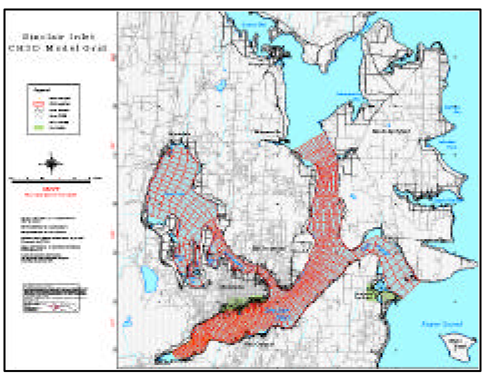
User's Guide For A Three-Dimensional Numerical Hydro-dynamic, Salinity, and Temperature Model of Sinclair Inlet

July 31,2001



Prepared For:
Puget Sound Naval Shipyard Project ENVVEST

Prepared By:
J. Brown (ed)
Concurrent Technologies Corporation
5780 W. Werner Road
Bremerton, WA 98312

NAVSEA
NAVAL SEA SYSTEMS COMMAND
Puget Sound Naval Shipyard
EPA United States Environmental Protection Agency
WASHINGTON STATE DEPT. OF ECOLOGY

ADMINISTRATIVE INFORMATION

J. Brown was supported under Contract No: GS-10T-EBD-005, Task Order ID: ABH-170-037.

Preface

This document has been prepared to provide an electronic version of the CH3D users guide developed by: Johnson, B. H., Heath, R. E., Hsieh, B. B., Kim, K. W., Butler, H. L., 1991. User's Guide for a Three-Dimensional Numerical Hydrodynamic, Salinity, and Temperature Model of Chesapeake Bay, Technical Report HL-91-20, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS. The guide has been updated to include the applications of the model to Sinclair and Dyes Inlet.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF APPENDICES

Note: The Appendices are in a separate electronic file.

LIST OF ACRONYMS

2D	two-dimensional
3D	three-dimensional
CH3D	Curvilinear Hydrodynamics in 3 Dimensions
POWT	publicly owned water treatment
PSNS	Puget Sound Naval Shipyard
SPAWAR	U.S. Navy Space and Warfare Center
WES	Waterways Experiment Station

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
feet	0.3048	meters

EXECUTIVE SUMMARY

A time-varying three-dimensional (3D) numerical hydrodynamic model of Sinclair Inlet has been developed to provide flow fields to a 3D-water quality model of the inlet. The water surface, 3D-velocity field, salinity, and temperature are computed. Major physical processes affecting inlet circulation and vertical mixing are modeled. The model solves transformed, boundary-fitted equations in "horizontal" (i.e., constant vertical elevation) planes. A particular feature of the model is the resolution of depth variations on a z-grid in the vertical direction.

This user's guide presents a detailed discussion of theoretical aspects of the 3D model (e.g., basic equations, boundary conditions, turbulence closure, etc.), followed by a discussion of the organization of the computer code and input data requirements. Listings of portions of the various input data files for an application that simulates the hydrodynamics of the Sinclair Inlet during the period June 9, 1998 through July 19, 1998 are also provided.

Major portions of the CH3D Methodology were taken from Johnson, B. H., Heath, R. E., Hsieh, B. B., Kim, K. W., Butler, H. L., 1991. User's Guide for a Three-Dimensional Numerical Hydrodynamic, Salinity, and Temperature Model of Chesapeake Bay, Technical Report HL-91-20, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

1.0 INTRODUCTION

Sinclair Inlet is located in Kitsap County in Washington State. The inlet is located on the west side of Puget Sound between the cities of Bremerton and Port Orchard. As shown in Figure 1-1, Port Washington Narrows connects the inlet to Dyes Inlet—which also divides the city of Bremerton into east and west parts. Silverdale, a heavily populated unincorporated area of Kitsap County lies at the north end of Dyes Inlet. Tidal motion in Dyes Inlet comes through Port Washington Narrows only. Bainbridge Island lies at the mouth of Sinclair Inlet and creates two paths to Puget Sound: Port Orchard Passage to the north, and Rich Passage to the east. Sinclair Inlet runs roughly southwest to northeast and is 11.5 km in length. The width of the inlet varies from 0.8 km to 2.2 kilometers (km). The depth ranges from approximately 6 meters (m) in the southeast part of the inlet to approximately 200 meters in the northeast part of the inlet. The simulation models the hydrodynamics in Sinclair Inlet, Dyes Inlet and through Rich Passage to its mouth into Puget Sound and also Port Orchard Passage as far north as the Port of Brownsville. Tidal boundary conditions are enforced at both the northern boundary in Port Orchard Passage and the eastern boundary in Rich Passage.

A particular feature of Sinclair Inlet is its relatively shallow depth over the southwestern third of its length. The shallow depth and isolation from the tidal boundaries of the inlet leads to minimal tidal flushing of this portion of the inlet.

Several relatively minor streams feed Sinclair Inlet. Among these, Blackjack Creek and Gorst Creek feed the inlet itself. In addition, Chico Creek and Clear Creek feed Dyes Inlet. In addition, two publicly owned water treatment (POWT) facilities discharge into Sinclair Inlet from the city of Bremerton to the north and from the city of Port Orchard to the south. The Bremerton POWT discharges into the shallow southeast end of the inlet. Puget Sound Naval Shipyard (PSNS) is located on the north shore of Sinclair Inlet to the west of Port Washington Narrows (Figure 1-1).

The numerical grid employed in the Sinclair Inlet 3D hydrodynamic model is shown in Figure 1-2. The model uses a maximum of 74 cells in the I direction (along the inlet length from southwest to northeast) and 48 cells in the J direction (across the inlet from southeast to northwest). There is a maximum of 20 vertical layers—the distribution of vertical layers is shown in Figure 1-2. To capture the important features of the hydrodynamic processes and bathymetry in the bay, grid resolution is 1.52 meters (m) vertical and approximately 10 kilometers (km) longitudinal and 3 km lateral. Major tributaries are modeled fully 3D in the lower reach and as constant-width, two-dimensional (2D) in the upper reach.

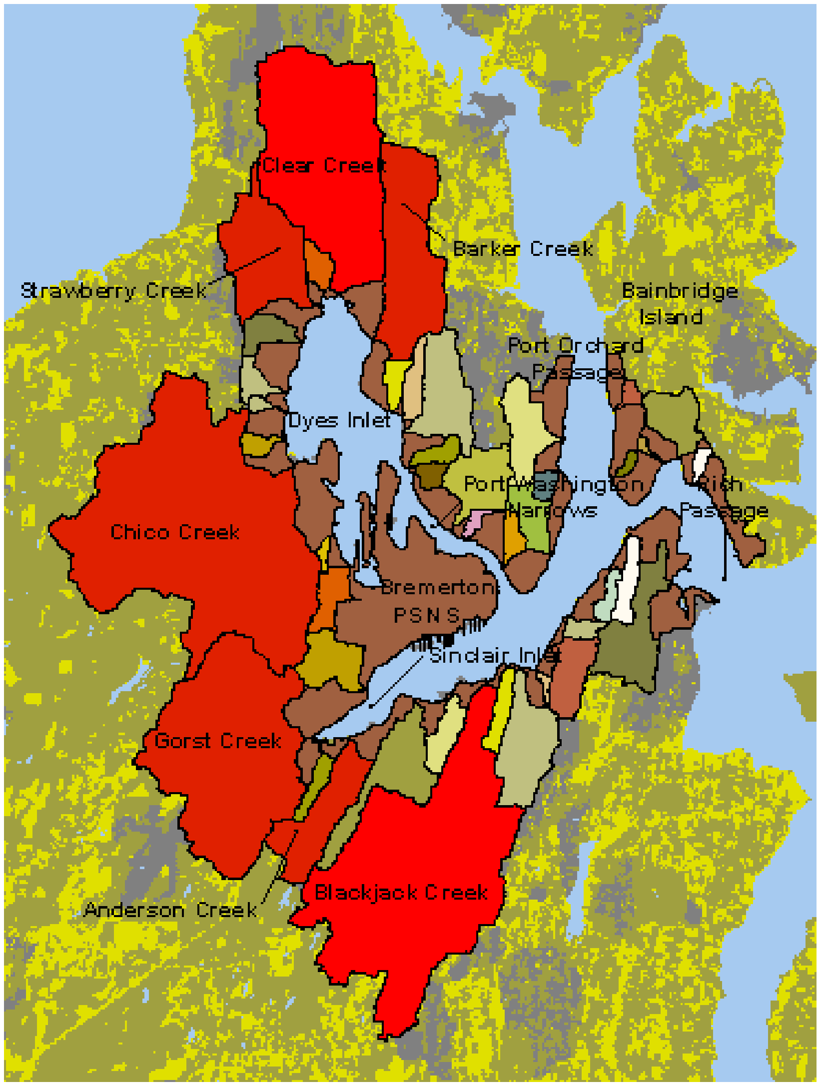


Figure 1-1. Sinclair Inlet and Adjacent Water Bodies

This user's guide presents a detailed discussion of theoretical aspects of the 3D model. The governing equations solved in the 3D model are presented in Cartesian form for both the external and internal modes. The external mode consists of vertically averaged equations, and is used to compute the water surface elevation. The internal mode contains the full 3D equations and is used to update the velocity fields, temperature and salinity. Required boundary conditions, along with a discussion of the algorithm employed to numerically solve the equations, are given. In addition, the structure of the computer model is discussed. Detailed descriptions of the function of each subroutine are provided along with a discussion of the flow of computations in the model. The type of input data required to operate the model and the setup of those data are also presented.

Basic inputs required are time-varying water-surface elevations at the ocean entrance and freshwater inflows at the head of all tributaries. In addition, time-varying salinity and temperature data must be prescribed at all inflow boundaries. Also, time-varying wind and surface heat exchange data must be prescribed at one or more locations. These are then distributed in some manner over the entire grid. All input data, including initial conditions, bathymetry, boundary, and computational control data are input from fixed files. An application using data from June 9, 1998 through July 19, 1998, serves to demonstrate the set up of input files. A detailed list of the input data requirements and the proper format are also given. Standard outputs are water-surface elevations, velocity, salinity, and temperature in each cell of the grid at some specified time interval.

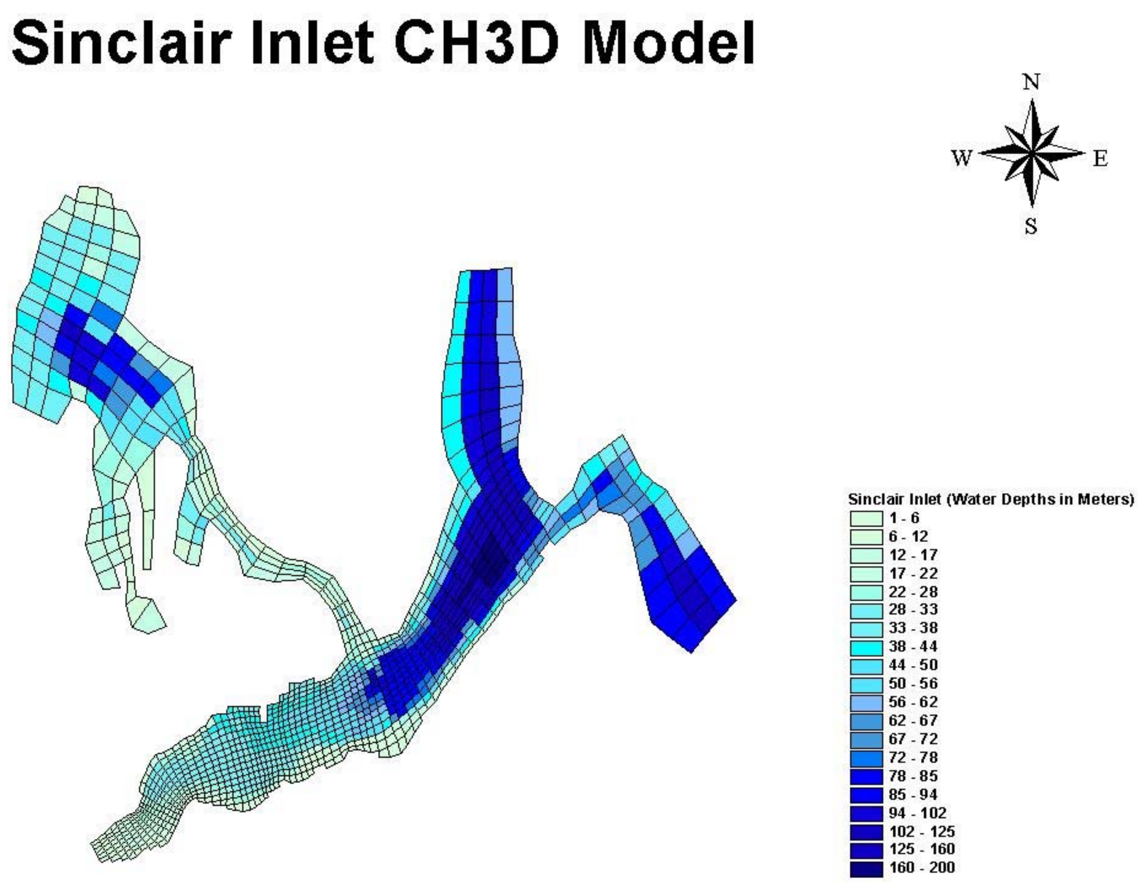


Figure 1-2. Planform Numerical Grid of Sinclair Inlet

2.0 THEORETICAL BASIS OF SINCLAIR INLET 3D HYDRODYNAMIC MODEL

As noted, the particular hydrodynamic computer model employed is called CH3D-WES. Sheng (1986) developed the basic model (CH3D) for the Waterways Experiment Station (WES) of the Army Corps of Engineers. The model was extensively modified in its application to Chesapeake Bay (Johnson, Heath, Hsieh, et al., 1991). The Chesapeake Bay version of CH3D-WES was used to model the flow in Sinclair Inlet. The modifications to CH3D-WES for Chesapeake Bay consisted of different basic formulations as well as substantial recoding for more efficient computing.

As its name implies, CH3D-WES makes hydrodynamic computations on a curvilinear or boundary-fitted planform grid. Physical processes impacting inlet-wide circulation and vertical mixing that are modeled include tides, wind, density effects (salinity and temperature), freshwater inflows, turbulence, and the effect of the earth's rotation. Adequately representing the vertical turbulence is crucial to a successful simulation of stratification/destratification. A second-order turbulence model based upon the assumption of local equilibrium of turbulence is employed. The boundary-fitted coordinate feature of the model provides enhancement to resolve the deep navigation channel, the shallow southwest third of the inlet and the irregular shoreline configuration of the inlet and permits adoption of an accurate and economical grid schematization. The solution algorithm employs an external mode consisting of vertically averaged equations to provide the solution for the free surface to the internal mode consisting of the full 3D equations.

2.1 Basic Equations

The basic equations for an incompressible fluid in a right-handed Cartesian coordinate system (x, y, z) are (Note: in the Sinclair Inlet model, x is essentially in the west to east direction, y is in essentially the south to north direction and z is from the inlet bottom to the free surface.):

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \qquad (1)$$

$$\frac{\partial u}{\partial t} + \frac{\partial u^2}{\partial x} + \frac{\partial uv}{\partial y} + \frac{\partial uw}{\partial z} = fv - \frac{1}{\rho_0}\frac{\partial p}{\partial x} + \frac{\partial}{\partial x}\left(A_H \frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(A_H \frac{\partial u}{\partial y}\right) + \frac{\partial}{\partial z}\left(A_V \frac{\partial u}{\partial z}\right) \qquad (2)$$

$$\frac{\partial v}{\partial t} + \frac{\partial uv}{\partial x} + \frac{\partial v^2}{\partial y} + \frac{\partial vw}{\partial z} = -fu - \frac{1}{\rho_0}\frac{\partial p}{\partial y} + \frac{\partial}{\partial x}\left(A_H \frac{\partial v}{\partial x}\right) + \frac{\partial}{\partial y}\left(A_H \frac{\partial v}{\partial y}\right) + \frac{\partial}{\partial z}\left(A_V \frac{\partial v}{\partial z}\right) \qquad (3)$$

$$\frac{\partial p}{\partial z} = -\rho g \tag{4}$$

$$\frac{\partial T}{\partial t} + \frac{\partial uT}{\partial x} + \frac{\partial vT}{\partial y} + \frac{\partial wT}{\partial z} = \frac{\partial}{\partial x}\left(K_H \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_H \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_V \frac{\partial T}{\partial z}\right) \tag{5}$$

$$\frac{\partial S}{\partial t} + \frac{\partial uS}{\partial x} + \frac{\partial vS}{\partial y} + \frac{\partial wS}{\partial z} = \frac{\partial}{\partial x}\left(K_H \frac{\partial S}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_H \frac{\partial S}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_V \frac{\partial S}{\partial z}\right) \tag{6}$$

$$\rho = \rho(T, S) \tag{7}$$

where

$(u, v, w) =$ velocities in (x, y, z) directions

$t =$ time

$f =$ Coriolis parameter defined as $2\Omega \sin\phi$

where

$\Omega =$ rotational speed of the earth
$\phi =$ latitude

$\rho =$ density

$p =$ pressure

$A_H, K_H =$ horizontal turbulent eddy viscosity, diffusivity coefficient

$A_V, K_V =$ vertical turbulent eddy viscosity, diffusivity coefficient

$g =$ gravitational acceleration

$T =$ temperature

$S =$ salinity

Equation 4 implies that vertical accelerations are negligible and thus the pressure is hydrostatic.

Various forms of the equation of state can be used for Equation 7. In the present model, the equation given below is used:

$$\rho = P / (\alpha + 0.698P) \tag{8}$$

where

$$P = 5890 + 38T - 0.375T^2 + 3S$$
$$\alpha = 1779.5 + 11.25T - 0.0745T^2 - (3.8 + 0.01T)S$$

and T is in degrees Celsius, S is in parts per thousand, and ρ is in grams per cubic centimeter.

