediment layer 3, in dynes/cm^2
TAUCR(4)	=	critical shear stress of sediment layer 4, in dynes/cm^2
TAUCR(5)	=	critical shear stress of sediment layer 5, in dynes/cm^2
TAUCR(6)	=	critical shear stress of sediment layer 6, in dynes/cm^2
TAUCR(7)	=	critical shear stress of sediment layer 7, in dynes/cm^2

15. Comment - Initial Suspended Sediment Concentration

80
COM
80A1

COM = user specified comment for initial suspended sediment concentration

16. Initial Suspended Sediment Concentration

10
CSI
F10.0

CSI = initial, spatially-constant cohesive sediment concentration, in mg/l

17. Comment - Cohesive Sediment Concentrations at Open Boundaries

10
COM
80A1

COM = user specified comment for cohesive sediment concentrations at open boundaries

18. Number of Grid Elements

5
NUMEBSCE
I5

NUMEBCSE = total number of open boundary elements at which cohesive sediment concentrations will be specified

19. Time of Observation

10
TIME
F10.1

TIME = time in hours
= 0.0 for initial time

20. Location of Grid Elements and Cohesive Sediment Data

5	10	15	20	25	
ISEED	JSEED	ISEEC	JSEEC	CBDRYSL(1)	... CBDRYSL(IKSL)
4I5,100F5.0					

ISEED = i number of grid element where cohesive sediment is specified

JSEED = j number of grid element where cohesive sediment is specified

ISEEC = i number of connecting grid element (nearest interior non-boundary grid element)

JSEEC = j number of connecting grid element (nearest interior non-boundary grid element)

CBDRYSL = cohesive sediment concentration in mg/l at "TIME" for each standard level (not sigma level)

NOTE: 1. Sequence (ISEED/JSEED/ISEEC/JSEEC/CBDRYSL) is repeated for each location. Total number = NUMEBCSE (total number of boundary grid elements). The sequence (TIME/CBDRYSL) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. "TIME" for cohesive sediment observations need not be the same as for elevation observations in run_data.

2. If HYDTYPE = 'INTERNAL', then NUMEBCSE = NUMEBC (as specified in Data Group F, Table 8-3B: Open Boundary Condition Information in run_data).

3. If HYDTYPE = 'EXTERNAL', then cohesive sediment concentrations **must** be specified at all open boundaries in the domain.

21. Comment - Cohesive Sediment Concentrations at River Discharges

10
COM
80A1

COM = user specified comment for cohesive sediment concentrations at river discharges

22. Number of Grid Elements

5
NUMQBCSE
I5

NUMQBCSE = total number of river discharges at which cohesive sediment concentrations will be specified

23. Location of Grid Elements

5	10	15	20
ISEQD	JSEQD	ISEQC	JSEQC

4I5

ISEQD = i number of grid element discharge enters
JSEQD = j number of grid element discharge enters
ISEQC = i number of connecting exterior boundary grid element
JSEQC = j number of connecting exterior boundary grid element

NOTE: Sequence ISEQD/JSEQD/ISEQC/JSEQC is repeated for each discharge location.

24. Time of Observation

10
TIME

F10.1

TIME = time in hours
= 0.0 for initial time

25. Cohesive Sediment Data

10	20	30	80
CDIS(1)	CDIS(2)	CDIS(3)	... CDIS(NUMQBCSE)

8F10.1

CDIS = cohesive sediment concentration of river discharge in mg/l

NOTE: 1. The sequence (TIME/CDIS) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. Discharges leaving the mode domain (shore-based intakes) do not require associated CDIS values. However, a value of zero should be input for CDIS of these discharges.

2. If HYDTYPE = 'INTERNAL', then NUMQBCSE = NUMQBC (as specified in Data Group G, Table 8-3B: Discharge Information in run_data).

3. If HYDTYPE = 'EXTERNAL', then cohesive sediment concen-trations **must** be specified at all river discharges in the domain.

NOTE: "TIME" for all the above boundary conditions is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

26. Comment - Cohesive Sediment Loading in Diffuser Discharges

80
COM
80A1

COM = user specified comment for cohesive sediment loading in diffuser discharges

27. Number of Grid Elements

5
NUMDBCSE
15

NUMDBCSE = total number of diffusers at which cohesive sediment loading will be specified. If NUMDBCSE = 0, then terminate input.

28. Location of Grid Elements/Vertical Distribution of Diffuser Loadings

5	10	15	20	. . .110
IDDSE(NUMDBCSE)	JDDSE(NUMDBCSE)	VDDISTSE(1)	VDDISTSE(2)	VDDISTSE(KBM1)
2I5,20F5.0				

IDDSE	=	i number of grid element diffuser enters/leaves
JDDSE	=	j number of grid element diffuser enters/leaves
VDDISTSE	=	percentage (not fraction) of total diffuser loading CDIFF apportioned in each model layer from surface to bottom at location (IDDSE, JDDSE)
KBM1	=	KB-1

NOTE:
1. Sequence (IDDSE/JDDSE/VDDISTSE) is repeated for each diffuser
2. More than one diffuser can be specified at the same location (IDDSE, JDDSE)

29. Time of Observation

10
TIME
F10.5

TIME = time in hours
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

30. Diffuser Loading Data

10	20	. . .	80
CDIFF(1)	CDIFF(2)	. . .	CDIFF(NUMDBCSE)
8F10.5			

CDIFF = diffuser loading in kg/day.

NOTE: Sequence (TIME/CDIFF) repeated for each observation. Final "TIME" must be greater than (NSTEPS*DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPSxDTI)/3600 for HOT START runs.

Table 10-9. noncoh_sed.inp INPUT FILE

NOTE: This file must be included for non-cohesive sediment transport simulations. (SEDTRAN = "INCLUDE" and SEDTYPE = "BOTH" or "SAND")

1. Comment - Sediment Transport Control Parameters

	10
	COM
80A1	

COM = user specified comment for sediment transport control parameters

2. Sediment Transport Control Parameters

	10	20
	NSEDBEG	NSBED
2I10		

NSEDBEG = time step at which to start sediment transport calculation

NSBED = frequency, in time steps, at which to calculate deposition/ resuspension fluxes

NOTE: If SEDTYPE = "BOTH", then NSEDBEG and NSBED must have the same values in both coh_sed.inp and noncoh_sed.inp.