2.2 Non-Dimensionalization of Equations

Working with the dimensionless form of the governing equations makes it easier to compare the relative magnitude of various terms in the equations. Therefore, the following dimensionless variables are used:

$$(u^*, v^*, w^*) = \frac{\left(u, v, \frac{wX_r}{Z_r}\right)}{U_r}$$

$$(x^*, y^*, z^*) = \frac{\left(x, y, \frac{zX_r}{Z_r}\right)}{X_r}$$

$$(\tau_x^*, \tau_y^*) = \frac{(\tau_x^w, \tau_y^w)}{\rho_0 f Z_r U_r}$$

$$t^* = tf$$

$$\varsigma^* = \frac{g\varsigma}{fU_r X_r} = \frac{\varsigma}{S_r}$$

$$\rho^* = \frac{(\rho - \rho_0)}{(\rho_r - \rho_0)} \tag{9}$$

$$T^* = \frac{(T - T_0)}{(T_r - T_0)}$$

$$A_H^* = \frac{A_H}{A_{Hr}}$$

$$A_V^* = \frac{A_V}{A_{Vr}}$$

$$K_H^* = \frac{K_H}{K_{Hr}}$$

$$K_V^* = \frac{K_V}{K_{Vr}}$$

where

(τ_x^w, τ_y^w) = wind stress in (x, y) directions
ς = water surface elevation
ρ_0 = expected minimum density
T_0 = expected minimum temperature

which then yields the following dimensionless parameters in the governing equations:

Vertical Ekman Number: $E_V = A_{Vr} / (f Z_r^2)$

Lateral Ekman Number: $E_H = A_{Hr} / (f X_r^2)$

Vertical Prandtl (Schmidt) Number: $\Pr_V = A_{Vr} / K_{Vr}$

Lateral Prandtl (Schmidt) Number: $\Pr_H = A_{Hr} / K_{Hr}$

Froude Number: $Fr = U_r / (g Z_r)^{1/2}$ (10)

Rossby Number: $R_o = U_r / (f X_r)$

Densimetric Froude Number $$Fr_D = {Fr}/{\sqrt{\varepsilon}}$$

where $$\varepsilon = {(\rho_r - \rho_0)}/{\rho_0}$$

$S_r, T_r, U_r, \rho_r, X_r, Z_r, A_{Hr}, A_{Vr}, K_{Hr}$, and K_{Vr} are arbitrary reference values of the salinity, temperature, velocity, density, etc.

2.3 External-Internal Modes

The basic equations (Equations 1-4) can be integrated over the depth to yield a set of vertically integrated equations for the water surface, ς, and unit flow rates U and V in the x and y directions. Using the dimensionless variables (asterisks have been dropped) and the parameters previously defined, the vertically integrated equations constituting the external mode are:

$$\frac{\partial \varsigma}{\partial t} + \beta\left(\frac{\partial U}{\partial x} + \frac{\partial V}{\partial y}\right) = 0 \tag{11}$$

$$\frac{\partial U}{\partial t} = -H\frac{\partial \varsigma}{\partial x} + \tau_{sx} - \tau_{bx} + V - R_o\left[\frac{\partial}{\partial x}\left(\frac{UU}{H}\right) + \frac{\partial}{\partial y}\left(\frac{UV}{H}\right)\right]$$
$$+ E_H\left[\frac{\partial}{\partial x}\left(A_H\frac{\partial U}{\partial x}\right) + \frac{\partial}{\partial y}\left(A_H\frac{\partial U}{\partial y}\right)\right] - \frac{R_o}{Fr_D^{\,2}}\frac{H^2}{2}\frac{\partial \rho}{\partial x} \tag{12}$$

$$\frac{\partial V}{\partial t} = -H\frac{\partial \varsigma}{\partial y} + \tau_{sy} - \tau_{by} - U - R_o\left[\frac{\partial}{\partial x}\left(\frac{UV}{H}\right) + \frac{\partial}{\partial y}\left(\frac{VV}{H}\right)\right]$$
$$+ E_H\left[\frac{\partial}{\partial x}\left(A_H\frac{\partial V}{\partial x}\right) + \frac{\partial}{\partial y}\left(A_H\frac{\partial V}{\partial y}\right)\right] - \frac{R_o}{Fr_D^{\,2}}\frac{H^2}{2}\frac{\partial \rho}{\partial y} \tag{13}$$

where

$$\beta = \frac{gZ_r}{f^2 X_r^{\,2}} = \left(\frac{R_o}{Fr}\right)^2$$

As will be discussed later, the major purpose of the external mode is to provide the updated water-surface field.

The internal mode equations from which the 3D velocity, salinity, and temperature fields are computed are:

$$\frac{\partial hu}{\partial t} = -h\frac{\partial \varsigma}{\partial x} + E_V\frac{\partial}{\partial z}\left(A_V\frac{\partial hu}{\partial z}\right) + hv - R_o\left[\frac{\partial huu}{\partial x} + \frac{\partial huv}{\partial y} + \frac{\partial huw}{\partial z}\right]$$
$$+ E_H\left[\frac{\partial}{\partial x}\left(A_H\frac{\partial hu}{\partial x}\right) + \frac{\partial}{\partial y}\left(A_H\frac{\partial hu}{\partial y}\right)\right] - \frac{R_o}{{Fr_D}^2}\left(\int_z^{\varsigma}\frac{\partial \rho}{\partial x}dz\right) \tag{14}$$

$$\frac{\partial hv}{\partial t} = -h\frac{\partial \varsigma}{\partial y} + E_V\frac{\partial}{\partial z}\left(A_V\frac{\partial hv}{\partial z}\right) - hu - R_o\left[\frac{\partial huv}{\partial x} + \frac{\partial hvv}{\partial y} + \frac{\partial hvw}{\partial z}\right]$$
$$+ E_H\left[\frac{\partial}{\partial x}\left(A_H\frac{\partial hv}{\partial x}\right) + \frac{\partial}{\partial y}\left(A_H\frac{\partial hv}{\partial y}\right)\right] - \frac{R_o}{{Fr_D}^2}\left(\int_z^{\varsigma}\frac{\partial \rho}{\partial y}dz\right) \tag{15}$$

$$W_{k+\frac{1}{2}} = W_{k-\frac{1}{2}} - \left(\frac{\partial hu}{\partial x} + \frac{\partial hv}{\partial y}\right) \tag{16}$$

$$\frac{\partial hT}{\partial t} = \frac{E_V}{\mathrm{Pr}_V}\frac{\partial}{\partial z}\left(K_V\frac{\partial T}{\partial z}\right) - R_o\left[\frac{\partial huT}{\partial x} + \frac{\partial hvT}{\partial y} + \frac{\partial hwT}{\partial z}\right]$$
$$+ \frac{E_H}{\mathrm{Pr}_H}\left[\frac{\partial}{\partial x}\left(K_H\frac{\partial hT}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_H\frac{\partial hT}{\partial y}\right)\right] \tag{17}$$

$$\frac{\partial hS}{\partial t} = \frac{E_V}{\mathrm{Pr}_V}\frac{\partial}{\partial z}\left(K_V\frac{\partial S}{\partial z}\right) - R_o\left[\frac{\partial huS}{\partial x} + \frac{\partial hvS}{\partial y} + \frac{\partial hwS}{\partial z}\right]$$
$$+ \frac{E_H}{\mathrm{Pr}_H}\left[\frac{\partial}{\partial x}\left(K_H\frac{\partial hS}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_H\frac{\partial hS}{\partial y}\right)\right] \tag{18}$$

In Equations 14 through 18, h is the thickness of an internal layer and k+1/2 and k-1/2 represent the top and bottom, respectively, of the k^{th} vertical layer.

2.4 Boundary-Fitted Equations

To better resolve the complex geometry in the horizontal directions, the Sinclair Inlet 3D model makes computations on the boundary-fitted or generalized curvilinear planform grid shown in Figure 1-2. This requires transforming the governing equations into boundary-fitted coordinates (ξ, η). If only the (x, y) coordinates are transformed, a system of equations similar to those solved by Johnson (1980) for vertically averaged flow fields is obtained. However, in the Sinclair Inlet 3D model not only are the (x, y) coordinates transformed into the (ξ, η) curvilinear system but also the velocity is transformed such that its components are perpendicular to the (ξ, η) coordinate lines. This is accomplished by employing the definitions below for the components of the Cartesian velocity (u, v) in terms of contravariant components $\overline{u}$ and $\overline{v}$.

$$
\begin{aligned}
u &= x_\xi \overline{u} + x_\eta \overline{v} \\
v &= y_\xi \overline{u} + y_\eta \overline{v}
\end{aligned}
\tag{19}
$$

along with the following expressions for replacing Cartesian derivatives:

$$
\begin{aligned}
f_x &= \frac{1}{J}\left[\left(fy_\eta\right)_\xi - \left(fy_\xi\right)_\eta\right] \\
f_y &= \frac{1}{J}\left[-\left(fx_\eta\right)_\xi + \left(fx_\xi\right)_\eta\right]
\end{aligned}
\tag{20}
$$

Where J is the Jacobian of the transformation defined as:

$$J = x_\xi y_\eta - x_\eta y_\xi$$

The contravariant components of the velocity, $\overline{u}$ and $\overline{v}$, are perpendicular to the curvilinear cell faces. Thus, writing the governing equations in terms of the contravariant components greatly facilitates the enforcement of boundary conditions: at a land boundary, either $\overline{u}$ or $\overline{v}$ is set to zero.

Initially the vertical dimension was handled through the use of what is commonly called a sigma-stretched grid. Such a grid was used in the Chesapeake Bay study (Johnson, Heath, Hsieh, et al., 1991). However, it was observed that stratification in the deep channels could not be maintained during long-term simulations on Chesapeake Bay. With a sigma-stretched grid, the bottom layer in one column communicates with the bottom layer in an adjacent column. Thus, if depth changes are rather coarsely resolved, channel stratification could not be maintained in the Chesapeake Bay study. As a result, the Sinclair Inlet model, discussed in this report, uses a staggered grid in the z, or vertical, direction. Different numbers of cells are used in the vertical direction to resolve depth features. The variation in number of z-cells with horizontal position is shown in Figure 1-2. Notice that fewer cells are used to resolve the shallow portions of Sinclair Inlet than are used in the deep navigation channel. This approach is referred to as a z-plane method. The governing equations presented below for solution on the

Cartesian or z-plane in the vertical direction are the equations constituting the internal mode in the Sinclair Inlet model.

A sample z-plane grid is shown in Figure 2-1. A cross section of the inlet is shown. Notice that as one moves from one shore to another (either in the x or y direction), the number of cells used in the vertical, or z, direction varies in order to resolve the depth features of the inlet.

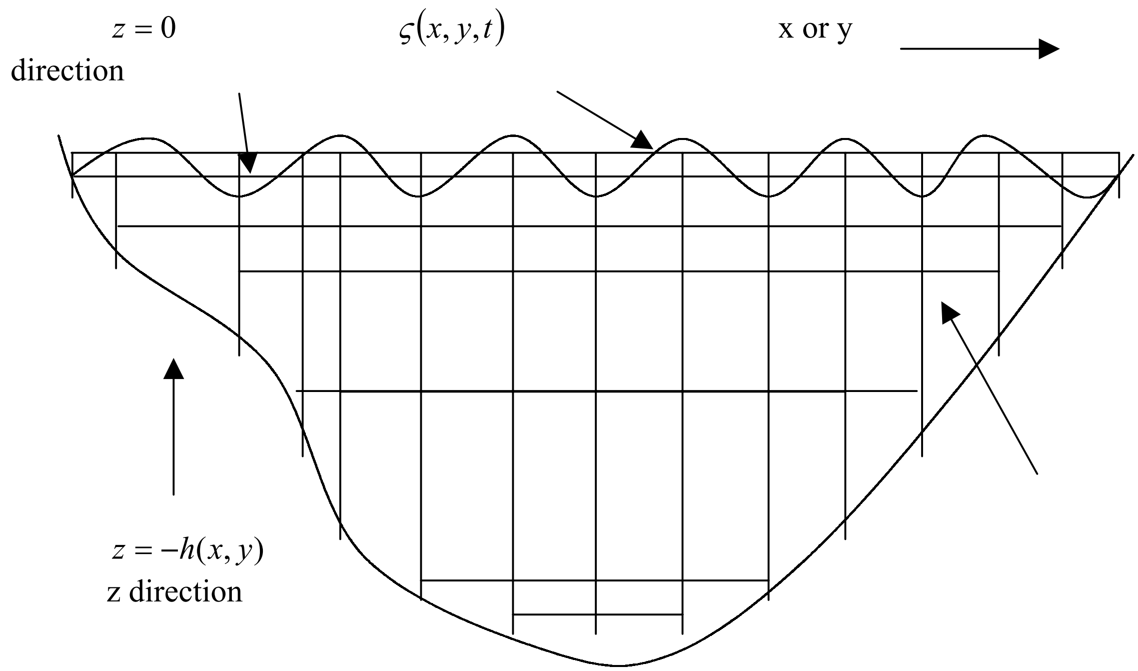


Figure 2-1. Sample z-plane Grid

With the Cartesian coordinates and the Cartesian velocity transformed, the following boundary-fitted equations for $\overline{u}$, $\overline{v}$, w, S, and T to be solved in each vertical layer are obtained. (Recall that the equations are boundary fitted in the x and y directions only. Another way to think of this is that the equations are fitted to the contours of the shoreline in each horizontal plane.)

$$
\begin{aligned}
\frac{\partial h\bar{u}}{\partial t} &= -h\left(\frac{G_{22}}{J^2}\frac{\partial \varsigma}{\partial \xi} - \frac{G_{12}}{J^2}\frac{\partial \varsigma}{\partial \eta}\right) + \frac{h}{J}\left(G_{12}\bar{u} + G_{22}\bar{v}\right) \\
&+ \frac{R_o x_\eta}{J^2}\left[\frac{\partial}{\partial \xi}\left(Jy_\xi h\overline{u}\overline{u} + Jy_\eta h\overline{u}\overline{v}\right) + \frac{\partial}{\partial \eta}\left(Jy_\xi h\overline{u}\overline{v} + Jy_\eta h\overline{v}\overline{v}\right)\right] \\
&- \frac{R_o y_\eta}{J^2}\left[\frac{\partial}{\partial \xi}\left(Jx_\xi h\overline{u}\overline{u} + Jx_\eta h\overline{u}\overline{v}\right) + \frac{\partial}{\partial \eta}\left(Jx_\xi h\overline{u}\overline{v} + Jx_\eta h\overline{v}\overline{v}\right)\right] \\
&- R_o\left[\left(w\bar{u}\right)_{top} - \left(w\bar{u}\right)_{bot}\right] + E_V\left[\left(A_V\frac{\partial \bar{u}}{\partial z}\right)_{top} - \left(A_V\frac{\partial \bar{u}}{\partial z}\right)_{bot}\right] \\
&- \frac{R_o h}{{Fr_D}^2}\left[\int_z^{\varsigma}\left(\frac{G_{22}}{J^2}\frac{\partial \rho}{\partial \xi} - \frac{G_{12}}{J^2}\frac{\partial \rho}{\partial \eta}\right)dz\right] + Horizontal\ Diffusion
\end{aligned} \tag{21}
$$

$$
\begin{aligned}
\frac{\partial h\bar{v}}{\partial t} &= -h\left(-\frac{G_{21}}{J^2}\frac{\partial \varsigma}{\partial \xi} + \frac{G_{11}}{J^2}\frac{\partial \varsigma}{\partial \eta}\right) - \frac{h}{J}\left(G_{11}\bar{u} + G_{21}\bar{v}\right) \\
&- \frac{R_o x_\xi}{J^2}\left[\frac{\partial}{\partial \xi}\left(Jy_\xi h\overline{u}\overline{u} + Jy_\eta h\overline{u}\overline{v}\right) + \frac{\partial}{\partial \eta}\left(Jy_\xi h\overline{u}\overline{v} + Jy_\eta h\overline{v}\overline{v}\right)\right] \\
&+ \frac{R_o y_\xi}{J^2}\left[\frac{\partial}{\partial \xi}\left(Jx_\xi h\overline{u}\overline{u} + Jx_\eta h\overline{u}\overline{v}\right) + \frac{\partial}{\partial \eta}\left(Jx_\xi h\overline{u}\overline{v} + Jx_\eta h\overline{v}\overline{v}\right)\right] \\
&- R_o\left[\left(w\bar{v}\right)_{top} - \left(w\bar{v}\right)_{bot}\right] + E_V\left[\left(A_V\frac{\partial \bar{v}}{\partial z}\right)_{top} - \left(A_V\frac{\partial \bar{v}}{\partial z}\right)_{bot}\right] \\
&- \frac{R_o h}{{Fr_D}^2}\left[\int_z^{\varsigma}\left(-\frac{G_{21}}{J^2}\frac{\partial \rho}{\partial \xi} + \frac{G_{11}}{J^2}\frac{\partial \rho}{\partial \eta}\right)dz\right] + Horizontal\ Diffusion
\end{aligned} \tag{22}
$$

$$
w_{top} = w_{bot} - \frac{1}{J}\left(\frac{\partial J\bar{u}h}{\partial \xi} + \frac{\partial J\bar{v}h}{\partial \eta}\right) \tag{23}
$$

$$
\begin{aligned}
\frac{\partial hS}{\partial t} &= \frac{E_V}{\mathrm{Pr}_V}\left[\left(K_V\frac{\partial S}{\partial z}\right)_{top} - \left(K_V\frac{\partial S}{\partial z}\right)_{bot}\right] - \frac{R_o}{J}\left(\frac{\partial hJ\bar{u}S}{\partial \xi} + \frac{\partial hJ\bar{v}S}{\partial \eta}\right) \\
&- R_o\left[\left(wS\right)_{top} - \left(wS\right)_{bot}\right] + Horizontal\ Diffusion
\end{aligned} \tag{24}
$$

$$
\begin{aligned}
\frac{\partial hT}{\partial t} &= \frac{E_V}{\mathrm{Pr}_V}\left[\left(K_V\frac{\partial T}{\partial z}\right)_{top} - \left(K_V\frac{\partial T}{\partial z}\right)_{bot}\right] - \frac{R_o}{J}\left(\frac{\partial hJ\bar{u}T}{\partial \xi} + \frac{\partial hJ\bar{v}T}{\partial \eta}\right) \\
&- R_o\left[\left(wT\right)_{top} - \left(wT\right)_{bot}\right] + Horizontal\ Diffusion
\end{aligned} \tag{25}
$$

where

$$
\begin{aligned}
G_{11} &= x_{\xi}^{\;2} + y_{\xi}^{\;2} \\
G_{22} &= x_{\eta}^{\;2} + y_{\eta}^{\;2} \\
G_{12} &= G_{21} = x_{\xi} x_{\eta} + y_{\xi} y_{\eta}
\end{aligned} \tag{26}
$$

Similarly, the transformed external mode equations become:

$$
\frac{\partial \varsigma}{\partial t} + \beta\left(\frac{\partial \overline{U}}{\partial \xi} + \frac{\partial \overline{V}}{\partial \eta}\right) = 0 \tag{27}
$$

$$
\begin{aligned}
\frac{\partial \overline{U}}{\partial t} &= -\frac{H}{J^2}\left(G_{22}\frac{\partial \varsigma}{\partial \xi} - G_{12}\frac{\partial \varsigma}{\partial \eta}\right) + \frac{1}{J}\left(G_{12}\overline{U} + G_{22}\overline{V}\right) \\
&+ \frac{R_o x_\eta}{J^2 H}\left[\frac{\partial}{\partial \xi}\left(Jy_\xi \overline{U}\,\overline{U} + Jy_\eta \overline{U}\,\overline{V}\right) + \frac{\partial}{\partial \eta}\left(Jy_\xi \overline{U}\,\overline{V} + Jy_\eta \overline{V}\,\overline{V}\right)\right] \\
&- \frac{R_o y_\eta}{J^2}\left[\frac{\partial}{\partial \xi}\left(Jx_\xi \overline{U}\,\overline{U} + Jx_\eta \overline{U}\,\overline{V}\right) + \frac{\partial}{\partial \eta}\left(Jx_\xi \overline{U}\,\overline{V} + Jx_\eta \overline{V}\,\overline{V}\right)\right] \\
&+ \tau_{s\xi} - \tau_{b\xi} - \frac{R_o}{Fr_D^{\;2}}\frac{H^2}{2}\left(G_{22}\frac{\partial \rho}{\partial \xi} - G_{12}\frac{\partial \rho}{\partial \eta}\right) + Horizontal\ Diffusion
\end{aligned} \tag{28}
$$

$$
\begin{aligned}
\frac{\partial \overline{V}}{\partial t} &= -\frac{H}{J^2}\left(-G_{21}\frac{\partial \varsigma}{\partial \xi} + G_{11}\frac{\partial \varsigma}{\partial \eta}\right) - \frac{1}{J}\left(G_{11}\overline{U} + G_{21}\overline{V}\right) \\
&- \frac{R_o x_\xi}{J^2 H}\left[\frac{\partial}{\partial \xi}\left(Jy_\xi \overline{U}\,\overline{U} + Jy_\eta \overline{U}\,\overline{V}\right) + \frac{\partial}{\partial \eta}\left(Jy_\xi \overline{U}\,\overline{V} + Jy_\eta \overline{V}\,\overline{V}\right)\right] \\
&+ \frac{R_o y_\xi}{J^2 H}\left[\frac{\partial}{\partial \xi}\left(Jx_\xi \overline{U}\,\overline{U} + Jx_\eta \overline{U}\,\overline{V}\right) + \frac{\partial}{\partial \eta}\left(Jx_\xi \overline{U}\,\overline{V} + Jx_\eta \overline{V}\,\overline{V}\right)\right] \\
&+ \tau_{s\eta} - \tau_{b\eta} - \frac{R_o}{Fr_D^{\;2}}\frac{H^2}{2}\left(-G_{21}\frac{\partial \rho}{\partial \xi} + G_{11}\frac{\partial \rho}{\partial \eta}\right) + Horizontal\ Diffusion
\end{aligned} \tag{29}
$$

Equations 27-29 are solved first to yield the water-surface elevations, which are then used to evaluate the water-surface slope terms in the internal mode equations. The horizontal diffusion terms are quite lengthy and thus are presented separately in Appendix A for the internal mode equations. Similar expressions for the vertically averaged equations can be inferred from those for the internal mode.

2.5 Boundary Conditions

The boundary conditions at the free surface are

$$A_V\left(\frac{\partial \overline{u}}{\partial z},\frac{\partial \overline{v}}{\partial z}\right)=\frac{\left(\tau_{s\xi},\tau_{s\eta}\right)}{\rho}=\left(CW_{\xi}^{\ 2},CW_{\eta}^{\ 2}\right)$$
$$\frac{\partial T}{\partial z}=\frac{\Pr}{E_V}K\left(T-T_e\right) \tag{30}$$
$$\frac{\partial S}{\partial z}=0$$

whereas the boundary conditions at the bottom are:

$$A_V\left(\frac{\partial \overline{u}}{\partial z},\frac{\partial \overline{v}}{\partial z}\right)=\frac{\left(\tau_{b\xi},\tau_{b\eta}\right)}{\rho}=\frac{U_r}{A_{Vr}}Z_r C_d\left(\overline{u}_1^2+\overline{v}_1^2\right)^{1/2}\left(\overline{u}_1,\overline{v}_1\right)$$
$$\frac{\partial T}{\partial z},\frac{\partial S}{\partial z}=0 \tag{31}$$

where

C = surface drag coefficient
W = wind speed
K = surface heat exchange coefficient
T_e = equilibrium temperature
C_d = bottom friction coefficient
$\bar{u}_1, \bar{v}_1$ = values of the horizontal velocity components next to the bottom.

With z_1 equal to one-half the bottom layer thickness, C_d is given by

$$C_d = k^2 \left[\ln\left(z_1 / z_0 \right) \right]^{-2} \tag{32}$$

where

k = von Karman constant
z_0 = bottom roughness height

Manning's formulation is employed for the bottom friction in the external mode equations if the model is used purely to compute vertically averaged flow fields. As presented by Garratt (1977), the surface drag coefficient is computed from

$$C = (0.75 + 0.067W) \times 10^{-3} \tag{33}$$

with the maximum allowable value being 0.003. The surface heat exchange coefficient, K, and the equilibrium temperature, T_e, are computed from meteorological data (wind speed, cloud cover, wet and dry bulb air temperatures, and relative humidity) as discussed by Edinger, Brady, and Geyer (1974).

Along the shoreline where river inflow occurs, the freshwater inflow and its temperature are prescribed and the salinity is assumed to be zero. At an ocean boundary, the water-surface elevation is prescribed along with time-varying vertical distributions of salinity and temperature. During flood, the specified values of salinity and temperature are employed, whereas during ebb, interior values are advected out of the grid. Along a solid boundary, the normal component of the velocity and the viscosity and diffusivity are set to zero.

2.6 Initial Conditions

When initiating a run of the Sinclair Inlet model, the values of ς, $\bar{u}$, $\bar{v}$, w, $\overline{U}$ and $\overline{V}$ are all set to zero. Values of the salinity and temperature are read from input files. These initial fields are generated from known data at a limited number of locations. Once the values in individual cells are determined by interpolating from the field data, the resulting 3D field is smoothed several times. Generally, the salinity and temperature fields are frozen for the first few days of a simulation.

2.7 Numerical Grid

A staggered grid is used in both the horizontal and vertical directions of the computational domain (Figure 2-2). In the horizontal directions, a unit cell consists of a ς-point in the center $(\varsigma_{i,j})$ a U-point to its left $(U_{i,j})$, and a V-point to its bottom $(V_{i,j})$. In the vertical direction, the vertical velocities are computed at the "full" grid points. Horizontal velocities, temperature, salinity, and density are computed at the "half" grid points (half grid spacing below the full points).

Two arrays, each of dimension (IMAX, JMAX), are used to index the grid cells. The array NS indicates the condition of the left and right cell boundaries, while the array MS denotes the condition of the top and bottom cell boundaries (Figure 2-2).

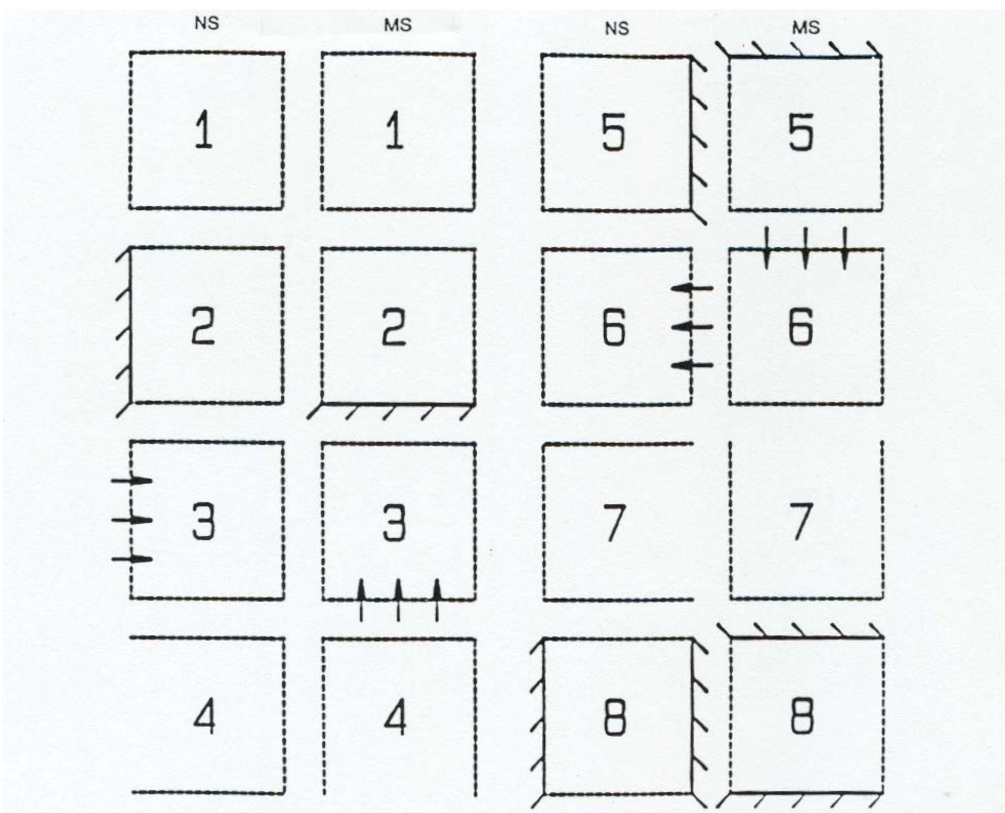


Figure 2-2. Computational Arrays

2.8 Numerical Solution Algorithm

Finite differences are used to replace derivatives in the governing equations resulting in a system of linear algebraic equations to be solved in both the external and internal modes.

The external mode solution consists of the surface displacement and vertically integrated contravariant unit flows $\overline{U}$ and $\overline{V}$. All of the terms in the transformed vertically averaged continuity equation are treated implicitly whereas only the water-surface slope terms in the transformed vertically averaged momentum equations are treated implicitly. If the external mode is used as purely a vertically averaged model, the bottom friction is also treated implicitly. Those terms treated implicitly are weighted between the new and old time-steps. The resulting finite difference equations are then factored such that a ξ-sweep followed by an η-sweep of the horizontal grid yields the solution at the new time-step.

Writing Equations 11-13 as

$$\frac{\partial \varsigma}{\partial t} + \beta\left(\frac{\partial \overline{U}}{\partial \xi} + \frac{\partial \overline{V}}{\partial \eta}\right) = 0 \tag{34}$$

$$\frac{\partial \overline{U}}{\partial t} + \frac{H}{J^2} G_{22} \frac{\partial \varsigma}{\partial \eta} = M \tag{35}$$

$$\frac{\partial \overline{V}}{\partial t} + \frac{H}{J^2} G_{11} \frac{\partial \varsigma}{\partial \eta} = N \tag{36}$$

the ξ-sweep is

$$\begin{aligned} &\xi - sweep \Rightarrow \varsigma_{ij}^{*} + \frac{\beta\theta\Delta t}{\Delta\xi}\left(\overline{U}_{i+1,j}^{*} - \overline{U}_{ij}^{*}\right) = \varsigma_{ij}^{n} \\ &-(1-\theta)\frac{\Delta t}{\Delta\xi}\left(\overline{U}_{i+1,j}^{n} - \overline{U}_{ij}^{n}\right) - \frac{\Delta t}{\Delta\eta}\left(\overline{V}_{i,j+1}^{n} - \overline{V}_{ij}^{n}\right) \end{aligned} \tag{37}$$

and

$$\begin{aligned} &\overline{U}_{ij}^{n+1} + \frac{\theta\Delta t H G_{22}}{\Delta\xi J^2}\left(\varsigma_{ij}^{*} - \varsigma_{i-1,j}^{*}\right) = \overline{U}_{ij}^{n} \\ &-(1-\theta)\frac{\Delta t H G_{22}}{\Delta\xi J^2}\left(\varsigma_{ij}^{n} - \varsigma_{i-1,j}^{n}\right) + \Delta t M^{n} \end{aligned} \tag{38}$$

the η-sweep then provides the updated ς and $\overline{V}$ at the $n+1$ level.

$$\begin{aligned} &\eta - sweep \Rightarrow \varsigma_{ij}^{n+1} + \frac{\beta\theta\Delta t}{\Delta\eta}\left(\overline{V}_{i,j+1}^{n+1} - \overline{V}_{ij}^{n+1}\right) = \varsigma_{ij}^{*} \\ &-(1-\theta)\frac{\Delta t}{\Delta\eta}\left(\overline{V}_{i,j+1}^{n} - \overline{V}_{ij}^{n}\right) + \frac{\Delta t}{\Delta\eta}\left(\overline{V}_{i,j+1}^{n} - \overline{V}_{ij}^{n}\right) \end{aligned} \tag{39}$$

and

$$\begin{aligned} &\overline{V}_{ij}^{n+1} + \frac{\theta\Delta t H G_{11}}{\Delta\eta J^2}\left(\varsigma_{i,j+1}^{n+1} - \varsigma_{ij}^{n+1}\right) = \overline{V}_{ij}^{n} \\ &-(1-\theta)\frac{\Delta t H G_{11}}{\Delta\eta J^2}\left(\varsigma_{i,j+1}^{n} - \varsigma_{ij}^{n}\right) + \Delta t N^{n} \end{aligned} \tag{40}$$

A typical value of θ of 0.55 yields stable and accurate solutions.

The internal mode consists of computations from Equations 21-25 for the three velocity components $\bar{u}$, $\bar{v}$, and w, salinity, and temperature. The only terms treated implicitly are the vertical diffusion terms in all equations and the bottom friction and surface slope terms in the momentum equations. Values of the water-surface elevations from the external mode are used to evaluate the surface slope terms in Equations 21 and 22. As a result, the extremely restrictive speed of a free-surface gravity wave is removed from the stability criteria. Roache's second upwind differencing is used to represent the convective terms in the momentum equations, whereas a spatially third-order scheme developed by Leonard (1979) called QUICKEST is used to represent the advective terms in Equations 24 and 25 for salinity and temperature, respectively. For example, if the velocity on the right face of a computational cell is positive then with QUICKEST the value of the salinity used to compute the flux through the face is given by:

$$\begin{aligned} S_R &= \tfrac{1}{2}\left(S_{i,j,k} + S_{i+1,j,k}\right) \\ &- \tfrac{1}{6}\left[1 - \left(\frac{\bar{U}_{i+1,j,k}\Delta t}{\Delta \xi}\right)^2\right]\left(S_{i+1,j,k} - 2S_{i,j,k} + S_{i-1,j,k}\right) \\ &- \tfrac{1}{2}\frac{U_{i+1,j,k}\Delta t}{\Delta \xi}\left(S_{i+1,j,k} - S_{i,j,k}\right) \end{aligned} \qquad (41)$$

The more interested reader is referred to the paper by Leonard (1979).

It should be noted that once the $\bar{u}$ and $\bar{v}$ velocity components are computed they are slightly adjusted to ensure the conservation of mass. This is accomplished by forcing the sum of $\bar{u}$ over the vertical to be the vertically averaged velocity $\bar{U}/H$ and the sum of $\bar{v}$ over the vertical to equal $\bar{V}/H$, where H is the total water depth.

2.9 Turbulence Parameterization

Vertical turbulence is handled by using the concept of eddy viscosity and diffusivity to represent the velocity and density correlation terms that arise from a time averaging of the governing equations. These eddy coefficients are computed from mean flow characteristics using a simplified second-order closure model originally developed by Donaldson (1973). The closure model has been further developed and applied to various types of flows by Lewellen (1977) and Sheng (1982 and 1986). A discussion of the implementation of the turbulence model taken from Sheng (1982 and 1986) is as follows. For more details the interested reader should refer to these references and to Johnson, Kim, Heath, and Butler (1991).

Assuming local equilibrium of turbulence, i.e., there is no time evolution or spatial diffusion of the second-order correlation, an equation relating the turbulent kinetic energy and the macroscale of turbulence to the mean flow shear and stratification (given by the Richardson number Ri) can be derived as:

$$3A^2b^2sQ^4 + A\left[\left(bs + 3b + 7b^2s\right)Ri - \left|1 - 2b\right|\right]Q^2 + b\left(s + 3 + 4bs\right)Ri^2 + \left(bs - A\right)\left(1 - 2b\right)Ri = 0 \tag{42}$$

where

$$b = 0.125$$
$$s = 1.8$$
$$A = 0.75$$

and

$$Q = \frac{q}{\Lambda\sqrt{\left(\frac{\partial \overline{u}}{\partial z}\right)^2 + \left(\frac{\partial \overline{v}}{\partial z}\right)^2}} \tag{43}$$

In the above expression, q is defined as

$$q = \left(\overline{u'u'} + \overline{v'v'} + \overline{w'w'}\right)^{1/2}$$

and Λ is the macroscale of turbulence, u', v' and w' are the turbulent velocity fluctuations and the overbar indicates time averaging.

It can also be shown that the following relations hold

$$\overline{u'w'} = -\frac{\frac{\partial \overline{u}}{\partial z}\Lambda}{q}\frac{\left(1 + \frac{\overline{\omega}}{A}\right)}{\left(1 - \omega\right)}\overline{w'w'} \tag{44}$$

$$\overline{v'w'} = -\frac{\frac{\partial \overline{v}}{\partial z}\Lambda}{q}\frac{\left(1 + \frac{\overline{\omega}}{A}\right)}{\left(1 - \omega\right)}\overline{w'w'} \tag{45}$$

$$q^2b = \left[\frac{\left(1 + \frac{\overline{\omega}}{A}\right)}{Q^2\left(1 - \omega\right)} + \overline{\omega}\right]\overline{w'w'} \tag{46}$$

where

$$\omega = \frac{Ri}{AQ^2} \qquad (47)$$

and

$$\overline{\omega} = \frac{\omega}{1 - \frac{\omega}{bs}} \qquad (48)$$

Thus, after the velocity shear and flow stratification are determined, q can be computed from Equations 42 and 43. $\overline{w'w'}$ is then determined from

$$\overline{w'w'} = \frac{\frac{q^2}{2} - q^2 b}{\frac{3}{2}(1 - 2\omega)} \qquad (49)$$

Finally, after Λ is prescribed, $\overline{u'w'}$ and $\overline{v'w'}$ can be computed from Equations 44 and 45 and the vertical eddy coefficients can be determined from

$$A_V = \frac{\overline{-u'w'}}{\frac{\partial \overline{u}}{\partial z}} = \frac{\Lambda}{q} \frac{(A + \overline{\omega})}{A(1 - \omega)} \overline{w'w'} \qquad (50)$$

$$K_V = \frac{\overline{-\rho' w'}}{\frac{\partial \rho}{\partial z}} = \frac{\Lambda}{q} \frac{bs}{A(bs - \omega)} \overline{w'w'} \qquad (51)$$

In addition to setting $\Lambda = 0.65z$ near boundaries, three basic constraints are used to compute Λ at a vertical position z.

$$\left| \frac{\partial \Lambda}{\partial z} \right| \le 0.65 \qquad (52)$$

$$\Lambda \le \frac{q}{N} = q \Big/ \left(-\frac{g}{\rho} \frac{\partial \rho}{\partial z} \right)^{0.5} \qquad (53)$$

$$\Lambda \le Q_{cut} \left(z_{q = q\max} - z_{q = q\max/2} \right) \qquad (54)$$

where N is the Brunt-Vaisala frequency.