3. Comment - Non-Cohesive Sediment Transport Parameters

	10
	COM
80A1	

COM = user specified comment for non-cohesive sediment transport parameters

4. Non-Cohesive Sediment Transport Parameters

10	20	30	40	50
WS2	DENNON	VARIBULK	SUSARM	BEDTHI

2F10.0,3X,A7,2F10.0

WS2 = settling speed of non-cohesive sediment, in µm/s
DENNON = bulk density of non-cohesive sediment bed, in g/cm^3
VARIBULK = "INCLUDE" - spatially-variable sediment bed bulk density (g/cm^3), input from bed_bulkden file
"NEGLECT" - spatially-constant bulk density, input as DENCOH (cohesive bed) and DENNON (non-cohesive bed)
SUSARM = non-cohesive bed armoring constant (0 - 1.0 range)

NOTE: If SEDTYPE = "BOTH", then VARIBULK must have same values for both coh_sed.inp and noncoh_sed.inp

BEDTHI = initial thickness of non-cohesive bed, in cm

5. Comment - Initial Suspended Sediment Concentration

10
COM

80A1

COM = user specified comment for initial suspended sediment concentration

6. Initial Suspended Sediment Concentration

10
CSI

F10.0

CSI = initial, spatially-constant non-cohesive sediment concentration, in mg/l

7. Comment - Non-Cohesive Sediment Concentrations at Open Boundaries

10
COM
80A1

COM = user specified comment for non-cohesive sediment concentrations at open boundaries

8. Number of Grid Elements

5
NUMEBCSE
I5

NUMEBCSE = total number of open boundary elements at which non-cohesive sediment concentrations will be specified

9. Time of Observation

10
TIME
F10.1

TIME = time in hours
= 0.0 for initial time

10. Location of Grid Elements and Non-Cohesive Sediment Data

5	10	15	20	25	
ISEED	JSEED	ISEEC	JSEEC	CBDRYSL(1)	... CBDRYSL(IKSL)
4I5,100F5.0					

ISEED = i number of grid element where non-cohesive sediment is specified

JSEED = j number of grid element where non-cohesive sediment is specified

ISEEC = i number of connecting grid element (nearest interior non-boundary grid element)

JSEEC = j number of connecting grid element (nearest interior non-boundary grid element)

CBDRYSL = non-cohesive sediment concentration in mg/l at "TIME" for each standard level (not sigma level)

NOTE: 1. Sequence (ISEED/JSEED/ISEEC/JSEEC/CBDRYSL) is repeated for each loca-tion. Total number = NUMEBCSE (total number of boundary grid elements). The sequence (TIME/CBDRYSL) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. "TIME" for non-cohesive sediment observations need not be the same as for elevation observations in run_data.

2. If HYDTYPE = 'INTERNAL', then NUMEBCSE = NUMEBC (as specified in Data Group F, Table 8-3B: Open Boundary Condition Information in run_data).

3. If HYDTYPE = 'EXTERNAL', then non-cohesive sediment concentrations **must** be specified at all open boundaries in the domain.

11. Comment - Non-Cohesive Sediment Concentrations at River Discharges

Columns	10
Variable	COM
Format	80A1

COM = user specified comment for non-cohesive sediment concentrations at river discharges

12. Number of Grid Elements

Columns	5
Variable	NUMQBCSE
Format	I5

NUMQBCSE = total number of river discharges at which non-cohesive sediment concentrations will be specified

13. Location of Grid Elements

	5	10	15	20
	ISEQD	JSEQD	ISEQC	JSEQC
4I5				

ISEQD = i number of grid element discharge enters
JSEQD = j number of grid element discharge enters
ISEQC = i number of connecting exterior boundary grid element
JSEQC = j number of connecting exterior boundary grid element

NOTE: Sequence ISEQD/JSEQD/ISEQC/JSEQC is repeated for each discharge location.

14. Time of Observation

	10
	TIME
F10.1	

TIME = time in hours
= 0.0 for initial time

15. Non-cohesive Sediment Data

	10	20	30	80
	CDIS(1)	CDIS(2)	CDIS(3)	... CDIS(NUMQBCSE)
8F10.1				

CDIS = non-cohesive sediment concentration of river discharge in mg/l

NOTE: 1. The sequence (TIME/CDIS) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. Discharges leaving the mode domain (shore-based intakes) do not require associated CDIS values. However, a value of zero should be input for CDIS of these discharges.

2. If HYDTYPE = 'INTERNAL', then NUMQBCSE = NUMQBC (as specified in Data Group G, Table 8-3B: Discharge Information in run_data).

3. If HYDTYPE = 'EXTERNAL', then non-cohesive sediment concentrations **must** be specified at all river discharges in the domain.

NOTE: "TIME" for all the above boundary conditions is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

16. Comment - Non-cohesive Sediment Loading in Diffuser Discharges

80
COM
80A1

COM = user specified comment for non-cohesive sediment loading in diffuser discharges

17. Number of Grid Elements

5
NUMDBCSE
I5

NUMDBCSE = total number of diffusers at which non-cohesive sediment loading will be specified. If NUMDBCSE = 0, then terminate input.

18. Location of Grid Element/Vertical Distribution of Diffuser Loadings

5	10	15	20	. . .	110
IDDSE(NUMDBCSE)	JDDSE(NUMDBCSE)	VDDISTSE(1)	VDDISTSE(2)		VDDISTSE(KBM1)
2I5,20F5.0					

IDDSE = i number of grid element diffuser enters/leaves
JDDSE = j number of grid element diffuser enters/leaves
VDDISTSE = percentage (not fraction) of total diffuser loading CDIFF apportioned in each model layer from surface to bottom at location (IDDSE, JDDSE)

KBM1 = KB-1

NOTE:
1. Sequence (IDDSE/JDDSE/VDDISTSE) is repeated for each diffuser
2. More than one diffuser can be specified at the same location (IDDSE, JDDSE)

19. Time of Observation

10
TIME
F10.5

TIME = time in hours
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

20. Diffuser Loading Data

10	20	. . .	80
CDIFF(1)	CDIFF(2)	. . .	CDIFF(NUMDBCSE)
8F10.5			

CDIFF = diffuser loading in kg/day.

NOTE: Sequence (TIME/CDIFF) repeated for each observation. Final "TIME" must be greater than (NSTEPS*DTI)/3600 (the duration of the run), for COLD START runs, and greater than 1END + (NSTEPSxDTI)/3600 for HOT START runs.