Equation 54 states that Λ is less than a fraction of the spread of turbulence as measured by the distance between the location of a maximum q^2 to where q^2 is equal to 25 percent of the maximum. The coefficient Q_{cut} is on the order of 0.15 to 0.25.

3.0 STRUCTURE OF THE SINCLAIR INLET 3D HYDRODYNAMIC COMPUTER MODEL

Array dimensions are defined in two parameter statements, which are compiled as include statements at the beginning of each of the program routines. The include files are called chesv.inc and comm.inc. Include file chesv.inc is listed in Appendix B. Include file chesv.inc contains grid dimensioning information such as the maximum number of cells in the I (east to west), J (south to north) and K (depth) directions. Include file chesv.inc also contains the maximum dimensions for all other arrays (such as the number of rivers, number of tidal boundaries, etc.). Include file comm.inc contains all the COMMON blocks which actually define the arrays used in the program.

3.1 Main Program

VCH3D is the main program. There are several subroutines in the Sinclair Inlet Model plus a main program. Subroutines governing model setup are called from the main program while subroutines governing the computations are called from subroutine CH3DM2. Each subroutine is listed below with a description of its function. Entry points in particular subroutines are also noted. The subroutines are listed in the order in which they are called.

CH3DIR - Reads control data from File 4 (see Appendix C for a sample of the inputs for Sinclair Inlet). Manning's n values are read from File 18 (Note: this is a dummy read; the Manning n values are hardwired in this subroutine—this call is preserved for continuity with other CH3D analyses). Water depths at the center of each computational cell (variable HS) are read from File 50. (See Appendix D for a sample listing of this file.) (Note: for I, J indices outside the active cells, HS is set to zero.) Various constants are computed, the layer thicknesses are set, and the array KM (I, J) indicating the bottom layer of each column is set. Subroutine CH3DIM is called to compute the x and y mapping coefficients.

CH3DTR - Reads (x, y) coordinates of the boundary-fitted grid from File 15. The coordinates are then multiplied by the scale factor, XMAP, and divided by XREF to make them nondimensional. Subroutine BJINTR is called to provide the coordinate derivatives needed to compute the metrics of the transformation.

BJINTR - Computes various coordinate derivatives and sets the water depth HU (I, J) and HV (I, J) on the faces of each computational cell.

CH3DIH - Prints water depth arrays if requested by input data. Also, the water depths are made nondimensional by dividing by ZREF. The non-dimensionalized water depths are written to File 22 if requested.

CH3DV1, CH3DV3, CH3DV5 - Writes flowfield information to Files 42, 43 and 44 for visualization.

CH3DND - Computes many constants as nondimensional quantities. These include the Eckman number, Rosby number, time-step, etc.

CH3DII - Sets up the arrays that indicate the types of boundaries comprising a computational cell. In addition, arrays controlling the computation of the convective terms in the momentum equations and the averaging of water-surface elevations at points other than the cell center are set up.

CH3DIF - Initializes various variables for a cold run and creates time files for tide, salinity, etc. The hot start (i.e., restart) capability is not operational.

CH3DIV - The arrays created in CH3DII concerning the averaging of water-surface elevations contain logical values. Those arrays are used in this subroutine to create arrays containing a numerical value. These arrays, i.e., AFVI (I, J), etc., are used to control the averaging of not only water-surface elevations but other variables as well.

CH3DWS - Controls the reading of either wind speed or wind stress. If the wind speed is read, the stress is computed from Garrett's equation. ENTRY CH3DWT controls the time-varying reads and computations

CH3DTD - Computes a sinusoidal tide from amplitude, phase, and offset values input in CH3DIR. Hardwired specifications are included for the two tidal boundaries in this analysis (variable ITIDE is set to 11). ENTRY CH3DTI controls the reading of time-varying tabular tide data.

3.2 Subroutines

The subroutines above are called from VCH3D in the sequence given. Before calling CH3DM2, which controls the computations, the initial salinity field is read from File 74. The initial temperature field is read from File 17.

CH3DM2 - Final subroutine called from VCH3D. All subroutines controlling the actual 3D computations are called from this subroutine in the order as they appear below.

CH3DDP - Computes total water depths and the thickness of the top layer from the latest water-surface elevation field. ENTRY CH3DDM sets total water depths at the intermediate time level, and ENTRY CH3DDN sets total water depths and the top layer thickness at the previous time level.

CH3DTK - Reads equilibrium temperatures and surface-heat exchange coefficients from File 19 and then casts them into nondimensional form. ENTRY CH3DTB controls the time varying read and interpolation.

CH3DRI - Reads river inflows from File 13. ENTRY CH3DRV controls the time varying read and interpolation.

CH3DSAI - Reads salinity and temperatures at tidal boundaries from File 76. ENTRY CH3DSAV controls the time varying reads, interpolation, and conversion to nondimensional form.

CH3DTEI - Reads temperatures at river inflow boundaries from File 78. ENTRY CH3DTEV controls the reading of time-varying temperatures and interpolation.

CH3DQI - Reads lateral flow rates from File 33 and computes lateral flow rates at each cell.

At this point the loop over time is entered in CH3DM2 and each of the subroutines below is called each time-step.

CH3DDE - Computes the water density using Eckert's equation. The baroclinic terms in the momentum equations are then evaluated.

CH3DKE - Computes the terms in the k-ε turbulence model. The turbulence model is based on quasi-equilibrium theory in which the algebraic stresses are obtained based on local equilibrium assumption while the turbulent kinetic energy and dissipation are calculated based on time and spatial varying k-ε formulation.

CH3DDN - ENTRY in CH3DDP for assigning total water depths at the previous time level.

CH3DGD - ENTRY in CH3DDP to update the lateral flow rates in each cell.

CH3DWT - ENTRY in CH3DWS for reading time-varying wind data from File 14. New wind shear stresses are also calculated.

CH3DTB - ENTRY in CH3DTK for reading time-varying equilibrium temperature and heat-exchange coefficients from File 19.

CH3DRV - ENTRY in CH3DRI for reading time-varying river flows from File 13.

CH3DTEV - ENTRY in CH3DTEI for reading time-varying temperatures at river inflow boundaries from File 78.

CH3DQV - ENTRY in CH3DQI for reading new lateral flow rates every time step from File 33.

CH3DTI - ENTRY in CH3DTD for reading time-varying tabular tide data.

CH3DTD - If a sinusoidal tide is imposed this subroutine is called instead of ENTRY CH3DTI.

CH3DSAV - Entry in CH3DSAI for reading time-varying salinity and temperatures at tidal boundaries from File 76.

CH2DXY - Controls the External Mode of the calculations: the vertically averaged flow field computed from the vertically averaged equations of motion. Calls ENTRY CH3DDM in CH3DDP to compute the cell depths at the intermediate time level.

CH3DDP – Computes the total water depth at time level N + 1 using the water-surface field computed in CH2DXY.

CH2DDI - Calculates inertia and diffusion terms (2D mode only).

CH3DXYZ - Controls the Internal Mode of the calculations. The routine computes the 3D-velocity field. Forcing the vertical sum of the horizontal components of the 3D velocity to match the vertically averaged values computed in CH2DXY ensures mass conservation.

CH3DDI - Computes the convective and diffusion terms in the momentum equations using the most recent computations from CH3DDP and CH3DXYZ. These terms are then employed at the next time step in CH2DXY and CH3DXYZ.

CH3DSA - Computes the salinity field.

CH3DTE - Computes the temperature field.

CH3DOT - Controls the output printed and/or written to files for plotting. Output can be requested in terms of the transformed nondimensional variables or the physical dimensional variables. Generally, values for the physical variables in dimensional form are more meaningful. If physical velocities and dimensional output are requested by setting IDIM = 1, SUBROUTINE CH3DC1 is called with ENTRIES CH3DC2, CH3DC3, CH3DC4, CH3DC5, CH3DC6, CH3DC7, CH3DC8, CH3DC9, CH3DCA, CH3DCB, CH3DCC. Each is described below.

CH3DC1 - Provides dimensional water-surface elevations.

CH3DC2 - Provides dimensional physical vertically averaged unit flow rate in x-direction.

CH3DC3 - Provides dimensional physical vertically averaged unit flow rate in y-direction.

CH3DC4 - Provides dimensional physical components of wind shear stress.

CH3DC5 - Provides dimensional physical horizontal components of 3D velocity.

CH3DC6 - Provides dimensional physical vertical component of 3D velocity.

CH3DC7 - Provides dimensional physical components of the vertically averaged velocity.

CH3DC8 - Provides dimensional water density.

CH3DC9 - Provides dimensional physical horizontal components of 3D velocity averaged over some period of time.

CH3DCA - Provides dimensional physical horizontal components of 3D velocity at the center of a cell.

CH3DCB - Provides dimensional water temperature.

CH3DCC - Provides dimensional physical horizontal components of 3D velocity at the center of a cell averaged over some period of time.

CH3DV2, CH3DV4, CH3DV6 - Writes flowfield information to Files 42, 43 and 44 for visualization.

In SUBROUTINE CH3DOT, the following files are created for use in generating time series plots, vector plots, or contour plots.

File 21 - For generating time series plots of dimensional, Cartesian vertically averaged velocities (x and y direction) at cell faces at specified horizontal locations.

File 22 - For generating time series plots of water surface fluctuations at specified horizontal locations.

File 24 - For generating time series plots of nondimensional contravariant vertically integrated velocities at cell faces at specified horizontal locations.

File 26 - For generating time series plots of dimensional x and y-direction components of velocity at cell centers at specified horizontal locations in all layers.

File 31 - For generating time series plots of salinity at specified horizontal locations in all layers.

File 34 - For generating time series plots of temperatures at specified horizontal locations in all layers.

File 40 - Geometry of basin needed to generate snapshot plots.

File 42 - For generating snapshot velocity vector plots (dimensional Cartesian) at particular points in time in all layers.

File 43 - For generating snapshot salinity plots at particular points in time in all layers.

File 44 - For generating a vector plot of time-averaged velocities in all layers.

File 75 - The salinity in all cells.

File 77 - The water temperature in all cells.

File 92 - Grid variables for snapshot plots.

4.0 DEMONSTRATION OF SETUP OF INPUT FILES

To illustrate the setup of input data files, portions of the input files for a simulation of the hydrodynamics of Sinclair Inlet during the period June 9, 1998 through July 19, 1998 are presented. In the case where existing model set up files are not developed for Sinclair Inlet, input data files from Johnson, Kim, Heath, and Butler (1991) were incorporated for illustrative purposes.

4.1 Basic Control Data

Input data controlling the computations are provided in File 4 and are listed in Appendix C. As can be seen, the computational time-step is 60 seconds with a total of 101,000 time-steps simulated. Both temperature and salinity computations are made with the initial fields frozen for 2880 time-steps. As discussed above, there are four river boundaries. The present analysis neglects the river boundaries (in July, the period of the simulation, the flow rate of each river is very small). There are two tidal boundaries. Time-varying harmonic data are prescribed for the tides since ITIDE = 11.

4.2 Water Depths

The water depth field read from File 50 is shown in Appendix D. The depth at the center of each I, J cell shown in Figure 1-2 is input in feet. The code internally adds 5.5 ft to convert from Mean Lower Low Water to Mean Water for Sinclair Inlet. The code then internally converts the depths to centimeters. The code then adjusts the depths to be no less than DELTAZ, which is 310 cm, and no more than 200 feet. Appendix D presents input for the first 3 rows in the matrix of cells (all 74 values of I and J = 1, 2 and 3). Note that the depths for J = 1 are all set to zero.

4.3 Freshwater Inflows

No river inflows are modeled in this analysis. Consequently, no data on freshwater inflows is included.

If one desired to include freshwater inflows, daily averaged freshwater inflows at the fall lines of rivers would be needed. This data is included in File 4. It can be seen from Appendix C that after the day and hour are specified, the location of the fall line boundaries and a discharge for each are given. These data continue in this fashion for the remainder of the simulation period. The inflows at the lateral locations are set internally in the computer code as a percentage of the fall line flows.

4.4 Wind Speed

Wind data are read from File 14. Since IWIND = 5, time-varying wind speed is read and the wind stress is computed from Equation 30. For the July 1998 application one wind field is read (NWIND = 1). These data were collected during hydrodynamic and atmospheric surveys of Sinclair Inlet by the U.S. Navy Space and Warfare Center (SPAWAR), San Diego. Thirty-four days of data were collected. As can be seen in Appendix E, each line of input in File 14 contains the day, hour of the day, and the x

and y components of the wind speed from the measurements. The wind stresses computed in the x and y components are then transformed to the contravariant components $\bar{\tau}_\xi$ and $\bar{\tau}_\eta$ by

$$\bar{\tau}_\xi = \frac{1}{J}\left(\tau_x y_\eta - \tau_y x_\eta\right)$$
$$\bar{\tau}_\eta = \frac{1}{J}\left(-\tau_x y_\xi - \tau_y x_\xi\right) \quad (55)$$

The wind stresses in each cell are constant over the I, J domain and are varied each hour. Hourly wind data are presented in Appendix E for only the first few days in July 1998.

4.5 Grid Coordinates

The (x, y) coordinates of the computational grid shown in Figure 1-2 are read from File 15. File 15 was created from running the grid generation code WESCORA. The form of these data for a few points is illustrated in Appendix F. The first line is the number of points in the ξ and η directions, respectively. The (x, y) coordinates of each point, starting with row 1 and moving from left to right, are then input as one point per line. These values correspond to the arbitrary Cartesian system used to generate the grid. They are multiplied by the variable XREF to convert them into real world distances. Points outside the grid are assigned a value of 9.0×10^{18}.

4.6 Tabular Tides

CH3DTD subroutine contains the hardwired specification of tidal boundary conditions at the two open boundaries. These boundary conditions are invoked by setting ITIDE = 11.

Tidal height is composed of major (16) tidal constituents, as depicted by Equation (56) (Foreman, 1978)

$$H = H_0 + \sum_{i=1}^{N} f_i H_i COS(\omega_i t + (\kappa_i - E_i)) \quad (56)$$

where,

$H_0 =$ mean water level (cm)

$H_i =$ mean tidal constituent amplitude (cm)

$f_i =$ node factor (dimensionless)

$\omega_i =$ constituent angular frequency $(2\pi/T)$

$T =$ tidal constituent period (hours)
$\kappa_i =$ local epoch (degree)
$t =$ time (hour)
$E_i =$ local equilibrium argument (degree)

The boundary condition file contains constants for 16 tidal constituents, including Q1, O1, M1, P1, K1, J1, MU2, N2, NU2, M2, L2, T2, S2, K2, M4, and K3, assigned at the model boundaries. The tidal boundary conditions are read from File 16. The file is shown in Appendix G.

Tidal Constituents	Period (hours)
Q1	26.868
O1	25.820
M1	24.833
P1	24.066
K1	23.934
J1	23.098
MU2	12.872
N2	12.658
NU2	12.626
M2	12.421
L2	12.192
T2	12.016
S2	12.000
K2	11.967
M4	6.210
K3	8.177

4.7 Initial Temperature (Salinity)

The Sinclair Inlet study does not analyze changes in temperature or salinity. Consequently, no input is required.

If temperature or salinity calculations were desired, Files 17 and 74 respectively would be used. Files 17 and 74 are identical in form. File 17 contains the initial temperature field, whereas File 74 contains the initial salinity field. A computer program that uses a few observed values to assign values to the individual cells in each of the vertical layers generated these files. The resulting field is then smoothed in each horizontal direction in each layer before writing the final field to either File 17 or File 74. Appendix H presents the initial temperature field for layers 1, 2 and 3. Note that most of the values are zero since the only active cells in these layers are in the deep channel in the middle of Rich Passage.

4.8 Drag Coefficient

Since the Sinclair Inlet model is a 3D model, the bottom drag coefficient is computed from Equation 32. Thus, File 18 containing a spatially varying Manning's n field is not needed. In addition, since the bottom roughness is constant, File 20 containing a spatially varying roughness height field is not needed.

4.9 Surface Heat Exchange Information

Since the Sinclair Inlet study does not include variations in temperature, no heat exchange data is required.

If one desired to compute changes in temperature, daily averaged equilibrium temperatures and surface heat exchange coefficients computed from meteorological data would be read from File 19. Each input data line consists of the day and hour since the initiation of the simulation and the equilibrium temperature in degrees Celsius, and the surface heat exchange coefficient in watts/m^2/°C.

4.10 Tidal Boundary Salinity and Temperature

No information is needed since the Sinclair Inlet study does not include salinity or temperature variations.

If one desired to include temperature or salinity variations, one would need to specify the time-varying vertical distributions of temperature and salinity at tidal boundaries. This data is read from File 76. These data are grouped in the following manner. The day and hour since the initiation of the simulation is input on a line and followed by separate lines of coding giving the (I, J) location of the tidal boundary cell followed by the vertical distribution of salinity. A separate line gives the same (I, J) location followed by the vertical distribution of temperature. These distributions consist of values in each active layer starting with the surface layer.

5.0 SUMMARY

This report serves two purposes. First, a discussion of the equations solved, turbulence closure, numerical techniques employed, boundary conditions applied, etc., provides the interested reader with theoretical details concerning the 3D model. Second, because sufficient information is presented concerning the structure of the computer code and input data requirements, the report serves as a user's guide for those readers who may be interested in applying the model. Examples of the setup of input data files for the June-July, 1998 simulation of Sinclair Inlet serve to strengthen the use of the report as a user's guide.

The basic equations solved are first presented in their dimensional form for a Cartesian coordinate system. The numerical solution of the governing equations involves an external mode consisting of vertically averaged equations along with the full 3D internal mode equations. The Cartesian equations for the two modes are then non-dimensionalized before casting them into a form for solution on a boundary-fitted coordinate system. In this transformation, only terms in the horizontal directions are transformed since the Cartesian form is retained in the vertical direction. It was found in the Chesapeake Bay long-term simulations (Johnson, Heath, Hsieh, et al., 1991) that this form was required to maintain the observed stratification in the deep channels.

A discussion of boundary conditions reveals that both the wind stress at the free surface and the bottom friction stress are cast in a quadratic form. The exchange of heat at the free surface is represented using the concept of an equilibrium temperature. At a tidal boundary the time-varying water surface and vertical distributions of salinity and temperature are required, whereas at river boundaries the freshwater discharge and the temperature of the inflow are required.

The method of finite differences is used to solve the governing equations. In the external mode the vertically averaged continuity equation is treated completely implicitly, whereas only the water-surface slope terms are treated implicitly in the momentum equations. The resulting difference equations are factored into (ξ, η) sweeps to yield an extremely efficient solution scheme. In the internal mode equations, the only terms treated implicitly are the vertical diffusion terms, the bottom friction and the water-surface slope terms. The surface slope terms are "fed" into the internal mode computations from the external mode.

The vertical turbulence closure model is based upon the assumption of local equilibrium of turbulence. Thus, all time derivatives plus the advection and diffusion terms in the Reynold's stress equations are neglected. This results in algebraic equations relating the eddy coefficients to the water column stratification, a turbulence length scale and the kinetic energy of the turbulence.