Table 10-10. coh_trace.inp INPUT FILE

NOTE: This file must be included for cohesive sediment-bound transport simulations. (CHEMTRAN = " INCLUDE", SEDTRAN = "INCLUDE" and SEDTYPE = "BOTH" or "MUD ")

1. Comment - Sediment-Bound Transport Control Parameters

10
COM

80A1

COM = user specified comment for sediment-bound transport control parameters

2. Sediment-Bound Transport Control Parameters

10	20	30	40	50
CHEMI(1)	NCHEMLAY	CHEMTHIK	CHEMACT	CHEMDRAT

F10.0, I10, 4F10.0

CHEMI(1)	=	initial, spatially-constant, cohesive sediment-bound concentration (water column), in µg/l
NCHEMLAY	=	number of layers in sediment-bound tracer bed model
CHEMTHIK	=	thickness of layers in sediment-bound tracer bed model, in cm
CHEMACT	=	active layer thickness, in cm (CHEMACT ≥ CHEMTHICK)
CHEMDRAT	=	sediment-bound tracer decay rate (first-order decay), in day^{-1}

NOTE: NCHEMLAY, CHEMTHIK and CHEMACT must have the same values in both coh_trace.inp and noncoh_trace.inp

3. Comment - Cohesive Sediment-Bound Tracer Concentrations at Open Boundaries

10
COM
80A1

COM = user specified comment for cohesive sediment-bound tracer concentrations at open boundaries

4. Number of Grid Elements

5
NUMEBCCH
I5

NUMEBCCH = total number of open boundary elements at which cohesive sediment-bound tracer concentrations will be specified

5. Time of Observation

10
COM
80A1

TIME = time in hours
= 0.0 for initial time

6. Location of Grid Elements and Cohesive Sediment-Bound Tracer Data

5	10	15	20	25	
ICHED	JCHED	ICHEC	JCHEC	CBDRYSL(1)	... CBDRYSL(IKSL)
4I5,100F5.0					

ICHED = i number of grid element where cohesive sediment is specified

JCHED = j number of grid element where cohesive sediment is specified

ICHEC = i number of connecting grid element (nearest interior non-boundary grid element)

JCHEC = j number of connecting grid element (nearest interior non-boundary grid element)

CBDRYSL = cohesive sediment-bound tracer concentration in μg/l at "TIME" for each standard level (not sigma level)

NOTE:

1. Sequence (ICHED/JCHED/ICHEC/JCHEC/CBDRYSL) is repeated for each location. Total number = NUMEBCCH (total number of boundary grid elements). The sequence (TIME/CBDRYSL) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. "TIME" for cohesive tracer observations need not be the same as for elevation observations in run_data.

2. If HYDTYPE = 'INTERNAL', then NUMEBCCH = NUMEBC (as specified in Data Group F, Table 8-3B: Open Boundary Condition Information in run_data).

3. If HYDTYPE = 'EXTERNAL', then cohesive sediment-bound tracer concentrations **must** be specified at all open boundaries in the domain.

7. Comment - Cohesive Sediment-Bound Tracer Concentrations at River Discharges

	10
	COM
80A1	

COM = user specified comment for cohesive sediment-bound tracer concentrations at river discharges

8. Number of Grid Elements

	5
	NUMQBCCH
I5	

NUMQBCCH = total number of river discharges at which cohesive sediment-bound tracer concentrations will be specified

9. Location of Grid Elements

	5	10	15	20
	ICHQD	JCHQD	ICHQC	JCHQC
4I5				

ICHQD = i number of grid element discharge enters
JCHQD = j number of grid element discharge enters
ICHQC = i number of connecting exterior boundary grid element
JCHQC = j number of connecting exterior boundary grid element

NOTE: Sequence ICHQD/JCHQD/ICHQC/JCHQC is repeated for each discharge location.

10. Time of Observation

	10
	TIME
F10.1	

TIME = time in hours
= 0.0 for initial time

11. Cohesive Sediment-Bound Tracer Data

10	20	30	80
CDIS(1)	CDIS(2)	CDIS(3)	... CDIS(NUMQBCCH)

8F10.1

CDIS = cohesive sediment-bound tracer concentration of river discharge in µg/l

NOTE:

1. The sequence (TIME/CDIS) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. Discharges leaving the mode domain (shore-based intakes) do not require associated CDIS values. However, a value of zero should be input for CDIS of these discharges.

2. If HYDTYPE = 'INTERNAL', then NUMQBCCH = NUMQBC (as specified in Data Group G, Table 8-3B: Discharge Information in run_data).

3. If HYDTYPE = 'EXTERNAL', then cohesive sediment-bound tracer concentrations **must** be specified at all river discharges in the domain.

NOTE: "TIME" for all the above boundary conditions is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

12. Comment - Cohesive Sediment-Bound Tracer Loading in Diffuser Discharges

80
COM

80A1

COM = user specified comment for cohesive sediment-bound tracer loading in diffuser discharges

13. Number of Grid Elements

5
NUMDBCCH
I5

NUMDBCCH = total number of diffusers at which cohesive sediment-bound tracer loading will be specified. If NUMDBCCH = 0, then terminate input.

14. Location of Grid Elements/Vertical Distribution of Diffuser Loadings

5	10	15
IDDCH(NUMDBCCH)	JDDCH(NUMDBCCH)	VDDISTCH(1)

20	110
VDDISTCH(2)	...VDDISTCH(KBM1)

2I5,20F5.0

IDDCH = i number of grid element diffuser enters/leaves
JDDCH = j number of grid element diffuser enters/leaves
VDDISTCH = percentage (not fraction) of total diffuser loading CDIFF apportioned in each model layer from surface to bottom at location (IDDCH, JDDCH)
KBM1 = KB-1

NOTE:
1. Sequence (IDDCH/JDDCH/VDDISTCH) is repeated for each diffuser.
2. More than one diffuser can be specified at the same location (IDDCH, JDDCH).

15. Time of Observation

	10
	TIME
F10.5	

TIME = time in hours
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

16. Diffuser Loading Data

	10	20	. . .	80
	CDIFF(1)	CDIFF(2)	. . .	CDIFF(NUMDBCCH)
8F10.5				

CDIFF = diffuser loading in kg/day

NOTE: Sequence (TIME/CDIFF) repeated for each observation. Final "TIME" must be greater than (NSTEPS * DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs.

Table 10-11. noncoh_trace.inp INPUT FILE

NOTE: This file must be included for non-cohesive sediment-bound transport simulations. (CHEMTRAN = " INCLUDE", SEDTRAN = "INCLUDE" and SEDTYPE = "BOTH" or "SAND")

1. Comment - Sediment-Bound Transport Control Parameters

	10
	COM
80A1	

COM = user specified comment for sediment-bound transport control parameters

2. Sediment-Bound Transport Control Parameters

10	20	30	40	50
CHEMINIT	NCHEMLAY	CHEMTHIK	CHEMACT	CHEMDRAT

F10.0, I10, 4F10.0

CHEMINIT = initial, spatially-constant, non-cohesive sediment-bound concentration (water column), in µg/l

NCHEMLAY = number of layers in sediment-bound tracer bed model

CHEMTHIK = thickness of layers in sediment-bound tracer bed model, in cm

CHEMACT = active layer thickness, in cm (CHEMACT ≥ CHEMTHICK)

CHEMDRAT = non-cohesive sediment-bound tracer decay rate (first-order decay), in day^{-1}

NOTE: NCHEMLAY, CHEMTHIK and CHEMACT must have the same values in both coh_trace.inp and noncoh_trace.inp

3. Comment - Non-Cohesive Sediment-Bound Tracer Concentrations at Open Boundaries

10
COM

80A1

COM = user specified comment for non-cohesive sediment-bound tracer concentrations at open boundaries

4. Number of Grid Elements

5
NUMEBCCH

I5

NUMEBCCH = total number of open boundary elements at which non-cohesive sediment-bound tracer concentrations will be specified

5. Time of Observation

10
TIME
F10.1

TIME = time in hours
= 0.0 for initial time

6. Location of Grid Elements and Non-Cohesive Sediment-Bound Tracer Data

5	10	15	20	25	
ICHED	JCHED	ICHEC	JCHEC	CBDRYSL(1)	CBDRYSL(IKSL)
4I5,100F5.0					

ICHED = i number of grid element where non-cohesive tracer is specified

JCHED = j number of grid element where non-cohesive tracer is specified

ICHEC = u number of connecting grid element (nearest interior non-boundary grid element)

JCHEC = j number of connecting grid element (nearest interior non-boundary grid element)

CBDRYSL = non-cohesive sediment-bound tracer concentration in µg/l at "TIME" for each standard level (not sigma level)

NOTE: 1. Sequence (ICHED/JCHED/ICHEC/JCHEC/CBDRYSL) is repeated for each location. Total number = NUMEBCCH (total number of boundary grid elements). The sequence (TIME/CBDRYSL) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. "TIME" for non-cohesive tracer observations need not be the same as for elevation observations in run_data.

2. If HYDTYPE = 'INTERNAL', then NUMEBCCH = NUMEBC (as specified in Data Group F, Table 8-3B: Open Boundary Condition Information in run_data).

3. If HYDTYPE = 'EXTERNAL', then non-cohesive sediment-bound tracer concentrations **must** be specified at all open boundaries in the domain.

7. Comment - Non-Cohesive Sediment-Bound Tracer Concentrations at River Discharges

	10
	COM
80A1	

COM = user specified comment for non-cohesive sediment-bound tracer concentrations at river discharges

8. Number of Grid Elements

	5
	NUMQBCCH
I5	

NUMQBCCH = total number of river discharges at which non-cohesive sediment-bound tracer concentrations will be specified

9. Location of Grid Elements

	5	10	15	20
	ICHQD	JCHQD	ICHQC	JCHQC
4I5				

ICHQD = i number of grid element discharge enters
JCHQD = j number of grid element discharge enters
ICHQC = i number of connecting exterior boundary grid element
JCHQC = j number of connecting exterior boundary grid element

NOTE: Sequence ICHQD/JCHQD/ICHQC/JCHQC is repeated for each discharge location.

10. Time of Observation

```
         10
       TIME
F10.1
```

TIME = time in hours
= 0.0 for initial time

11. Non-Cohesive Sediment-Bound Tracer Data

```
         10        20        30
    CDIS(1)   CDIS(2)   CDIS(3)    ... CDIS(NUMQBCCH)
8F10.1
```

CDIS = non-cohesive sediment-bound tracer concentration of river discharge in μg/l

NOTE:

1. The sequence (TIME/CDIS) is repeated for each observation. Final "TIME" must be greater than (NSTEPS x DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs. Discharges leaving the mode domain (shore-based intakes) do not require associated CDIS values. However, a value of zero should be input for CDIS of these discharges.

2. If HYDTYPE = 'INTERNAL', then NUMQBCCH = NUMQBC (as specified in Data Group G, Table 8-3B: Discharge Information in run_data).

3. If HYDTYPE = 'EXTERNAL', then non-cohesive sediment-bound tracer concentrations **must** be specified at all river discharges in the domain.

NOTE: "TIME" for all the above boundary conditions is absolute time measured from beginning of COLD

START run and incremented with each subsequent HOT START run.

12. Comment - Non-Cohesive Sediment-bound Tracer Loading in Diffuser Discharges

	80
	COM
80A1	

COM = user specified comment for non-cohesive sediment-bound tracer loading in diffuser discharges

13. Number of Grid Elements

	5
	NUMDBCCH
I5	

NUMDBCCH = total number of diffusers at which non-cohesive sediment-bound tracer loading will be specified. If NUMDBCCH = 0, then terminate input.

14. Location of Grid Elements/Vertical Distribution of Diffuser Loadings

	5	10	15
	IDDCH(NUMDBCH)	JDDCH(NUMDBCCH)	VDDISTCH(1)
	20	...	110
	VDDISTCH(2)	...	VDDISTCH(KBM1)
2I5,20F5.0			

IDDCH = i number of grid element diffuser enters/leaves
JDDCH = j number of grid element diffuser enters/leaves
VDDISTCH = percentage (not fraction) of total diffuser loading CDIFF apportioned in each model layer from surface to bottom at location (IDDCH, JDDCH)
KBM1 = KB-1

NOTE:
1. Sequence (IDDCH/JDDCH/VDDISTCH) is repeated for each diffuser.
2. More than one diffuser can be specified at the same location (IDDCH, JDDCH).

15. Time of Observation

	10
	TIME
F10.5	

TIME = time in hours
= 0.0 for initial time

NOTE: TIME is absolute time measured from beginning of COLD START run and incremented with each subsequent HOT START run.

16. Diffuser Loading Data

	10	20	. . .	80
	CDIFF(1)	CDIFF(2)	. . .	CDIFF(NUMDBCCH)
8F10.5				

CDIFF = diffuser loading in kg/day.

NOTE: Sequence (TIME/CDIFF) repeated for each observation. Final "TIME" must be greater than (NSTEPS * DTI)/3600 (the duration of the run), for COLD START runs, and greater than IEND + (NSTEPS x DTI)/3600 for HOT START runs.