A discussion of the functions of all subroutines and the order in which they are called provides a basic understanding of the flow of computations in the computer program. Appendices B through G provide detailed information on the input and the form of the input required in various files for operation of the numerical model. A partial listing of all the input files created for the simulation of the hydrodynamics of Sinclair Inlet during June—July 1998 illustrates the setup of these input data.

6.0 REFERENCES

Donaldson, C. 1973. “Atmospheric Turbulence and the Dispersal of Atmospheric Pollutants.” In *AMS Workshop on Micrometeorology*, ed., D. A. Haugen, 313-390. Boston: Science Press.

Edinger, J. E., Brady, D. K., and Geyer, J. C. 1974. “Heat Exchange and Transport in the Environment.” *Report 14, EPRI Publication No. 74-049-00-3*. Prepared for Electric Power Research Institute. Palo Alto, CA.

Foreman, M. 1978. “Manual for Tidal Currents Analysis and Prediction.” *Pacific Marine Science Report 78-6*. Institute of Ocean Sciences. Sidney, British Columbia, Canada (1993 version). 66p.

Garratt, J. R. 1977. “Review of Drag Coefficients Over Oceans and Continents.” *Monthly Weather Review* 105:915-929.

Johnson, B. H. 1980. “VAHM - A Vertically Averaged Hydrodynamic Model Using Boundary-Fitted Coordinates.” *Miscellaneous Paper HL-80-3*. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Johnson, B. H., Heath, R. E., Hsieh, B. B., Kim, K. W., Butler, H. L. 1991. “User’s Guide for a Three-Dimensional Numerical Hydrodynamic, Salinity, and Temperature Model of Chesapeake Bay.” *Technical Report HL-91-20*. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Johnson, B. H., Kim, K. W., Heath, R. E., and Butler, H. L. 1991. “Verification of a Three-Dimensional Numerical Hydrodynamic Model of Chesapeake Bay.” *Technical Report HL-91-7*. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Leonard, B. P. 1979. “A Stable and Accurate Convective Modeling Procedure Based on Upstream Interpolation.” *Computer Methods in Applied Mechanics and Engineering* 19:59-98.

Lewellen, W. S. 1977. “Use of Invariant Modeling.” *Handbook of Turbulence*. W. Frost, ed. Plenum Publishing 1:237-280.

Sheng, Y. P. 1982. “Hydraulic Applications of a Second-Order Closure Model of Turbulent Transport.” *Applying Research to Hydraulic Practice,* ed., P. Smith, 106-119. ASCE.

________. 1986. “A Three-Dimensional Mathematical Model of Coastal, Estuarine and Lake Currents Using Boundary Fitted Grid.” *Report No. 585*. A.R.A.P. Group of Titan Systems, New Jersey, Princeton, NJ.

USER'S GUIDE FOR A THREE-DIMENSIONAL NUMERICAL HYDRODYNAMIC, SALINITY, AND TEMPERATURE MODEL OF SINCLAIR INLET

July 31, 2001

APPENDICES

Contract No. GS-10T-EBD-0005

Task Order ID: ABH-170-037

Submitted/Prepared by:

Concurrent Technologies Corporation
5780 W. Werner Road
Bremerton, WA 98312

TABLE OF CONTENTS

APPENDIX A
Transformed Horizontal Diffusion Terms

When transforming second derivative terms, many additional terms arise. For example, the horizontal diffusion of momentum terms in Equation 14 of the main text become:

$$
\begin{aligned}
&\left[\frac{\partial}{\partial x}\left(A_H \frac{\partial hu}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_H \frac{\partial hu}{\partial y}\right)\right]= \\
&\frac{Y_\eta}{J^2}\left[\frac{A_H Y_\eta}{J}\left(X_\xi Y_\eta h\bar{u}\right)_\xi+\frac{A_H X_\eta}{J}\left(X_\xi X_\eta h\bar{u}\right)_\xi\right]_\xi-\frac{X_\eta}{J^2}\left[\frac{A_H Y_\eta}{J}\left(Y_\xi Y_\eta h\bar{u}\right)_\xi+\frac{A_H X_\eta}{J}\left(Y_\xi X_\eta h\bar{u}\right)_\xi\right]_\xi \\
&+\frac{Y_\eta}{J^2}\left[\frac{A_H Y_\xi}{J}\left(X_\xi Y_\xi h\bar{u}\right)_\eta+\frac{A_H X_\xi}{J}\left(X_\xi X_\xi h\bar{u}\right)_\eta\right]_\eta-\frac{X_\eta}{J^2}\left[\frac{A_H Y_\xi}{J}\left(Y_\xi Y_\xi h\bar{u}\right)_\eta+\frac{A_H X_\xi}{J}\left(X_\xi Y_\xi h\bar{u}\right)_\eta\right]_\eta \\
&+\frac{Y_\eta}{J^2}\left[\frac{A_H Y_\eta}{J}\left(Y_\eta X_\eta h\bar{v}\right)_\xi+\frac{A_H X_\eta}{J}\left(X_\eta X_\eta h\bar{v}\right)_\xi\right]_\xi-\frac{X_\eta}{J^2}\left[\frac{A_H Y_\eta}{J}\left(Y_\eta Y_\eta h\bar{v}\right)_\xi+\frac{A_H X_\eta}{J}\left(X_\eta Y_\eta h\bar{v}\right)_\xi\right]_\xi \\
&+\frac{Y_\eta}{J^2}\left[\frac{A_H Y_\xi}{J}\left(X_\eta Y_\xi h\bar{v}\right)_\eta+\frac{A_H X_\xi}{J}\left(X_\xi X_\eta h\bar{v}\right)_\eta\right]_\eta-\frac{X_\eta}{J^2}\left[\frac{A_H Y_\xi}{J}\left(Y_\eta Y_\xi h\bar{v}\right)_\eta+\frac{A_H X_\xi}{J}\left(X_\xi Y_\eta h\bar{v}\right)_\eta\right]_\eta \\
&+\frac{Y_\eta}{J^2}\left[-\left\{\frac{A_H Y_\eta}{J}\left(X_\xi Y_\xi h\bar{u}\right)_\eta\right\}_\xi-\left\{\frac{A_H Y_\xi}{J}\left(X_\xi Y_\eta h\bar{u}\right)_\xi\right\}_\eta\right. \\
&\left.-\left\{\frac{A_H X_\eta}{J}\left(X_\xi X_\xi h\bar{u}\right)_\eta\right\}_\xi-\left\{\frac{A_H X_\xi}{J}\left(X_\xi X_\eta h\bar{u}\right)_\xi\right\}_\eta\right] \\
&-\frac{X_\eta}{J^2}\left[-\left\{\frac{A_H Y_\eta}{J}\left(Y_\xi Y_\xi h\bar{u}\right)_\eta\right\}_\xi-\left\{\frac{A_H Y_\xi}{J}\left(Y_\xi Y_\eta h\bar{u}\right)_\xi\right\}_\eta\right. \\
&\left.-\left\{\frac{A_H X_\eta}{J}\left(X_\xi Y_\xi h\bar{u}\right)_\eta\right\}_\xi-\left\{\frac{A_H X_\xi}{J}\left(Y_\xi X_\eta h\bar{u}\right)_\xi\right\}_\eta\right] \\
&+\frac{Y_\eta}{J^2}\left[-\left\{\frac{A_H Y_\eta}{J}\left(X_\eta Y_\xi h\bar{v}\right)_\eta\right\}_\xi-\left\{\frac{A_H Y_\xi}{J}\left(X_\eta Y_\eta h\bar{v}\right)_\xi\right\}_\eta\right. \\
&\left.-\left\{\frac{A_H X_\eta}{J}\left(X_\xi X_\eta h\bar{v}\right)_\eta\right\}_\xi-\left\{\frac{A_H X_\xi}{J}\left(X_\eta X_\eta h\bar{v}\right)_\xi\right\}_\eta\right] \\
&-\frac{X_\eta}{J^2}\left[-\left\{\frac{A_H Y_\eta}{J}\left(Y_\xi Y_\eta h\bar{v}\right)_\eta\right\}_\xi-\left\{\frac{A_H Y_\xi}{J}\left(Y_\eta Y_\eta h\bar{v}\right)_\xi\right\}_\eta\right. \\
&\left.-\left\{\frac{A_H X_\eta}{J}\left(X_\xi Y_\eta h\bar{v}\right)_\eta\right\}_\xi-\left\{\frac{A_H X_\xi}{J}\left(X_\eta Y_\eta h\bar{v}\right)_\xi\right\}_\eta\right]
\end{aligned}
$$

Likewise, these terms in Equation 15 of the main text become:

$$\left[\frac{\partial}{\partial x}\left(A_H \frac{\partial hv}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_H \frac{\partial hv}{\partial y}\right)\right]=$$

$$+\frac{X_\xi}{J^2}\left[\frac{A_H Y_\xi}{J}\left(Y_\xi Y_\eta h\bar{v}\right)_\eta+\frac{A_H X_\xi}{J}\left(X_\xi Y_\eta h\bar{v}\right)_\eta\right]_\eta-\frac{Y_\xi}{J^2}\left[\frac{A_H Y_\xi}{J}\left(Y_\xi X_\eta h\bar{v}\right)_\eta+\frac{A_H X_\xi}{J}\left(X_\xi X_\eta h\bar{v}\right)_\eta\right]_\eta$$

$$+\frac{X_\xi}{J^2}\left[\frac{A_H Y_\eta}{J}\left(Y_\eta Y_\eta h\bar{v}\right)_\xi+\frac{A_H X_\eta}{J}\left(X_\eta Y_\eta h\bar{v}\right)_\xi\right]_\xi-\frac{Y_\xi}{J^2}\left[\frac{A_H Y_\eta}{J}\left(Y_\eta X_\eta h\bar{v}\right)_\xi+\frac{A_H X_\eta}{J}\left(X_\eta X_\eta h\bar{v}\right)_\xi\right]_\xi$$

$$+\frac{X_\xi}{J^2}\left[\frac{A_H Y_\eta}{J}\left(Y_\xi Y_\eta h\bar{u}\right)_\xi+\frac{A_H X_\eta}{J}\left(X_\eta Y_\xi h\bar{u}\right)_\xi\right]_\xi-\frac{Y_\xi}{J^2}\left[\frac{A_H Y_\eta}{J}\left(X_\xi Y_\eta h\bar{u}\right)_\xi+\frac{A_H X_\eta}{J}\left(X_\xi X_\eta h\bar{u}\right)_\xi\right]_\xi$$

$$+\frac{X_\xi}{J^2}\left[\frac{A_H Y_\xi}{J}\left(Y_\xi Y_\xi h\bar{u}\right)_\eta+\frac{A_H X_\xi}{J}\left(X_\xi Y_\xi h\bar{u}\right)_\eta\right]_\eta-\frac{Y_\xi}{J^2}\left[\frac{A_H Y_\xi}{J}\left(X_\xi Y_\xi h\bar{u}\right)_\eta+\frac{A_H X_\xi}{J}\left(X_\xi X_\xi h\bar{u}\right)_\eta\right]_\eta$$

$$+\frac{X_\xi}{J^2}\left[-\left\{\frac{A_H Y_\eta}{J}\left(Y_\xi Y_\xi h\bar{u}\right)_\eta\right\}_\xi-\left\{\frac{A_H Y_\xi}{J}\left(Y_\xi Y_\eta h\bar{u}\right)_\xi\right\}_\eta\right.$$

$$\left.-\left\{\frac{A_H X_\eta}{J}\left(X_\xi Y_\xi h\bar{u}\right)_\eta\right\}_\xi-\left\{\frac{A_H X_\xi}{J}\left(Y_\xi X_\eta h\bar{u}\right)_\xi\right\}_\eta\right]$$

$$-\frac{Y_\xi}{J^2}\left[-\left\{\frac{A_H Y_\eta}{J}\left(X_\xi Y_\xi h\bar{u}\right)_\eta\right\}_\xi-\left\{\frac{A_H Y_\xi}{J}\left(X_\xi Y_\eta h\bar{u}\right)_\xi\right\}_\eta\right.$$

$$\left.-\left\{\frac{A_H Y_\eta}{J}\left(X_\xi X_\xi h\bar{u}\right)_\eta\right\}_\xi-\left\{\frac{A_H X_\xi}{J}\left(X_\xi X_\eta h\bar{u}\right)_\xi\right\}_\eta\right]$$

$$+\frac{X_\xi}{J^2}\left[-\left\{\frac{A_H Y_\eta}{J}\left(Y_\eta Y_\xi h\bar{v}\right)_\eta\right\}_\xi-\left\{\frac{A_H Y_\xi}{J}\left(Y_\eta Y_\eta h\bar{v}\right)_\xi\right\}_\eta\right.$$

$$\left.-\left\{\frac{A_H X_\eta}{J}\left(X_\xi Y_\eta h\bar{v}\right)_\eta\right\}_\xi-\left\{\frac{A_H X_\xi}{J}\left(X_\eta Y_\eta h\bar{v}\right)_\xi\right\}_\eta\right]$$

$$-\frac{Y_\xi}{J^2}\left[-\left\{\frac{A_H Y_\eta}{J}\left(Y_\xi X_\eta h\bar{v}\right)_\eta\right\}_\xi-\left\{\frac{A_H Y_\xi}{J}\left(X_\eta Y_\eta h\bar{v}\right)_\xi\right\}_\eta\right.$$

$$\left.-\left\{\frac{A_H X_\eta}{J}\left(X_\xi X_\eta h\bar{v}\right)_\eta\right\}_\xi-\left\{\frac{A_H X_\xi}{J}\left(X_\eta X_\eta h\bar{v}\right)_\xi\right\}_\eta\right]$$

The transformed horizontal diffusion terms in Equations 17 and 18 of the main text are somewhat simpler since contravariant velocity components are not involved. These terms, written for the salinity, are given below.

$$\left[\frac{\partial}{\partial x}\left(K_H \frac{\partial hS}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_H \frac{\partial hS}{\partial y}\right)\right]=\frac{1}{J}\left\{\left[\frac{K_H Y_\eta}{J}\left(hSY_\eta\right)_\xi+\frac{K_H X_\eta}{J}\left(hSX_\eta\right)_\xi\right]_\xi\right.$$

$$+\left[\frac{K_H Y_\xi}{J}\left(hSY_\xi\right)_\eta+\frac{K_H X_\xi}{J}\left(hSX_\xi\right)_\eta\right]_\eta$$

$$-\left[\frac{K_H Y_\eta}{J}\left(hSY_\xi\right)_\eta\right]_\xi-\left[\frac{K_H X_\eta}{J}\left(hSX_\xi\right)_\eta\right]_\xi$$

$$\left.-\left[\frac{K_H Y_\xi}{J}\left(hSY_\eta\right)_\xi\right]_\eta-\left[\frac{K_H X_\xi}{J}\left(hSX_\eta\right)_\xi\right]_\eta\right\}$$

Identical terms exist for the temperature.

$$\left[\frac{\partial}{\partial x}\left(K_H \frac{\partial hT}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_H \frac{\partial hT}{\partial y}\right)\right]=\frac{1}{J}\left\{\left[\frac{K_H Y_\eta}{J}\left(hTY_\eta\right)_\xi+\frac{K_H X_\eta}{J}\left(hTX_\eta\right)_\xi\right]_\xi\right.$$

$$+\left[\frac{K_H Y_\xi}{J}\left(hTY_\xi\right)_\eta+\frac{K_H X_\xi}{J}\left(hTX_\xi\right)_\eta\right]_\eta$$

$$-\left[\frac{K_H Y_\eta}{J}\left(hTY_\xi\right)_\eta\right]_\xi-\left[\frac{K_H X_\eta}{J}\left(hTX_\xi\right)_\eta\right]_\xi$$

$$\left.-\left[\frac{K_H Y_\xi}{J}\left(hTY_\eta\right)_\xi\right]_\eta-\left[\frac{K_H X_\xi}{J}\left(hTX_\eta\right)_\xi\right]_\eta\right\}$$

APPENDIX B
Parameter File chesv.inc

This include file is compiled with the computer program. It contains array dimension parameters (i.e., the maximum size for arrays). Notice that the number of cells in the I and J directions are specified in this file. Consequently, if one desires to change the number of cells in either direction, one would have to change this file and recompile the program. Note: there is a second include file called comm.inc which contains the shared COMMON blocks used by the code. That file is not listed here, but it must be included in any compilation of the code.

```
PARAMETER (CELLS =74, JCELLS = 48, IJMAX  =75)
PARAMETER (STATS = 40, NTIDES = 30, NRIVRS = 12)
PARAMETER (LATERLS = 10 , NLATS= 10)
PARAMETER (CNST  = 37, NBNDS  = 30, NBARRS = 10)
PARAMETER (TIDFN = 30, NTIDBN = 30, NTIDPT=10000)
PARAMETER (WINDS =  1)
PARAMETER (ROWS  = 900, NCOLS  = 900, KROWS = 200)
PARAMETER (X8PTS = 256, NY8PTS =  256)
PARAMETER (C1 = ICELLS + 1, JC1 = JCELLS + 1)
PARAMETER (M  = ICELLS + 2, JM  = JCELLS + 2)
PARAMETER (MAX  = 20, K1M = KMAX - 1)
PARAMETER (SSMAX = 200, NPLPTS =150)
PARAMETER (NSDMAX  = 20, SPVAL  = .1234E-6)
```