Table 10-12. partrack.inp INPUT FILE

NOTE: This file must be included for particle tracking simulations. (PARTICLE = "INCLUDE")

1. Comment - Particle Tracking Input Parameters

	10
	COM
80A1	

COM = user specified comment for particle tracking input parameters

2. Particle Tracking Input Parameters

	8	16	24	32	40	48
	NFREQ	NPART	NCONV	IRELST	NPCLASS	NSOURCE
6I8						

NFREQ = number of time steps between each particle release
NPART = number of particles per release
NCONV = total number of releases before conversion of particles
IRELST = time step of first particle release
NPCLASS = number of particle classes
NSOURCE = number of particle sources

3. Particle Source Locations

	8	16	24
	ISOURCE(M)	JSOURCE(M)	KSOURCE(M)
3I8			

ISOURCE(M) = i number of grid element for particle source M
JSOURCE(M) = j number of grid element for particle source M
KSOURCE(M) = k number of grid element for particle source M

NOTE:

1. There must be M = 1, ..., NSOURCE lines specified after line 2 for the particle source locations.

2. The corner_loc file is needed for particle tracking.

Table 10-13. bed_mask INPUT FILE

NOTE: This file must be included for all sediment transport simulations. (SEDTRAN = "INCLUDE")

Input sediment bed map for the model grid as follows:

```
      DO 10 I = 1, IM
         READ (5,20) (IBMSK(I,J), J= 1, JM)
10    CONTINUE
20    FORMAT (40I3)
```

IBMSK = 0, cohesive sediment element
= 1, non-cohesive sediment element with suspended transport
= -1, hard bottom (no suspended transport)

Table 10-14. p0_init INPUT FILE

NOTE: Include this file only if SEDTRAN = "INCLUDE", SEDTYPE = "BOTH" or "MUD", and VARIP0 = 'INCLUDE'

Input spatially-variable, sediment bed bulk density for the model grid as follows:

```
      DO 10 I = 1, IM
            READ (5,20) (PINIT(I,J), J= 1, JM)
10    CONTINUE
20    FORMAT (20F6.2)
```

PINIT = fraction of sediment bed initally composed of cohesive sediment

NOTE: only specify PINIT for cohesive elements, IBMSK = 0

Table 10-15. a0_init INPUT FILE

NOTE: Include this file only if SEDTRAN = "INCLUDE", SEDTYPE = "BOTH" or "MUD" and VARIA0N = 'INCLUDE'

Input spatially-variable a_o values for the model grid as follows:

```
      DO 10 I = 1, IM
         READ (5,20) (A0(I,J), J= 1, JM)
10    CONTINUE
20    FORMAT (8E10.3)
```

A0 = a_0 value, for erosion potential in mg/cm^2

NOTE: only specify A0 for cohesive elements, IBMSK = 0

Table 10-16. exp_init INPUT FILE

NOTE: Include this file only if SEDTRAN = "INCLUDE", SEDTYPE = "BOTH" or "MUD", and VARIA0N = 'INCLUDE'

Input spatially-variable exponent n values for the model grid as follows:

```
        DO 10 I = 1, IM
           READ (5,20) (REXP(I,J), J= 1, JM)
10      CONTINUE
20      FORMAT (8E10.3)
```

REXP = exponent n, for erosion potential in mg/cm^2

NOTE: only specify REXP for cohesive elements, IBMSK = 0

Table 10-17. bed_d50 INPUT FILE

NOTE: Include this file only if non-cohesive suspended transport is simulated (SEDTRAN = "INCLUDE", SEDTYPE = "BOTH" or "SAND" and IBMSK = 1 for some elements in bed_mask)

Input spatially-variable D_{50} values for the model grid as follows:

```
      DO 10 I = 1, IM
         READ (5,20) (D50VAR(I,J), J= 1, JM)
10    CONTINUE
20    FORMAT (20F6.0)
```

D50VAR = median grain size of non-cohesive sediment (D_{50}), in microns

NOTE: only specify D_{50} for non-cohesive elements, IBMSK = 1

Table 10-18. bed_frac.mud INPUT FILE

NOTE: Include this file only if non-cohesive suspended transport is simulated (SEDTRAN = "INCLUDE", SEDTYPE = "BOTH" or "SAND" and IBMSK = 1 for some elements in bed_mask)

Input spatially-variable, initial non-cohesive bed fractions for the model grid as follows:

```
      DO 10 I = 1, IM
         READ (5,20) (FPBED(I,J), J= 1, JM)
10    CONTINUE
20    FORMAT (20F6.3)
```

FPBED = fraction of sediment bed initally composed of suspended non-cohesive sediment, this is the clay/silt fraction in the bed.

NOTE: only specify FPBED for non-cohesive elements, IBMSK = 1

Table 10-19. bed_frac.sand INPUT FILE

NOTE: Include this file only if non-cohesive suspended transport is simulated (SEDTRAN = "INCLUDE", SEDTYPE = "BOTH" or "SAND" and IBMSK = 1 for some elements in bed_mask)

Input spatially-variable, initial non-cohesive bed fractions for the model grid as follows:

```
      DO 10 I = 1, IM
         READ (5,20) (FPBED(I,J), J= 1, JM)
10    CONTINUE
20    FORMAT (20F6.3)
```

FPBED = fraction of sediment bed initally composed of suspended non-cohesive sediment, this is the fine sand fraction in the bed.

NOTE: only specify FPBED for non-cohesive elements, IBMSK = 1

Table 10-20. bed_bulkden INPUT FILE

<u>NOTE</u>: Include this file only if SEDTRAN = "INCLUDE", SEDTYPE = "BOTH" or "MUD", and VARIBULK = 'INCLUDE'

Input spatially-variable, sediment bed bulk density for the model grid as follows:

```
      DO 10 I = 1, IM
         READ (5,20) (CBED(I,J), J= 1, JM)
10    CONTINUE
20    FORMAT (20F6.2)
```

CBED = sediment bed bulk density (g/cm^3)

Table 10-21. bed_chemic INPUT FILE

NOTE: Include this file only if SEDTRAN = "INCLUDE" and CHEMTRAN = 'INCLUDE'

Input spatially-variable, initial bed concentration of sediment-bound tracer for the model grid as follows:

```
      DO 10 N = 1, NCHEMLAY
      DO 10 I = 1, IM
         READ (5,20) (CBEDCHEM (N,I,J),J=1,JM)
10    CONTINUE
20    FORMAT (10F8.0)
```

CBEDCHEM(N) = initial bed concentration of sediment-bound tracer in layer N (µg tracer/g sediment)

Table 10-22. hqi_geom INPUT FILE (UNFORMATTED)

```
READ(199) Z,ZZ,DZ,DZZ
READ(199) H1,H2,H,ANG
READ(199) ICNT
READ(199) (INDX(I), I = 1,ICNT)
READ(199) (JNDX(I), I =1,ICNT)
```

Unit 199	=	"hqi_geom"
Z	=	depth of the interface between sigma levels
ZZ	=	0.5 (Z(k) + Z(k+1))
DZ	=	thickness of the sigma level
DZZ	=	average depth of the grid element (m)
H1	=	distance in the ξ_1 direction at the center of the grid (m)
H2	=	distance in the ξ_2 direction at the center of the grid (m)
H	=	water depth (m)
ANG	=	angle between east and the ξ_1 direction measured in a counter-clockwise direction (deg)
ICNT	=	total number of water elements in horizontal plane
INDX(I)	=	i number of water element I
JNDX(I)	=	j number of water element I