APPENDIX C
List Of Input Data In File 4

The listing of this file is shown first, followed by an explanation of the meaning of the variables. Notice the structure of the file. Each group of variables is preceded by a line to remind the user of the order of the variables. The code reads but doesn't use the "reminder" information.

```
TITLE(A80)
8640 DT=60 (ITSALT=2880) RUN: IT2=57600 for 6/9/98-Jul/19/98 for 40 days,   Sinclair Inlet :  Sep-1997-RUN
     IT1       IT2        DT    ISTART     ITEST    ITSALT   LITTORL    LATERL
       1    101000      60.0         0         0      2880         0         0
    IPSW     IPUIW     IPVIW     IPSSW      IPUW      IPVW
       0         0         0         0         0         0
    IPSG     IPUIG     IPVIG     IPSSG      IPUG      IPVG
       0         0         0         0         0         0
     IPA       IPB        ID       JPA       JPB        JD       KPA       KPB        KD
       1        72         1         1        40         1         1        23         9
     IGI       IGH       IGT       IGS       IGU       IGW       IGC       IGQ       IGP
       0         0         0         0         0         0         0         0         1
    XREF      ZREF      UREF       COR        GR       RO0       ROR        T0        TR
  20000.     1000.      20.0     .0001     981.0       1.0     1.021        1.       30.
  DELTAZ   DELTAZM
  310.00    310.00    243.84    243.84
    SSS0
     0.0
  ISMALL       ISF       ITB   ZREFBN       CTB       BZ1    ZREFTN       TZ1
       1         0         5       7.5    0.0025    0.1000        5.        .2
   THETA    THETAS
    1.00       1.0
   ITEMP     ISALT       ICC       IFI       IFA       IFB       IFC       IFD      IFDS
       0         0         0         1        00         0         0         1         1
     BVR        S1        S2        PR       PRV       TWE       TWH       FKB       TQ0
     1.0       10.      3.33        1.       1.0       20.       20.        5.       0.0
    IVER      ICON      IUBO       IBL       IBR       JBM       JBP
       2         3         0         1       104         1        87
    CREF      CMAX        C0
      1.      100.        0.
    IIC1       IC2      JJC1       JC2       ID1       ID2       JD1       JD2
       0         0         0         0         0         0         0         0
    IEXP       IAV       AVR       AV1       AV2       AVM      AVM1       AHR
      -3         0       10.     0.000        0.      10.0     0.005    10000.
     FM1       FM2      ZTOP     SLMIN     QQMIN
     -.5      -1.5        0.        1.      0.01
    ICUT    KSMALL      QCUT    GAMAX     GBMAX       FZS
       0         0      0.15     5000.     5000.       0.2
   IWIND      TAUX      TAUY
       5       0.0       0.0         5       0.0       0.0
ISPAC(I),I
    =1,10
       0         0         0         0         0         0         1         0         1      0
JSPAC(I),I
    =1,10
       1         1         1         0         0         0         0         1         0      0
RSPAC(I),
  I=1,10
    .035        0.    .00001    .00001        0.        1.      100.     0.008       .25     4.
    XMAP      YMAP
   100.0     100.0
   ITRAN    IBD(1)       (2)       (3)       (4)
```

2	4	4	4	4					
ITBRK(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
900000	00	0	0	0	0	0	0	0	0
NSTA	NFREQ	NSTART							
12	60	1							

IST	JST	STATID(K)	(2I4,A48)	(ONE CARD FOR EACH STATION)
24	16	West 2 (USGS Jul/94)		
25	16	West 2 (USGS Jul/94)		
26	16	West 2 (USGS Jul/94)		
27	16	Central 2 (USGS Jul/94)		
24	15	Central 2 (USGS Jul/94)		
25	15	Central 2 (USGS Jul/94)		
26	15	East 2 (USGS Jul/94)		
27	15	East 2 (USGS Jul/94)		
24	14	East 2 (USGS Jul/94)		
25	14	deep cell		
26	14	deep cell		
27	14	deep cell		

NSTAS	NFREQS	NSTRTS	(TIDE STATIONS)
10	60	1	

IST	JST	STATS(K)	(2I4,A48)	(ONE CARD FOR EACH STATION)
25	15	West 2 (USGS Jul/94)		
26	15	West 2 (USGS Jul/94)		
25	16	West 2 (USGS Jul/94)		
47	12	Central 2 (USGS Jul/94)		
47	11	Central 2 (USGS Jul/94)		
46	12	Central 2 (USGS Jul/94)		
48	17	East 2 (USGS Jul/94)		
48	18	East 2 (USGS Jul/94)		
49	17	East 2 (USGS Jul/94)		
49	18	deep cell		

MSTA	MFREQ	MSTART	(SALINITY STATIONS)
10	60	1	

IST	JST	STATSA(K)	(2I4,A48)	(ONE CARD FOR EACH STATION)
25	15	West 2 (USGS Jul/94)		
26	15	West 2 (USGS Jul/94)		
25	16	West 2 (USGS Jul/94)		
47	12	Central 2 (USGS Jul/94)		
47	11	Central 2 (USGS Jul/94)		
46	12	Central 2 (USGS Jul/94)		
48	17	East 2 (USGS Jul/94)		
48	18	East 2 (USGS Jul/94)		
49	17	East 2 (USGS Jul/94)		
49	18	deep cell		

NRIVER				
0				
IJRDIR	IJRROW	IJRSTR	IJREND	(ONE CARD FOR EACH RIVER)
FACTOR	BASEF			
I	J	QRIVER		
NLATERL				

```
      0
 IJQDIR      IJQROW      IJQSTR      IJQEND
      I           J       QLAT
   NBAR
      0
 IJBDIR      IJBROW      IJBSTR      IJBEND       ( ONE CARD FOR EACH BAR )

  ITIDE       IJLINE        NCG        IRAD
     11            2          1           0   ITIDE=11 for tidal harmonic constants input (16 constituents)
TIDFNO       TIDBND

TIDSTR(1)         (2)         (3)         (4)         (5)        (6)        (7)        (8)        (9)     (10)


  IJDIR       IJROW      IJSTRT       IJEND       TIDTYP     TIDFN1      TIDFN2
      2           2          72          74     CONSTANT          1           1
      4          31          66          69     CONSTANT          4           4

  TP(1)         (2)         (3)         (4)
 43200.                                        Original period=44712.0

      J           K     AMPWX        PHWX       CAWX      AMPEX        PHEX        CAEX
      3           1       0.0          0.        0.0       180.          0.          0.
      4           1       0.0          0.        0.0       180.          0.          0.
      5           1       0.0          0.        0.0       180.          0.          0.
      6           1       0.0          0.        0.0       180.          0.          0.
      7           1       0.0          0.        0.0       180.          0.          0.
      8           1       0.0          0.        0.0       180.          0.          0.
      9           1       0.0          0.        0.0       180.          0.          0.
     10           1       0.0          0.        0.0       180.          0.          0.
     11           1       0.0          0.        0.0       180.          0.          0.
     12           1       0.0          0.        0.0       180.          0.          0.
     13           1       0.0          0.        0.0       180.          0.          0.
     14           1       0.0          0.        0.0       180.          0.          0.
     15           1       0.0          0.        0.0       180.          0.          0.
     16           1       0.0          0.        0.0       180.          0.          0.
     17           1       0.0          0.        0.0       180.          0.          0.
     -1           0         0           0          0          0           0           0
      I           K     AMPSX        PHSX       CASX      AMPNX        PHNX        CANX
     -1           0         0           0          0          0           0           0

                  RESET  NS(I, J, K)  VALUES
                  RESET  MS(I, J, K)  VALUES
                  RESET  NS(I, J, K)  VALUES
                  RESET  MS(I, J, K)  VALUES
                  RESET  NS(I, J, K)  VALUES
                  RESET  MS(I, J, K)  VALUES
                   STORAGE AREAS
                   END OF DATA
                   END OF FILE
```

A description of each input variable follows. The word DUMMY is used to indicate a line of reminder information that the code reads, but does not use. Notice that format information is included on the end of each line.

DUMMY

TITLE	Run descriptor	A80

DUMMY

IT1, IT2, DT, ISTART, ITEST, ITSALT, LITTORL, LATERL 2I8,F8.0,7I8

IT1		Starting time step (= 1)
IT2		Ending time step
DT		Computational time step in sec
ISTART	= 0	Cold start
	> 0	Hotstart (not operational)
ITEST	= 0	No diagnostic output
	> 0	Diagnostic output
ITSALT		Number of time steps before salinity and temperature Computations are initiated
LITTORL	= 1	Provides for geometry modification
	= 0	No geometry modification
LATERL	> 0	Time-variable unit lateral flow rates read from File 33
	< 0	Steady unit lateral flow rates read from main data set
	= 0	No lateral flow rate calculations

DUMMY

IPSW, IPUIW, IPVIW, IPSSW, IPUW, IPVW 10I8

IPSW	> 0	Frequency of printed output of water surface fluctuations for all cells (I, J) (output every IPSW iterations)
	= 0	No output
IPUIW	> 0	Frequency of printed output of u-integrated velocity for all cells (I, J) (output every IPUIW iterations)
	= 0	No output
IPVIW	> 0	Frequency of printed output of v-integrated velocity for all cells (I, J) (output every IPVIW iterations)
	= 0	No output
IPSSW	> 0	Frequency of printed output of surface shear stress for all cells (I, J) (output every IPSSW iterations)
	= 0	No output
IPUW	> 0	Frequency of printed output of velocities, salinities, temperatures and density for all cells (I, J) (output every IPUW iterations)
	= 0	No output
IPVW		Not used in the code

DUMMY

IPSG, IPUIG, IPVIG, IPSSG, IPUG, IPVG 10I8

IPSG	> 0	Frequency of printed output of water surface fluctuations for selected cells (I = IPA, IPB and, J = JPA, JPB) (output every IPSW iterations)
	= 0	No output
IPUIG	> 0	Frequency of printed output of u-integrated velocity for selected cells (I = IPA, IPB and, J = JPA, JPB) (output every IPSW iterations)
	= 0	No output
IPVIG	> 0	Frequency of printed output of v-integrated velocity for selected cells (I = IPA, IPB and, J = JPA, JPB) (output every IPSW iterations)
	= 0	No output
IPSSG	> 0	Frequency of printed output of surface shear stress for selected cells (I = IPA, IPB and, J = JPA, JPB) (output every IPSW iterations)
	= 0	No output
IPUG		Not used in the code
IPVG		Not used in the code

DUMMY

IPA, IPB, ID, JPA, JPB, JD, KPA, KPB, KD 10I8

IPA	Lower bound on I for printed output
IPB	Upper bound on I for printed output
ID	I increment for printed output
JPA	Lower bound on J for printed output
JPB	Upper bound on J for printed output
JD	J increment for printed output
KPA	Lower bound on K for printed output
KPB	Upper bound on K for printed output
KD	K increment for printed output

DUMMY

IGI, IGH, IGT, IGS, IGU, IGW, IGC, IGQ, IGP 10I8

IGI	= 1	Printout arrays such as NS, MS, etc.
	= 0	No printout
IGH	= 1	Printout all depth arrays
	= 0	No printout
IGT	= 1	Save all depth arrays on File 22
	≠ 1	Depth arrays not saved
IGS		Not used in the code
IGU		Not used in the code

IGW	= 1	Printout shear stress arrays
	= 0	No printout
IGC	= 1	Printout grid coordinates
	= 0	No printout
IGQ		Not used in the code
IGP	≥ 1	Save all grid variables on Files 23 and 92
	< 1	Depth arrays not saved

DUMMY
XREF, ZREF, UREF, COR, GR, ROO, ROR, TO, TR 10F8.0

XREF	Reference horizontal grid distance (Maximum horizontal dimension divided by number of cells in that direction in cm)
ZREF	Reference depth (Average typical depth in cm)
UREF	Reference horizontal velocity (Average velocity in cm/sec)
COR	Coriolis parameter
CR	Gravitational acceleration (cm/sec^2)
ROO	Minimum density expected (gm/cc)
ROR	Reference density (Maximum expected) (gm/cc)
TO	Minimum temperature (Celsius)
TR	Reference temperature (Maximum expected) (Celsius)

DUMMY
DELTAZ, DELTAZM 10F8.0

DELTAZ	Layer thickness in cm of all layers except the top layer
DELTAZM	Thickness of top layer in cm

DUMMY
SSSO 10F8.0

SSSO	Initial water surface elevation relative to initial water depth

DUMMY
ISMALL, ISF, ITB, ZREFBN, CTB, BZ1, ZREFTN, TZ1 3I8, 5F8.0

ISMALL		Used in calculating reference surface elevation according to the formula: SZ = COR*UREF*XREF/(GR*ZREF)*ISMALL
ISF		Not used in the code
ITB	= 1	Linear bottom friction for internal mode
	≠ 1	Quadratic bottom friction for internal mode

ZREFBN	Reference height above bottom in cm, used in Equation 32 to determine the bottom friction coefficient. Specifically it is used as follows: ZREFB = ZREFBN*BZ1/ZREF Z1 = ZREFB + 0.5*DZVV(I,J,KMV)
CTB	Constant bottom drag coefficient (typical value of 0.003)
BZ1	Bottom roughness height in cm
ZREFTN	Not used in the code
TZ1	Not used in the code

DUMMY
THETA, THETAS 10F8.0

THETA	Time level weighing factor in external mode numerical scheme
THETAS	Time level weighing factor in transport-diffusion equation

DUMMY
ITEMP, ISALT, ICC, IFI, IFA, IFB, IFC, IFD, IFDS 10I8

ITEMP	= 2	Compute temperature (use time-varying temperature as river boundary temperature)
	= 1	Compute temperature (use daily equilibrium temperature as river boundary temperature)
	= 0	No computation of temperature
ISALT	= 1	Compute salinity
	= 0	No computation of salinity
ICC		Not used in the code
IFI	= 1	Compute nonlinear inertia terms in the momentum equations
	= 0	Do not compute inertia terms
IFA		Not used in the code
IFB		Not used in the code
IFC		Not used in the code
IFD	= 1	Include viscous terms in momentum equations
	= 0	Does not include viscous terms
IFDS	= 1	Include diffusion terms in salinity and temperature computations
	= 0	Does not include diffusion terms

DUMMY
BVR, S1, S2, PR, PRV, TWE, TWH, FKB, TQ0 10F8.0

BVR	Not used in the code

S1	Constant in computation of variable vertical eddy viscosity (GA = GX $(1+S1*Ri)^{FMI}$ if first-order turbulence model is used
S2	Constant in computation of variable vertical eddy diffusivity [GB = GX $(1+S2*Ri)^{FM2}$] if first-order turbulence model is used
PR	Not used in the code
PRV	Not used in the code
TWE	Not used in the code
TWH	Not used in the code
FKB	Not used in the code
TQ0	Not used in the code

DUMMY
IVER, ICON, IUBO, IBL, IBR, JBM, JBP 10I8

IVER	Not used in the code
ICON	Not used in the code
IUBO	Not used in the code
IBL	Not used in the code
IBR	Not used in the code
JBM	Not used in the code
JBP	Not used in the code

DUMMY
CREF, CMAX, C0 10F8.0

CREF	Not used in the code
CMAX	Not used in the code
C0	Not used in the code

DUMMY
ICC1, ICC2, JCC1, JCC2, ID1, ID2, JD1, JD2 10I8

ICC1	Not used in the code
ICC2	Not used in the code
JCC1	Not used in the code
JCC2	Not used in the code
ID1	Not used in the code
ID2	Not used in the code
JD1	Not used in the code
JD2	Not used in the code

DUMMY
IEXP, IAV, AVR, AV1, AV2, AVM, AVM1, AHR 2I8, 8F8.0

IEXP		Vertical eddy coefficient flag
IEXP	= 0	Constant eddy coefficient
	= -1	Munk-Anderson type first order turbulence model Richardson-number dependent eddy coefficient with length scale linearly increasing from the bottom and surface
	= -2	Munk-Anderson type first order turbulence model Richardson-number dependent eddy coefficient with length scale linearly increasing from the bottom to the surface
	= -3	Second order turbulence model
IAV	= 0	Constant AVREF = AVR
	= 1	AVREF depends on wind shear stress.
AVR		Reference vertical eddy coefficient (cm^2/sec)
AV1		Constant in AVREF = AV1 + TXY * AV2 (IAV = 1)
AV2		Constant in AVREF = AV1 + TXY * AV2 (IAV = 1)
AVM		Minimum vertical eddy viscosity (cm^2/sec)
AVM1		Minimum vertical eddy diffusivity (cm^2/sec)
AHR		Reference horizontal eddy diffusivity or viscosity (cm^2/sec)

DUMMY
FM1, FM2, ZTOP, SLMIN, QQMIN 10F8.0

FM1	Parameter in Richardson-number dependent eddy-viscosity (see definition of S1)
FM2	Parameter in Richardson-number dependent eddy-diffusivity (see definition of S2)
ZTOP	Distance between the top of the computational domain and the free surface. Used in computing turbulence length scale (cm)
SLMIN	Minimum value of turbulence macroscale (cm)
QQMIN	Minimum value of turbulent kinetic energy (gm/cm/sec^2)

DUMMY
ICUT, KSMALL, QCUT, GAMAX, GBMAX, FZS 2I8, 7F8.0

ICUT	= 0	Eddy coefficients constant below halocline
	= 1	Eddy coefficients computed below halocline
KSMALL	$\neq 0$	Eddy viscosity/diffusivity in turbulence model is smoothed
	=0	No smoothing
QCUT		Coefficient in second-order turbulence model (0.15 – 0.25)
GAMAX		Maximum value of eddy viscosity (cm^2/sec)
GBMAX		Maximum value of eddy diffusivity (cm^2/sec)
FZS		Turbulence scale is not allowed to exceed the product of FZS and depth

DUMMY
IWIND, TAUX, TAUY I8, 8F8 .0

IWIND	= 0	Steady and uniform wind stress
	= 1	Steady and uniform wind speed
	= 2	Steady and space variable wind stress
	= 3	Steady and space variable wind speed
	= 4	Time variable and uniform wind stress
	= 5	Time variable and uniform wind speed
	= 6	Time and space variable wind stress
	= 7	Time and space variable wind speed
TAUX		Uniform wind stress in x-direction if IWIND = 0 Uniform wind speed in x-direction if IWIND = 1
TAUY		Uniform wind stress in y-direction if IWIND = 0 Uniform wind speed in y-direction if IWIND = 1

DUMMY
ISPAC(l), I=1,10 10I8

ISPAC(1-8)		Not used currently
ISPAC(9)	= 0	Constant vertical eddy coefficient
	= 1	Variable vertical eddy coefficients The turbulence closure model is chosen by setting IEXP above
	= 2	Munk-Anderson type first order turbulence model Richardson-number dependent eddy coefficient with length scale linearly increasing from the bottom and surface
	= 3	Variable vertical eddy coefficients computed from Kent-Prichard formulation
ISPAC(10)		Not used currently

DUMMY
JSPAC(l), I = 1, 10 10I8

JSPAC(1)		Not used currently
JSPAC(2)	= 1	Use Equation 32 to calculate bottom friction
	= 0	Constant bottom friction
JSPAC(3)	≠ -1	Coriolis ON
	= -1	Coriolis OFF
JSPAC(4-10)		Not used currently

DUMMY
RSPAC(l), I = 1, 10 10I8

RSPAC(1-5)		Not used currently
RSPAC(6)	= 1	Printed output of dimensional values for velocity, salinity, etc.

	≠ 1	Printed output of non-dimensional values
RSPAC(7)		Maximum reference height for bottom friction calculations
RSPAC(8)		Constant used to calculated depth dependent bottom friction
RSPAC(9-10)		Not used currently

DUMMY
XMAP 10F8.0

XMAP	Factor that scales the (x, y) coordinates created by GRID Generation Code to the real world
YMAP	YMAP is included in the Sinclair Inlet input file, but it is not even read in the code.

DUMMY
ITRAN, (IBD(L), L = 1, 4) 10I8

ITRAN	= 0	Generate uniform grid internally
	= 1	Read grid coordinates from File 15
	= 2	Read grid coordinates and initial water depths from File 15
IBD		Not used in the code

DUMMY
ITBRK (l), I = 1, 10 10I8

ITBRK (1-20)	Time breaks for storing data (e.g., when the number of iterations reaches ITBRK(1) data is stored, likewise when the number of iterations reaches ITBRK(2), etc.)