Table 10-23. hqi_tran INPUT FILE (UNFORMATTED)

```
READ (IUTRN) TMIDDLE
READ (IUTRN) HPRNU
READ (IUTRN) ((WETGU(I,K),I=1,ICNT), K=1,KBM1)
READ (IUTRN) ((WETGV(I,K),I=1,ICNT), K=1,KBM1)
READ (IUTRN) ((WETGW(I,K),I=1,ICNT), K=1,KBM1)
READ (IUTRN) ((WETGAAM(I,K),I=1,ICNT), K=1,KBM1)
READ (IUTRN) ((WETGKH(I,K),I=1,ICNT), K=1,KBM1)
READ (IUTRN) ((WETGKM(I,K),I=1,ICNT), K=1,KBM1)
READ (IUTRN) ((WETGES(I,K),I=1,ICNT), K=1,KBM1)
READ (IUTRN) ((WETGED(I,K),I=1,ICNT), K=1,KBM1)
```

IUTRN = 18 ("hqi_tran")

TMIDDLE	=	time at the middle of the averaging interval (days)
HPRNU	=	horizontal Prandtl number (momentum mixing/dispersive mixing)
WETGU	=	low-pass filtered volume flow rate in ξ_1 direction (m^3/s)
WETGV	=	low-pass filtered volume flow rate in ξ_2 direction (m^3/s)
WETGW	=	low-pass filtered vertical volume flow rate (m^3/s)
WETGAAM	=	low-pass filtered horizontal eddy viscosity (m^2/s)
WETGKH	=	low-pass filtered vertical eddy diffusivity (m^2/s)
WETGKM	=	low-pass filtered vertical eddy viscosity (m^2/s)
WETGES	=	initial surface elevation (m)
WETGED	=	time rate of change of elevation (m/s)

Table 10-24. wave_input INPUT FILE (UNFORMATTED)

READ (110) TIME
READ (110) WPERIOD
READ (110) WHEIGHT
READ (110) WDIR

Unit 110	=	"wave_input"
TIME	=	time at which wave parameters were output (hours)
WPERIOD	=	mean wave period (seconds)
WHEIGHT	=	significant wave height (meters)
WDIR	=	wave direction, measured clockwise from North (degrees)

NOTE:

1. The wave parameters, usually generated by WAM, must be interpolated from the wave model grid to the ECOMSED model grid before storing in "wave_input."

2. The dimensions of the WPERIOD, WHEIGHT and WDIR arrays are (IM,JM), which is the same as used in ECOMSED.

Table 10-25. Summary of Model Generated Output Files

File

A. gcmprt - this file is a formatted output file. It contains all input information as well as many model computed values.

B. gcmplt - this file is an unformatted output file. It contains the computed results for all grid elements at the times and for the intervals specified in the file "run_data". The contents of this file are described in detail in this section.

C. gcmtsr - this file is an unformatted output file. It contains the computed values of elevation, current, temperature, salinity, conservative tracer and fluxes for grid elements specified in the "run_data" file, as well as run-time global integrals of various parameters. The contents of this file are described in detail in this section.

D. part_location - this file is a formatted output file. It contains the computed locations of particles during a particle tracking simulation. This file is generated if PARTICLE = "INCLUDE" in "run_data." The contents of this file are described in detail in this section.

E. gcm_tran - this file is an unformatted output file. It contains computed results of surface elevations, volume transports and dispersions as a time history. It is to be used as input to a water quality model. The contents of this file are described in detail in this section.

F. gcm_geom - this file is an unformatted output file. It contains grid segmentation information. It is to be used as input to a water quality model. The contents of this file are described in detail in this section.

G. startup - this file is an unformatted output file. It contains all the information for the hydrodynamic model run which will become the initial conditions for the "HOT START" runs. The user should move or copy the "startup" file to "restart" before making the next "HOT START" run.

Table 10-26. gcmplt OUTPUT FILE (UNFORMATTED)

```
      READ(20) IM,JM,KB
      READ(20) EBCM,QBCM, NCHEMLAY
      READ(20) DTI,GRAV,UMOL,TOR, TRACER, SEDTRAN, CHEMTRAN
      READ(20) NUMEBC
      READ(20) (IETA(I),JETA(I),ICON(I),JCON(I),I=1,NUMEBC)
      READ(20) NUMQBC
      READ(20) (IQC(I),JQC(I),I=1,NUMQBC)
      READ(20) H
      READ(20) H1
      READ(20) H2
      READ(20) ANG
      READ(20) DUM
      READ(20) DVM
      READ(20) FSM

C
      DO 1000 JHIST=1,JHM
        READ(20) TMIDDLE
        READ(20) ARCET
        IF(TOR.EQ.'BAROTROPIC') THEN
          READ(20) ((ARCU (I,J,1),I=1,IM),J=1,JM)
          READ(20) ((ARCV (I,J,1),I=1,IM),J=1,JM)
          READ(20) ((ARCUX(I,J,1),I=1,IM),J=1,JM)
          READ(20) ((ARCVX(I,J,1),I=1,IM),J=1,JM)
        IF (TRACER.EQ.'INCLUDE') READ (20) ((ARCC(I,J,1),I=1,IM),J=1,JM)
        IF (SEDTRAN.EQ.'INCLUDE') THEN
          READ (20) ((ARCSED1(I,J,1),I=1,IM),J=1,JM)
          READ (20) ((ARCSED2(I,J,1),I=1,IM),J=1,JM)
          READ (20) ((ARCTHIK(I,J),I=1,IM),J=1,JM)
          ENDIF
        IF (CHEMTRAN.EQ.'INCLUDE') THEN
          READ (20) ((ARCCHEM1(I,J,1),I=1,IM),J=1,JM)
          READ (20) ((ARCCHEM2(I,J,1),I=1,IM),J=1,JM)
          READ (20) ((ARCPBED(N,I,J),I=1,IM),J=1,JM),N=1,NCHEMLAY)
          ENDIF
      ELSE
          READ(20) Z
          READ(20) ZZ
          READ(20) DZ
          READ(20) ARCU
          READ(20) ARCV
          READ(20) ARCUX
          READ(20) ARCVX
          READ(20) ARCT
          READ(20) ARCS
          READ(20) ARCW
          READ(20) ARCKH
        IF (TRACER.EQ.'INCLUDE') READ(20) ARCC
        IF (SEDTRAN.EQ.'INCLUDE') THEN
          READ (20) ARCSED1
          READ (20) ARCSED2
          READ (20) ARCTHIK
          READ (20) ARCTAU
          ENDIF
        IF (CHEMTRAN.EQ.'INCLUDE') THEN
```

```
            READ (20) ARCCHEM1
            READ (20) ARCCHEM2
            READ (20) ((ARCPBED(N,I,J),I=1,IM),J=1,JM),N=1,NCHEMLAY)
         ENDIF
1000 CONTINUE
```