DUMMY
NSTA, NFREQ, NSTART 10I8

NSTA	Number of stations where information is saved for time series plots of currents
NFREQ	Time step interval for saving currents
NSTART	Beginning time step for saving current information

DUMMY
IST(K), JST(K), STATID(K) 2I4, A48

IST(K), JST(K)	Coordinate (I, J) of a station where currents are saved
STATID(K)	Station descriptor

* Repeat NSTA Times

DUMMY
NSTATS, NFREQS, NSTRTS 10I8

NSTATS	Number of stations where water surface elevations are saved for time series plots
NFREQS	Time step interval for saving water surface elevations
NSTRTS	Beginning time step for saving water surface elevations

---

DUMMY
ISTS(K), JSTS(K), STATS(K) 2I4, A48

ISTS(K), JSTS(K)	Coordinate (I, J) of a station where water surface elevations are saved
STATS(K)	Station descriptor

* Repeat NSTAS Times

DUMMY
MSTA, MFREQ, MSTART 10I8

MSTA	Number of stations where salinity, temperature, etc., are saved for time series plots
MFREQ	Time step interval for saving information
MSTART	Beginning time step for saving information

DUMMY
ISTSA(K), JSTSA(K), STATSA(K) 2I4, A48

ISTSA(K), JSTSA(K)	Coordinate (I, J) of a station where salinities, etc., are saved
STATSA(K)	Station descriptor

* Repeat MSTA Times

DUMMY
NRIVER 10I8

NRIVER		Number of river boundaries
NRIVER	= 0	No river boundaries
	< 0	River inflows are steady
	> 0	Time variable inflows

If NRIVER = 0, use the following cards

DUMMY
DUMMY

If NRIVER > 0, use the following cards

DUMMY
IJRDIR(K), IJRROW(K), IJRSTR(K), IJREND(K) 10I8

IJRDIR(K) = 1	River boundary is on left (west)
= 2	River boundary is on bottom (south)
= 3	River boundary is on right (east)
= 4	River boundary is on top (north)
IJRROW(K)	Index of the column (I) or row (J) of the river boundary
IJRSTR(K)	Starting I or J index of the river boundary
IJREND(K)	Ending I or J index of the river boundary

* Repeat NRIVER times

DUMMY
FACTOR(K), BASEF(K) 10F8.0

FACTOR(K)	Factor by which time-varying inflow is multiplied
BASEF(K)	Additional inflow added to time-varying inflow (ft^3/sec)

* Repeat NRIVER times

If NRIVER < 0, use the following cards

DUMMY
IJRDIR(K), IJRROW(K), IJRSTR(K), IJREND(K) 10I8

IJRDIR(K) = 1	River boundary is on left (west)
= 2	River boundary is on bottom (south)
= 3	River boundary is on right (east)
= 4	River boundary is on top (north)
IJRROW(K)	Index of the column (I) or row (J) of the river boundary
IJRSTR(K)	Starting I or J index of the river boundary
IJREND(K)	Ending I or J index of the river boundary

DUMMY
ICELL, JCELL, QRIVER(K,I, J) 2I8, 8F8.0

ICELL, JCELL	Coordinate of a cell (I, J) where QRIVER is prescribed
QRIVER(K,I, J)	Steady river inflow (ft^3/s)

* Repeat NRIVER times

DUMMY
NLATERL Number of lateral flows specified.

If NLATERL = 0, Use the following cards

DUMMY
DUMMY
DUMMY

If NLATERL < 0, Use the following cards

DUMMY
IJQDIR(K), IJQROW(K), IJQSTR(K), IJQEND(K) 10I8

IJQDIR(K)	= 1	Flow enters cell thru west face
	= 2	Flow enters cell thru south face
	= 3	Flow enters cell thru east face
	= 4	Flow enters cell thru north face
IJQROW(K)	I or J index of range of cells for input	
IJQSTR(K)	Beginning value for the other index	
IJQEND(K)	Ending value for the other index	

* Repeat NLATERL times

DUMMY
I, J, ((QLAT(K, I, J), I, J = IJQSTR, IJQEND), K = 1, NLATERL) 2I8, F8.0

I, J	I and J indices of the cell where flow is specified
QLAT	Lateral flow rate (ft^3/s)

* Repeat NLATERL times

DUMMY
NBAR

NBAR Number of interior barriers

If NBAR = 0, Use the following card

DUMMY

If NBAR > 0, Use the following cards

DUMMY
IJBDIR(K), IJBROW(K), IJBSTR(K), IJBEND(K) 10I8

IJBDIR(K) = 1	Barrier is horizontal (ξ -direction)
= 2	Barrier is vertical (η -direction)
IJBROW(K)	Index of column (I) or row (J) of interior barrier
IJBSTR(K)	Starting I or J index of interior barrier
IJBEND(K)	Ending I or J index of interior barrier

* Repeat NBAR times

DUMMY
ITIDE, IJLINE, NCG, IRAD 10I8

ITIDE		Flags for tidal boundaries
ITIDE	= 0	No tidal boundaries
	> 0	Sinusoidal boundaries
	< 0	Tabular tidal boundaries
	= 11	Tidal harmonic constants input (16 constituents)—read from File 16
IJLINE		Number of tidal boundaries
NCG		Number of tidal constituents
IRAD	= 1	Include radiation in the tidal temperature boundary calculations
	= 0	Neglect radiation

If ITIDE = 0, use the following cards

DUMMY
DUMMY
DUMMY

If ITIDE > 0 (sinusoidal tidal boundaries), use the following cards

---

DUMMY
DUMMY
DUMMY
IJDIR(I), IJROW(I), IJSTRT(I), IJEND(I), TIDTYP(I),
TIDFN1(I), TIDFN2(I) 4I8, A8, 2I8

IJDIR(I)	= 1	Tidal boundary is on left (west)
	= 2	Tidal boundary is on bottom (south)
	= 3	Tidal boundary is on right (east)
	= 4	Tidal boundary is on top (north)
IJROW(I)		The index of the column (I) or row (J) of the tidal boundary
IJSTRT(I)		Starting I or J of the tidal boundary
IJEND(I)		Ending I or J of the tidal boundary
TIDTYP(I)	= "CONSTANT"	Constant tidal elevation between IJSTRT(I) and IJEND(L)
	= "INTERP"	Linear interpolation of tidal elevation between IJSTRT(I) and IJEND(L)
TIDFN1(I)		The number of the tidal elevation table for CONSTANT or INTERP type of boundaries
TIDFN2(I)		The number of the 2nd tidal elevation table used for interpolation on "INTERP" type boundary

* Repeat IJLINE times

DUMMY
TP(I) 10F8.0

TP(I)	Tidal period of the constituent I (sec)

DUMMY (NOTE: this input not used if ITIDE = 11—it is needed for read continuity)
J, K, AMPWX, PHWX, CAWX, AMPEX, PHEX, CAEX 2I8,6F8.0

J	J cell index of tidal boundary, J = -1 for end of input
K	K = 1 for active cell, K = 0 for end of input
AMPWX	Tidal amplitude on west boundaries in cm
PHWX	Phase angle on west boundaries in radians
CAWX	Additive constant for sinusoidal tidal distribution in cm
AMPEX	Tidal amplitude on east boundaries in cm
PHEX	Phase angle on east boundaries in radians
CAEX	Additive constant for sinusoidal tidal distribution in cm

DUMMY (NOTE: this input not used if ITIDE = 11—it is needed for read continuity)
J, K, AMPSX, PHSX, CASX, AMPNX, PHNX, CANX 2I8,6F8.0

J	J cell index of tidal boundary, J = -1 for end of input
K	K = 1 for active cell, K = 0 for end of input
AMPSX	Tidal amplitude on south boundaries in cm
PHSX	Phase angle on south boundaries in radians
CASX	Additive constant for sinusoidal tidal distribution in cm
AMPNX	Tidal amplitude on north boundaries in cm

PHNX	Phase angle on north boundaries in radians
CANX	Additive constant for sinusoidal tidal distribution in cm

APPENDIX D
File 50—Cell Centered Depths

This appendix lists the depth information for the first three J = constant rows in the grid. Notice that the depth is set to zero for non-active cells. The depths are all zero for the first row (J=1)—there are 74 values input for each row. The only active cells in rows 2 and 3 are in Rich Passage (Figure 1-2).

```
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0. 90. 110.  80.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0. 90. 110.  80.
```

For comparison the depths in row 16 are (this is the first row of cells that spans the inlet)

```
1.  1.  4.  14.  15.  16.  19.  21.  22.  23.  24.  24.  26.  27.  28.  29.
30.  31.  31.  32.  31.  33.  34.  35.  35.  36.  37.  37.  38.  40.  40.
39.
40.  39.  39.  40.  41.  41.  40.  42.  44.  48.  49.  52.  54.  56.  63.
70.
74.  75. 100.  86.  87.  88.  89.  90. 100. 110. 120. 120. 120. 125.
140. 200.
200. 140. 120. 120.  70.   0.   0.   0.   0.   0.
```

APPENDIX E
File 14—Wind Data

This appendix lists the hourly variation in measured x and y components of the wind speed in meters per second (m/s) at one measuring station. Each line contains required data consisting of day number, hour number, x component, and y component. The other fields are not read by the code and contain date information in this file. The code reads the first line at the beginning of the analysis, the second when the time counter reaches 1 hour, the third at 2 hours and so on. The time step in this analysis is 60 seconds; consequently this file is read once every 60 iterations.

Notice that the stresses are held constant at 1 for the first 2 days and then begin varying. One line is needed for each hour of the analysis (35 days for a total of 840 lines of input). Only the first 3 days' worth of data are shown in this appendix.

0	0	1.0000	1.0000	94	7	26	0
0	1	1.0000	1.0000	94	7	26	1
0	2	1.0000	1.0000	94	7	26	2
0	3	1.0000	1.0000	94	7	26	3
0	4	1.0000	1.0000	94	7	26	4
0	5	1.0000	1.0000	94	7	26	5
0	6	1.0000	1.0000	94	7	26	6
0	7	1.0000	1.0000	94	7	26	7
0	8	1.0000	1.0000	94	7	26	8
0	9	1.0000	1.0000	94	7	26	9
0	10	1.0000	1.0000	94	7	26	10
0	11	1.0000	1.0000	94	7	26	11
0	12	1.0000	1.0000	94	7	26	12
0	13	1.0000	1.0000	94	7	26	13
0	14	1.0000	1.0000	94	7	26	14
0	15	1.0000	1.0000	94	7	26	15
0	16	1.0000	1.0000	94	7	26	16
0	17	1.0000	1.0000	94	7	26	17
0	18	1.0000	1.0000	94	7	26	18
0	19	1.0000	1.0000	94	7	26	19
0	20	1.0000	1.0000	94	7	26	20
0	21	1.0000	1.0000	94	7	26	21
0	22	1.0000	1.0000	94	7	26	22
0	23	1.0000	1.0000	94	7	26	23
1	0	1.0000	1.0000	94	7	27	0
1	1	1.0000	1.0000	94	7	27	1
1	2	1.0000	1.0000	94	7	27	2
1	3	1.0000	1.0000	94	7	27	3
1	4	1.0000	1.0000	94	7	27	4
1	5	1.0000	1.0000	94	7	27	5
1	6	1.0000	1.0000	94	7	27	6
1	7	1.0000	1.0000	94	7	27	7
1	8	1.0000	1.0000	94	7	27	8
1	9	1.0000	1.0000	94	7	27	9
1	10	1.0000	1.0000	94	7	27	10
1	11	1.0000	1.0000	94	7	27	11
1	12	1.0000	1.0000	94	7	27	12
1	13	1.0000	1.0000	94	7	27	13
1	14	1.0000	1.0000	94	7	27	14
1	15	1.0000	1.0000	94	7	27	15
1	16	1.0000	1.0000	94	7	27	16
1	17	1.0000	1.0000	94	7	27	17
1	18	1.0000	1.0000	94	7	27	18
1	19	1.0000	1.0000	94	7	27	19
1	20	1.0000	1.0000	94	7	27	20
1	21	1.0000	1.0000	94	7	27	21

1	22	1.0000	1.0000	94	7	27	22
1	23	1.0000	1.0000	94	7	27	23
2	0	0.9031	0.9351	94	7	28	0
2	1	0.6999	0.0122	94	7	28	1
2	2	0.7469	-0.2867	94	7	28	2
2	3	1.0940	0.1150	94	7	28	3
2	4	1.3070	0.5017	94	7	28	4
2	5	1.9053	1.1000	94	7	28	5
2	6	1.7207	2.4575	94	7	28	6
2	7	2.0086	3.3430	94	7	28	7
2	8	2.2672	2.1142	94	7	28	8
2	9	3.1448	2.9326	94	7	28	9
2	10	2.9311	1.0093	94	7	28	10
2	11	2.1209	1.9778	94	7	28	11
2	12	2.1855	2.6046	94	7	28	12
2	13	2.2852	1.7854	94	7	28	13
2	14	2.3476	0.4990	94	7	28	14
2	15	2.5432	0.5406	94	7	28	15
2	16	1.9406	0.4838	94	7	28	16
2	17	-3.1503	-2.1249	94	7	28	17
2	18	-3.8105	-2.2000	94	7	28	18
2	19	-3.2708	-2.1241	94	7	28	19
2	20	-2.4321	-1.5795	94	7	28	20
2	21	0.7999	-0.0140	94	7	28	21
2	22	2.3615	1.3090	94	7	28	22
2	23	1.8910	0.6511	94	7	28	23

APPENDIX F
File 15—Grid Coordinates

This appendix contains a sample listing of the grid coordinate file. The first line contains the number of grid coordinates in the x and y directions. It is necessary to specify the coordinates of each corner of each cell. Consequently, there must be one more index in each direction than the number of cells. The remaining lines contain the x and y coordinates, in feet, one pair per line starting with the first J row, and continuing through the 49th row, 75 values per row. The remaining information on each line is the water depth, and I and J index. The code uses an x or y value of 0.900000020E+19 to indicate a coordinate that is outside the active cells. Notice that the first row is all outside the range of active cells.

```
75  49
0.900000020E+19   0.900000020E+19    0.0000E+00    1     1
0.900000020E+19   0.900000020E+19    0.0000E+00    2     1
0.900000020E+19   0.900000020E+19    0.0000E+00    3     1
0.900000020E+19   0.900000020E+19    0.0000E+00    4     1
0.900000020E+19   0.900000020E+19    0.0000E+00    5     1
0.900000020E+19   0.900000020E+19    0.0000E+00    6     1
0.900000020E+19   0.900000020E+19    0.0000E+00    7     1
0.900000020E+19   0.900000020E+19    0.0000E+00    8     1
0.900000020E+19   0.900000020E+19    0.0000E+00    9     1
0.900000020E+19   0.900000020E+19    0.0000E+00   10     1
0.900000020E+19   0.900000020E+19    0.0000E+00   11     1
0.900000020E+19   0.900000020E+19    0.0000E+00   12     1
0.900000020E+19   0.900000020E+19    0.0000E+00   13     1
0.900000020E+19   0.900000020E+19    0.0000E+00   14     1
0.900000020E+19   0.900000020E+19    0.0000E+00   15     1
0.900000020E+19   0.900000020E+19    0.0000E+00   16     1
0.900000020E+19   0.900000020E+19    0.0000E+00   17     1
0.900000020E+19   0.900000020E+19    0.0000E+00   18     1
0.900000020E+19   0.900000020E+19    0.0000E+00   19     1
0.900000020E+19   0.900000020E+19    0.0000E+00   20     1
0.900000020E+19   0.900000020E+19    0.0000E+00   21     1
0.900000020E+19   0.900000020E+19    0.0000E+00   22     1
0.900000020E+19   0.900000020E+19    0.0000E+00   23     1
0.900000020E+19   0.900000020E+19    0.0000E+00   24     1
0.900000020E+19   0.900000020E+19    0.0000E+00   25     1
0.900000020E+19   0.900000020E+19    0.0000E+00   26     1
0.900000020E+19   0.900000020E+19    0.0000E+00   27     1
0.900000020E+19   0.900000020E+19    0.0000E+00   28     1
0.900000020E+19   0.900000020E+19    0.0000E+00   29     1
0.900000020E+19   0.900000020E+19    0.0000E+00   30     1
0.900000020E+19   0.900000020E+19    0.0000E+00   31     1
0.900000020E+19   0.900000020E+19    0.0000E+00   32     1
0.900000020E+19   0.900000020E+19    0.0000E+00   33     1
0.900000020E+19   0.900000020E+19    0.0000E+00   34     1
0.900000020E+19   0.900000020E+19    0.0000E+00   35     1
```

0.900000020E+19	0.900000020E+19	0.0000E+00	36	1
0.900000020E+19	0.900000020E+19	0.0000E+00	37	1
0.900000020E+19	0.900000020E+19	0.0000E+00	38	1
0.900000020E+19	0.900000020E+19	0.0000E+00	39	1
0.900000020E+19	0.900000020E+19	0.0000E+00	40	1
0.900000020E+19	0.900000020E+19	0.0000E+00	41	1
0.900000020E+19	0.900000020E+19	0.0000E+00	42	1
0.900000020E+19	0.900000020E+19	0.0000E+00	43	1
0.900000020E+19	0.900000020E+19	0.0000E+00	44	1
0.900000020E+19	0.900000020E+19	0.0000E+00	45	1
0.900000020E+19	0.900000020E+19	0.0000E+00	46	1
0.900000020E+19	0.900000020E+19	0.0000E+00	47	1
0.900000020E+19	0.900000020E+19	0.0000E+00	48	1
0.900000020E+19	0.900000020E+19	0.0000E+00	49	1
0.900000020E+19	0.900000020E+19	0.0000E+00	50	1
0.900000020E+19	0.900000020E+19	0.0000E+00	51	1
0.900000020E+19	0.900000020E+19	0.0000E+00	52	1
0.900000020E+19	0.900000020E+19	0.0000E+00	53	1
0.900000020E+19	0.900000020E+19	0.0000E+00	54	1
0.900000020E+19	0.900000020E+19	0.0000E+00	55	1
0.900000020E+19	0.900000020E+19	0.0000E+00	56	1
0.900000020E+19	0.900000020E+19	0.0000E+00	57	1
0.900000020E+19	0.900000020E+19	0.0000E+00	58	1
0.900000020E+19	0.900000020E+19	0.0000E+00	59	1
0.900000020E+19	0.900000020E+19	0.0000E+00	60	1
0.900000020E+19	0.900000020E+19	0.0000E+00	61	1
0.900000020E+19	0.900000020E+19	0.0000E+00	62	1
0.900000020E+19	0.900000020E+19	0.0000E+00	63	1
0.900000020E+19	0.900000020E+19	0.0000E+00	64	1
0.900000020E+19	0.900000020E+19	0.0000E+00	65	1
0.900000020E+19	0.900000020E+19	0.0000E+00	66	1
0.900000020E+19	0.900000020E+19	0.0000E+00	67	1
0.900000020E+19	0.900000020E+19	0.0000E+00	68	1
0.900000020E+19	0.900000020E+19	0.0000E+00	69	1
0.900000020E+19	0.900000020E+19	0.0000E+00	70	1
0.900000020E+19	0.900000020E+19	0.0000E+00	71	1
0.900000020E+19	0.900000020E+19	0.0000E+00	72	1
0.900000020E+19	0.900000020E+19	0.0000E+00	73	1
0.900000020E+19	0.900000020E+19	0.0000E+00	74	1
0.900000020E+19	0.900000020E+19	0.0000E+00	75	1
0.900000020E+19	0.900000020E+19	0.0000E+00	1	2
0.900000020E+19	0.900000020E+19	0.0000E+00	2	2
0.900000020E+19	0.900000020E+19	0.0000E+00	3	2
0.900000020E+19	0.900000020E+19	0.0000E+00	4	2
0.900000020E+19	0.900000020E+19	0.0000E+00	5	2
0.900000020E+19	0.900000020E+19	0.0000E+00	6	2