Unit 20	=	"gcmplt"
IM	=	total number of grid elements in the ξ_1 direction
JM	=	total number of grid elements in the ξ_2 direction
KB	=	number of sigma levels
EBCM	=	maximum number of elevation boundary grid elements
QBCM	=	maximum number of discharge boundary grid elements
DTI	=	time step of the internal mode (sec)
GRAV	=	gravitational acceleration (m^2/sec)
UMOL	=	constant or background mixing (m^2/sec)
TOR	=	type of run ("BAROTROPIC"/"PROGNOSTIC"/"DIAGNOSTIC")
NCHEMLAY	=	number of layers in sediment-bound tracer bed model
TRACER	=	control parameter for dissolved tracer transport
SEDTRAN	=	control parameter for sediment transport
CHEMTRAN	=	control parameter for sediment-bound tracer transport
NUMEBC	=	total number of elevation boundary grid elements
IETA	=	i number of grid element where elevation is specified
JETA	=	j number of grid element where elevation is specified
ICON	=	i number of connecting grid element (nearest interior non-boundary grid element)
JCON	=	j number of connecting grid element (nearest interior non-boundary grid element)
NUMQBC	=	total number of discharge boundary grid elements
IQC	=	i number of grid element where discharge enters/leaves
JQC	=	j number of grid element where discharge enters/leaves
H	=	average depth of grid element (m)
H1	=	distance in the ξ_1 direction at the center of the grid (m)
H2	=	distance in the ξ_2 direction at the center of the grid (m)
ANG	=	angle between east and the ξ_1 direction measured in a counter-clockwise direction (deg)
DUM	=	land/water mask at the U interface of the grid element
DVM	=	land/water mask at the V interface of the grid element
FSM	=	land/water mask at the center of the grid element
TMIDDLE	=	time at the middle of the time interval (days)
ARCET	=	free surface elevation of the grid element (m)
Z	=	depth of the interface between sigma levels
	=	0.0 at the surface
	=	-1.0 at the bottom
ZZ	=	intermediate depth between sigma levels
DZ	=	thickness of the sigma level
	=	Z(K) - Z(K+1)
ARCU	=	velocity component in the ξ_1 direction (m/sec)
ARCV	=	velocity component in the ξ_2 direction (m/sec)
ARCUX	=	transport component in the ξ_1 direction (m^2/sec)
ARCVX	=	transport component in the ξ_2 direction (m^2/sec)
ARCT	=	temperature of the grid element (^oC)
ARCS	=	salinity of the grid element (psu)
ARCW	=	vertical velocity (m/sec)
ARCKH	=	vertical eddy viscosity (m^2/sec)
ARCC	=	conservative tracer concentration (only included if TRACER = "INCLUDE")

ARCSED1	=	cohesive sediment concentration (mg/l) (only included if SEDTRAN = "INCLUDE")
ARCSED2	=	non-cohesive sediment concentration (mg/l) (only included if SEDTRAN = "INCLUDE")
ARCTHIK	=	sediment bed elevation change (cm) (only included if SEDTRAN = "INCLUDE")
ARCTAU	=	bottom shear stress for use in sediment transport (dynes/cm^2)
ARCCHEM1	=	cohesive sediment-bound tracer concentration (µg/l) (only included if CHEMTRAN = "INCLUDE")
ARCCHEM2	=	non-cohesive sediment-bound tracer concentration (µg/l) (only included if CHEMTRAN = "INCLUDE")
ARCPBED	=	sediment bed concentration of sediment-bound tracer (ppm) (only included if CHEMTRAN = "INCLUDE")

Table 10-27. gcmtsr OUTPUT FILE (UNFORMATTED)

```
                 READ(30) TOR, TRACER, SEDTRAN, CHEMTRAN
                 READ(30) KBM1, NCHEMLAY
                 READ(30) EPTS
                 READ(30) (INXIE(N),INXJE(N),N=1,EPTS)
                 READ(30) VPTS
                 READ(30) (INXIV(N),INXJV(N),N=1,VPTS)
                 READ(30) (ANG (INXIV(N),INXJV(N)),N=1,VPTS)
                 READ(30) FPTS
                 READ(30) (ISFLX(N),JSFLX(N),DIRFLX(N),NFLXE(N),N=1,FPTS)
C
                 DO 1000 I=1,ID
                   READ(30) TMIDDLE
                   READ(30) (ESAVE(N),N=1,EPTS)
                 IF(TOR.EQ.'BAROTROPIC') THEN
                     READ(30) (UZSAVE(N,1),VZSAVE(N,1), N=1,VPTS)
                   IF (TRACER.EQ.'INCLUDE') READ (30) (C1ZSAVE(N,1),N=1,VPTS)
                   IF (SEDTRAN.EQ.'INCLUDE') THEN
                     READ (30)  (C1SAVE(N,1),C2SAVE(N,1),N=1,VPTS)
                     READ (30)  (THSAVE(N),N=1,VPTS)
                     READ(30) (TAUSAVE(N,1), N-1,VPTS)
                     ENDIF
                   IF (CHEMTRAN.EQ.'INCLUDE') THEN
                     READ (30)  (P1SAVE(N,1),P2SAVE(N,1),N=1,VPTS)
                     READ (30)  ((PBEDSAVE(N,LL),N=1,VPTS),LL=1,NCHEMLAY)
                     ENDIF
                     READ(30) (CCFLUX(N,1),N=1,FPTS)
                     READ(30) ESUM,TKE,APE
                   ELSE
                     READ(30) (DZSAVE(N),N=1,VPTS)
                     READ(30) ((UZSAVE(N,K),VZSAVE(N,K),SZSAVE(N,K),TZSAVE(N,K),
                                N=1,VPTS),K=1,KBM1)
                   IF (TRACER.EQ.'INCLUDE') READ (30) ((C1ZSAVE(N,K),N=1,VPTS),
                      K=1,KBM1)
                   IF (SEDTRAN.EQ.'INCLUDE') THEN
                     READ (30)  ((C1SAVE(N,K),C2SAVE(N,K),N=1,VPTS),K=1,KBM1)
                     READ (30)  (THSAVE(N),N=1,VPTS)
                     READ (30)  (TAUSAVE(N,KB),N-1,VPTS)
                     ENDIF
                   IF (CHEMTRAN.EQ.'INCLUDE') THEN
                     READ (30)  ((P1SAVE(N,K),P2SAVE(N,K),N=1,VPTS),K=1,KBM1)
                     READ (30)  ((PBEDSAVE(N,LL),N=1,VPTS),LL=1,NCHEMLAY)
                 ENDIF
                   READ(30) ((CCFLUX(N,K),N=1,FPTS),K=1,KBM1)
                     READ(30) VSTOR,EM,APEC,TSUM,SSUM
1000 CONTINUE
```