0.900000020E+19	0.900000020E+19	0.0000E+00	7	2
0.900000020E+19	0.900000020E+19	0.0000E+00	8	2
0.900000020E+19	0.900000020E+19	0.0000E+00	9	2
0.900000020E+19	0.900000020E+19	0.0000E+00	10	2
0.900000020E+19	0.900000020E+19	0.0000E+00	11	2
0.900000020E+19	0.900000020E+19	0.0000E+00	12	2
0.900000020E+19	0.900000020E+19	0.0000E+00	13	2
0.900000020E+19	0.900000020E+19	0.0000E+00	14	2
0.900000020E+19	0.900000020E+19	0.0000E+00	15	2
0.900000020E+19	0.900000020E+19	0.0000E+00	16	2
0.900000020E+19	0.900000020E+19	0.0000E+00	17	2
0.900000020E+19	0.900000020E+19	0.0000E+00	18	2
0.900000020E+19	0.900000020E+19	0.0000E+00	19	2
0.900000020E+19	0.900000020E+19	0.0000E+00	20	2
0.900000020E+19	0.900000020E+19	0.0000E+00	21	2
0.900000020E+19	0.900000020E+19	0.0000E+00	22	2
0.900000020E+19	0.900000020E+19	0.0000E+00	23	2
0.900000020E+19	0.900000020E+19	0.0000E+00	24	2
0.900000020E+19	0.900000020E+19	0.0000E+00	25	2
0.900000020E+19	0.900000020E+19	0.0000E+00	26	2
0.900000020E+19	0.900000020E+19	0.0000E+00	27	2
0.900000020E+19	0.900000020E+19	0.0000E+00	28	2
0.900000020E+19	0.900000020E+19	0.0000E+00	29	2
0.900000020E+19	0.900000020E+19	0.0000E+00	30	2
0.900000020E+19	0.900000020E+19	0.0000E+00	31	2
0.900000020E+19	0.900000020E+19	0.0000E+00	32	2
0.900000020E+19	0.900000020E+19	0.0000E+00	33	2
0.900000020E+19	0.900000020E+19	0.0000E+00	34	2
0.900000020E+19	0.900000020E+19	0.0000E+00	35	2
0.900000020E+19	0.900000020E+19	0.0000E+00	36	2
0.900000020E+19	0.900000020E+19	0.0000E+00	37	2
0.900000020E+19	0.900000020E+19	0.0000E+00	38	2
0.900000020E+19	0.900000020E+19	0.0000E+00	39	2
0.900000020E+19	0.900000020E+19	0.0000E+00	40	2
0.900000020E+19	0.900000020E+19	0.0000E+00	41	2
0.900000020E+19	0.900000020E+19	0.0000E+00	42	2
0.900000020E+19	0.900000020E+19	0.0000E+00	43	2
0.900000020E+19	0.900000020E+19	0.0000E+00	44	2
0.900000020E+19	0.900000020E+19	0.0000E+00	45	2
0.900000020E+19	0.900000020E+19	0.0000E+00	46	2
0.900000020E+19	0.900000020E+19	0.0000E+00	47	2
0.900000020E+19	0.900000020E+19	0.0000E+00	48	2
0.900000020E+19	0.900000020E+19	0.0000E+00	49	2
0.900000020E+19	0.900000020E+19	0.0000E+00	50	2
0.900000020E+19	0.900000020E+19	0.0000E+00	51	2
0.900000020E+19	0.900000020E+19	0.0000E+00	52	2

0.900000020E+19	0.900000020E+19	0.0000E+00	53	2
0.900000020E+19	0.900000020E+19	0.0000E+00	54	2
0.900000020E+19	0.900000020E+19	0.0000E+00	55	2
0.900000020E+19	0.900000020E+19	0.0000E+00	56	2
0.900000020E+19	0.900000020E+19	0.0000E+00	57	2
0.900000020E+19	0.900000020E+19	0.0000E+00	58	2
0.900000020E+19	0.900000020E+19	0.0000E+00	59	2
0.900000020E+19	0.900000020E+19	0.0000E+00	60	2
0.900000020E+19	0.900000020E+19	0.0000E+00	61	2
0.900000020E+19	0.900000020E+19	0.0000E+00	62	2
0.900000020E+19	0.900000020E+19	0.0000E+00	63	2
0.900000020E+19	0.900000020E+19	0.0000E+00	64	2
0.900000020E+19	0.900000020E+19	0.0000E+00	65	2
0.900000020E+19	0.900000020E+19	0.0000E+00	66	2
0.900000020E+19	0.900000020E+19	0.0000E+00	67	2
0.900000020E+19	0.900000020E+19	0.0000E+00	68	2
0.900000020E+19	0.900000020E+19	0.0000E+00	69	2
0.900000020E+19	0.900000020E+19	0.0000E+00	70	2
0.900000020E+19	0.900000020E+19	0.0000E+00	71	2
0.139532998E+05	0.540525977E+04	0.1000E+03	72	2
0.142465000E+05	0.575385010E+04	0.1000E+03	73	2
0.145397998E+05	0.610243994E+04	0.1000E+03	74	2
0.148330000E+05	0.645102979E+04	0.1000E+03	75	2
0.900000020E+19	0.900000020E+19	0.0000E+00	1	3
0.900000020E+19	0.900000020E+19	0.0000E+00	2	3
0.900000020E+19	0.900000020E+19	0.0000E+00	3	3
0.900000020E+19	0.900000020E+19	0.0000E+00	4	3
0.900000020E+19	0.900000020E+19	0.0000E+00	5	3
0.900000020E+19	0.900000020E+19	0.0000E+00	6	3
0.900000020E+19	0.900000020E+19	0.0000E+00	7	3
0.900000020E+19	0.900000020E+19	0.0000E+00	8	3
0.900000020E+19	0.900000020E+19	0.0000E+00	9	3
0.900000020E+19	0.900000020E+19	0.0000E+00	10	3
0.900000020E+19	0.900000020E+19	0.0000E+00	11	3
0.900000020E+19	0.900000020E+19	0.0000E+00	12	3
0.900000020E+19	0.900000020E+19	0.0000E+00	13	3
0.900000020E+19	0.900000020E+19	0.0000E+00	14	3
0.900000020E+19	0.900000020E+19	0.0000E+00	15	3
0.900000020E+19	0.900000020E+19	0.0000E+00	16	3
0.900000020E+19	0.900000020E+19	0.0000E+00	17	3
0.900000020E+19	0.900000020E+19	0.0000E+00	18	3
0.900000020E+19	0.900000020E+19	0.0000E+00	19	3
0.900000020E+19	0.900000020E+19	0.0000E+00	20	3
0.900000020E+19	0.900000020E+19	0.0000E+00	21	3
0.900000020E+19	0.900000020E+19	0.0000E+00	22	3
0.900000020E+19	0.900000020E+19	0.0000E+00	23	3

0.900000020E+19	0.900000020E+19	0.0000E+00	24	3
0.900000020E+19	0.900000020E+19	0.0000E+00	25	3
0.900000020E+19	0.900000020E+19	0.0000E+00	26	3
0.900000020E+19	0.900000020E+19	0.0000E+00	27	3
0.900000020E+19	0.900000020E+19	0.0000E+00	28	3
0.900000020E+19	0.900000020E+19	0.0000E+00	29	3
0.900000020E+19	0.900000020E+19	0.0000E+00	30	3
0.900000020E+19	0.900000020E+19	0.0000E+00	31	3
0.900000020E+19	0.900000020E+19	0.0000E+00	32	3
0.900000020E+19	0.900000020E+19	0.0000E+00	33	3
0.900000020E+19	0.900000020E+19	0.0000E+00	34	3
0.900000020E+19	0.900000020E+19	0.0000E+00	35	3
0.900000020E+19	0.900000020E+19	0.0000E+00	36	3
0.900000020E+19	0.900000020E+19	0.0000E+00	37	3
0.900000020E+19	0.900000020E+19	0.0000E+00	38	3
0.900000020E+19	0.900000020E+19	0.0000E+00	39	3
0.900000020E+19	0.900000020E+19	0.0000E+00	40	3
0.900000020E+19	0.900000020E+19	0.0000E+00	41	3
0.900000020E+19	0.900000020E+19	0.0000E+00	42	3
0.900000020E+19	0.900000020E+19	0.0000E+00	43	3
0.900000020E+19	0.900000020E+19	0.0000E+00	44	3
0.900000020E+19	0.900000020E+19	0.0000E+00	45	3
0.900000020E+19	0.900000020E+19	0.0000E+00	46	3
0.900000020E+19	0.900000020E+19	0.0000E+00	47	3
0.900000020E+19	0.900000020E+19	0.0000E+00	48	3
0.900000020E+19	0.900000020E+19	0.0000E+00	49	3
0.900000020E+19	0.900000020E+19	0.0000E+00	50	3
0.900000020E+19	0.900000020E+19	0.0000E+00	51	3
0.900000020E+19	0.900000020E+19	0.0000E+00	52	3
0.900000020E+19	0.900000020E+19	0.0000E+00	53	3
0.900000020E+19	0.900000020E+19	0.0000E+00	54	3
0.900000020E+19	0.900000020E+19	0.0000E+00	55	3
0.900000020E+19	0.900000020E+19	0.0000E+00	56	3
0.900000020E+19	0.900000020E+19	0.0000E+00	57	3
0.900000020E+19	0.900000020E+19	0.0000E+00	58	3
0.900000020E+19	0.900000020E+19	0.0000E+00	59	3
0.900000020E+19	0.900000020E+19	0.0000E+00	60	3
0.900000020E+19	0.900000020E+19	0.0000E+00	61	3
0.900000020E+19	0.900000020E+19	0.0000E+00	62	3
0.900000020E+19	0.900000020E+19	0.0000E+00	63	3
0.900000020E+19	0.900000020E+19	0.0000E+00	64	3
0.900000020E+19	0.900000020E+19	0.0000E+00	65	3
0.900000020E+19	0.900000020E+19	0.0000E+00	66	3
0.900000020E+19	0.900000020E+19	0.0000E+00	67	3
0.900000020E+19	0.900000020E+19	0.0000E+00	68	3
0.900000020E+19	0.900000020E+19	0.0000E+00	69	3

0.900000020E+19	0.900000020E+19	0.0000E+00	70	3
0.900000020E+19	0.900000020E+19	0.0000E+00	71	3
0.135612002E+05	0.570704004E+04	0.1000E+03	72	3
0.139420615E+05	0.610153809E+04	0.1000E+03	73	3
0.142834658E+05	0.646486377E+04	0.1000E+03	74	3
0.146080000E+05	0.681006006E+04	0.1000E+03	75	3

APPENDIX G
File 16—Tidal Boundary Conditions

This appendix contains the listing of the tidal boundary condition file. The first three lines include title information. The next 16 lines contain parameters for each of the tidal constituents modeled. The first number in each line is $H_i =$ mean tidal constituent amplitude (cm). The second number on each line is $\omega_i =$ constituent angular frequency (radians / hour). The third number is $\kappa_i =$ local epoch (degree). The fourth number on each line is $E_i =$ local equilibrium argument (degree). The fifth value is the reciprocal of $f_i =$ node factor (dimensionless). The remaining values on each line are not read by the code. The last value on each line is the tidal constituent designator. The total tidal height is calculated from Equation 56.

The first part of the file, shown below, prescribes the tidal boundary conditions on the eastern boundary in Rich Passage (in Clam Bay).

axbc(1) = 3 CLAM BAY, SINC97_9_V6.BCD

	YR	MO	DA	HOUR	C0-TILT	S0-VALUE	
	97	9	15	0	0.00	0.00	
7.32100	0.23385	165.85059	144.64999	1.23180	0.00000	0.00000	Q1
45.71600	0.24335	145.85986	144.50999	1.23180	0.00000	0.00000	O1
5.72800	0.25302	312.48926	242.64999	0.64371	0.00000	0.00000	M1
25.39300	0.26108	96.00146	156.19000	1.00000	0.00000	0.00000	P1
83.11700	0.26252	262.79932	157.92999	1.12966	0.00000	0.00000	K1
3.33000	0.27202	242.10889	161.66000	1.20125	0.00000	0.00000	J1
3.13200	0.48814	96.11816	8.91000	0.96439	0.00000	0.00000	MU2
21.18500	0.49637	67.94922	114.19000	0.96439	0.00000	0.00000	N2
3.56800	0.49764	76.02832	134.10001	0.96439	0.00000	0.00000	NU2
106.89500	0.50587	47.95801	141.33000	0.96439	0.00000	0.00000	M2
4.94900	0.51537	214.36816	187.21001	1.13123	0.00000	0.00000	L2
0.00000	0.52288	108.90234	0.00000	1.00000	0.00000	0.00000	T2
25.77900	0.52360	0.00000	159.58000	1.00000	0.00000	0.00000	S2
7.24000	0.52503	345.79785	157.34000	1.33056	0.00000	0.00000	K2
2.08700	1.01174	95.91602	99.29000	0.93005	0.00000	0.00000	M4
0.11700	0.76838	310.75781	205.86000	1.08943	0.00000	0.00000	MK3

The second part of the file, shown below, prescribes the tidal boundary conditions on the northern boundary in Port Orchard Passage (near the Port of Brownsville).

axbc(1) = 3 BROWN942.BCD

	YR	MO	DA	HOUR	C0-TILT	S0-VALUE	
	97	9	15	0	0.00	0.00	
7.47300	0.23385	165.85059	145.67999	1.23180	0.00000	0.00000	Q1
46.77600	0.24335	145.85986	145.48000	1.23180	0.00000	0.00000	O1
5.88100	0.25302	312.48926	242.00000	0.64371	0.00000	0.00000	M1
26.04400	0.26108	96.00146	157.25999	1.00000	0.00000	0.00000	P1
85.26500	0.26252	262.79932	159.03999	1.12966	0.00000	0.00000	K1
3.40400	0.27202	242.10889	162.72000	1.20125	0.00000	0.00000	J1
3.26200	0.48814	96.11816	9.21000	0.96439	0.00000	0.00000	MU2
21.83700	0.49637	67.94922	116.28000	0.96439	0.00000	0.00000	N2
3.70900	0.49764	76.02832	136.50000	0.96439	0.00000	0.00000	NU2
110.50500	0.50587	47.95801	143.52000	0.96439	0.00000	0.00000	M2
5.16400	0.51537	214.36816	189.11000	1.13123	0.00000	0.00000	L2
0.00000	0.52288	108.90234	0.00000	1.00000	0.00000	0.00000	T2
26.55700	0.52360	0.00000	161.86000	1.00000	0.00000	0.00000	S2
7.49000	0.52503	345.79785	159.48000	1.33056	0.00000	0.00000	K2
2.08700	1.01174	95.91602	0.00000	0.93005	0.00000	0.00000	M4
0.38100	0.76838	310.75781	269.42999	1.08943	0.00000	0.00000	MK3

APPENDIX H
List Of Data Input Files

File 13

River inflows are read from File 13. These data are read first as a time line (DAY and HOUR) formatted by 2I8. Next the (I, J) location and discharge in cubic feet per second for each cell of each river boundary are read and formatted by 2I8, F8.0.

File 14

Wind data are read from File 14. These data are in the form of time (DAY and HOUR) and the ξ (east-west) and η (north-south) components of the wind speed in meters per second of each wind field used. These data are formatted by (2I5, 6F10.0). See Appendix E for details.

File 15

The (x, y) coordinates of the Sinclair Inlet are read from File 15. This file was created from a run of the grid generation code called WESCORA. See Appendix F for details.

It is an unformatted file containing NX, NY, X(I, J), Y(I, J), HC(I, J).

File 16

Tabular tide data are read from File 16. These data are used to calculate the sinusoidal variation in tidal height resulting from 16 tidal constituents. See Appendix G for details. These data are formatted by (3I5, 8F8.0).

File 17

The initial temperature field in degrees Celsius is read from File 17 by format (10E12.5). This file is created from a few observed values. The resulting field is then smoothed in each horizontal direction several times before creating File 17.

File 18

If the model is run in a purely 2D vertically averaged mode, a field of Manning's n values may be input by format (20F4.0). The input values are multiplied by 0.001 to yield the actual values. They are input by rows, with the first row being at the bottom of the transformed plane.

File 19

Daily average equilibrium temperatures in degrees Celsius and surface heat exchange coefficients in units of watts/m^2/°C are read from File 19. These data are in the form of time (DAY and HOUR), equilibrium temperature, and heat exchange coefficient. They are formatted by (2I5, F10.0, E12.5).

File 33

The lateral flows are input in File 33.

File 50

The water depths at the center of each horizontal grid cell relative to the zero of the datum, e.g., NGVD, are read from File 50. These data are formatted by 16F5.0 and are read by rows with the first row being at the bottom of the transformed plane. The depths are input in units of feet[1] and then converted to centimeters in the model. See Appendix D for details.

File 51

Variable LICELL is input in File 51.

File 74

The initial salinity field in parts per thousand is read from File 74 by format (10E12.5). This file is normally created from a few observed values. The resulting salinity field is then smoothed in each horizontal direction several times before creating File 74. These data are read by rows, with the first row being at the bottom of the transformed plane.

File 76

Time-varying salinity in parts per thousand and temperatures in degrees Celsius at tidal boundaries are read from File 76 if salinity and temperature are to be computed. These data are in the form of time (DAY and HOUR) formatted by (2I5). Next the (I, J) location of each tidal boundary cell and a vertical distribution of salinity, starting from the top layer to the bottom layer are read. These data are followed by temperature data using the same format as for the salinity. They are formatted by (2I5, 11F6.0).

[1] A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 5 in the main text.

File 78

Time-varying temperature at river flow boundaries are read from File 78 if temperatures are to be computed and equilibrium temperatures are not used as river flow boundary temperatures. These data are in the form of a time (DAY and HOUR) formatted by (2I5). Next read (I, J) location of river flow boundary cells and corresponding temperatures starting from top layer to bottom layer. These data are formatted by (2I5,11F6.0).