Unit 30	=	"gcmtsr"
TOR	=	type of run ("BAROTROPIC"/"PROGNOSTIC"/"DIAGNOSTIC")
NCHEMLAY	=	number of layers in sediment-bound tracer bed model
TRACER	=	control parameter for dissolved tracer transport
SEDTRAN	=	control parameter for sediment transport
CHEMTRAN	=	control parameter for sediment-bound tracer transport
KBM1	=	number of sigma layers (KB-1)
EPTS	=	number of grid elements with elevation time series

INXIE	=	i number of user specified grid element
INXJE	=	j number of user specified grid element
VPTS	=	number of grid elements with current time series
INXIV	=	i number of user specified grid element
INXJV	=	j number of user specified grid element
ANG	=	angle in degrees between east and ξ_1 direction measured in a counter-clockwise direction
FPTS	=	number of user specified grid elements with cross sectional flux time series
ISFLX	=	i number of user specified grid element in which cross section begins
JSFLX	=	j number of user specified grid element in which cross section begins
DIRFLX	=	direction of the cross section
	=	"IDIR" - cross section in the ξ_1 direction
	=	"JDIR" - cross section in the ξ_2 direction
NFLXE	=	number of grid elements in the cross section
TMIDDLE	=	time at the middle of the time interval (days)
ESAVE	=	surface elevation of the user specified grid element (m)
DZSAVE	=	total depth of the user specified grid element (m)
	=	bottom topography + elevation
UZSAVE	=	U velocity averaged at the center of the user specified grid element (m/sec)
VZSAVE	=	V velocity averaged at the center of the user specified grid element (m/sec)
SZSAVE	=	salinity of the user specified grid element (psu)
TZSAVE	=	temperature of the user specified grid element (^oC)
CCFLUX	=	mass transport averaged at the center of the user specified grid element (m^3/sec)
ESUM	=	average surface elevation in the modeling domain (m)
TKE	=	volume averaged total kinetic energy (joule)
APE	=	volume averaged available potential energy (joule)
VSTOR	=	volume storage (m^3)
EM	=	excess mass (kg)
APEC	=	excess volume averaged available potential energy (joule)
SSUM	=	volume averaged salinity in the modeling domain (psu)
TSUM	=	volume averaged temperature in the modeling domain (^oC)
C1ZSAVE	=	conservative tracer concentration (only included if TRACER = "INCLUDE")
C1SAVE	=	cohesive sediment concentration (mg/l) (only included if SEDTRAN = "INCLUDE")
C2SAVE	=	non-cohesive sediment concentration (mg/l) (only included if SEDTRAN = "INCLUDE")
THSAVE	=	sediment bed elevation change (cm) (only included if SEDTRAN = "INCLUDE")
TAUSAVE	=	bottom shear stress for use in sediment transport (dynes/cm^2)
P1SAVE	=	cohesive sediment-bound tracer concentration (µg/l) (only included if CHEMTRAN = "INCLUDE")
P2SAVE	=	non-cohesive sediment-bound tracer concentration (µg/l) (only included if CHEMTRAN = "INCLUDE")
PBEDSAVE	=	sediment bed concentration of sediment-bound tracer (ppm) (only included if CHEMTRAN = "INCLUDE")

Table 10-28. part_location OUTPUT FILE (FORMATTED)

```
DO JHIST = 1, JHM
    DO LL = 1, NSOURCE
        DO NN = 1, NGRADELOOP

          READ(40,´(3I8,F10.4)´)LL,NN,NPART,TIME
          READ(40,´(20F10.1)´)(XOUTP(NP),NP=1,NPART)
          READ(40,´(20F10.1)´)(YOUTP(NP),NP=1,NPART)
          READ(40,´(20F10.1)´)(ZOUTP(NP),NP=1,NPART)
       ENDDO
    ENDDO
ENDDO
```

Unit 40	=	“part_location
NSOURCE	=	number of particle sources
NGRADELOOP	=	number of releases
NPART	=	number of particles per release
TIME	=	time (days) when the locations of released particles are recorded
XOUTP	=	particle location in x-direction (East) (m)
YOUTP	=	particle location in y-direction (North) (m)
ZOUTP	=	particle location in z-direction (Up) (m)

Table 10-29. gcm_tran OUTPUT FILE (UNFORMATTED)

```
     DO 1000 JTRAC=1,JTM
          READ(10) TMIDDLE
          READ(10) (((ULPF(I,J,K),I=1,IM),J=1,JM),K=1,KBM1)
          READ(10) (((VLPF(I,J,K),I=1,IM),J=1,JM),K=1,KBM1)
          READ(10) WLPF
          READ(10) (((AAMAX(I,J,K),I=1,IM),J=1,JM),K=1,KBM1)
          READ(10) (((AAMAY(I,J,K),I=1,IM),J=1,JM),K=1,KBM1)
          READ(10) KHLPF
          READ(10) ES
          READ(10) ED
          READ(10) (((SLPF(I,J,K),I=1,IM),J=1,JM),K=1,KBM1)
          READ(10) (((TLPF(I,J,K),I=1,IM),J=1,JM),K=1,KBM1)
1000 CONTINUE
```

Unit 10 = "gcm_tran"

TMIDDLE	=	time at the middle of the time averaging interval (days)
ULPF	=	low pass filtered volume flow rate in the ξ_1 direction (m3/sec)
VLPF	=	low pass filtered volume flow rate in the ξ_2 direction (m^3/sec)
WLPF	=	low pass filtered vertical volume flow rate (m^3/sec)
AAMAX	=	low pass filtered horizontal eddy viscosity in ξ_1 direction (m^2/sec)
AAMAY	=	low pass filtered horizontal eddy viscosity in ξ_2 direction (m^2/sec)
KHLPF	=	low pass filtered vertical eddy diffusivity (m^2/sec)
ES	=	initial surface elevation (m)
ED	=	time rate of change of elevation (m/sec)
SLPF	=	low pass filtered salinity (psu)
TLPF	=	low pass filtered temperature (°C)

Table 10-30. gcm_geom OUTPUT FILE (UNFORMATTED)

```
READ(10) DZ,DZZ
READ(10) H,H1,H2,TPS
READ(10) ANG, NU
```

Unit 10	= "gcm_geom"	
DZ	=	thickness of the sigma level
DZZ	=	average depth of the grid element (m)
H1	=	distance in the ξ_1 direction at the center of the grid (m)
H2	=	distance in the ξ_2 direction at the center of the grid (m)
TPS	=	land/water mask at the center of the grid element
ANG	=	angle between east and the ξ_1 direction measured in a counter-clockwise direction (deg)
NU	=	coefficient in time filter (non-dimensional)

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