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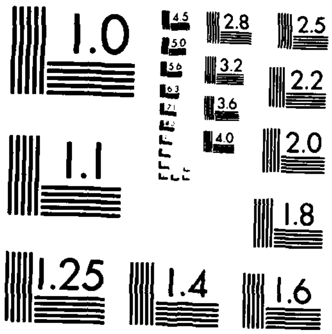

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USER GUIDE FOR CE-QUAL-ELV2: A LONGITUDINAL-VERTICAL, TIME-VARYING ESTUARINE WATER QUALITY MODEL

by

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This report is the user guide for a FORTRAN program that permits time-varying hydrodynamic and transport simulations of estuaries. It also includes a summary of the development of this program, with emphasis on the characteristics of estuaries, estuarine boundary conditions, turbulence, and validation tests.

CE-QUAL-ELV2, an acronym for the Estuarine Longitudinal-Vertical 2-Dimensional model, consists of the original Laterally Averaged Estuary Model -

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20. ABSTRACT (Continued)

(LAEM) plus the Water Quality Transport Module (WQTM). The LAEM program was developed for a test application to the Potomac Estuary from the then-current version of the Laterally Averaged Reservoir Model (LARM). The References section of this report lists all the available documents describing the related development of the LARM and LAEM programs.

This report contains an overview of the capabilities of CE-QUAL-ELV2; a summary of its theoretical foundation and a discussion of the validation tests; a synopsis of estuarine characteristics, including turbulence, with reference to the Patuxent Estuary; and a detailed discussion of the application procedure, again with reference to the Patuxent example. The appendices contain an input data description with examples and user notes for two auxiliary codes.

PREFACE

This report was prepared by J. E. Edinger Associates, Inc., (JEEAI) for the U. S. Army Engineer Waterways Experiment Station (WES) under Purchase Order No. DACW29-81-M-2788 dated 6 May 1981. The study was sponsored by the Office, Chief of Engineers, under the Environmental Impact Research Program.

The study was monitored at WES by Mr. Ross W. Hall, Jr., Ecosystem Research and Simulation Division (ERSD), Environmental Laboratory (EL). Mr. Donald L. Robey, Chief, ERSD, and Dr. John Harrison, Chief, EL, provided general supervision.

Director of WES during report preparation was Col. Tilford C. Creel, CE. The Technical Director was Mr. F. R. Brown.

This report should be referenced as follows:

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CONTENTS

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

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

Multiply	By	To Obtain
inches	0.0254	meters
miles (international nautical)	1852.0	meters
feet	0.3048	meters
Btu (thermochemical)/ $(\text{day} \cdot f^2 \cdot {}^{\circ}F)$	0.236436	watts per square meter Kelvin
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9)(F - 32). To obtain Kelvin (K) readings, use: K = (5/9)(F - 32) + 273.15 .

USER GUIDE FOR CE-QUAL-ELV2: A LONGITUDINAL-VERTICAL, TIME-VARYING ESTUARINE WATER QUALITY MODEL

PART I: CAPABILITIES AND LIMITATIONS

1. CE-QUAL-ELV2 was developed to assist in the analysis of water quality problems in estuaries where buoyancy is important and where lateral homogeneity can be assumed. The code is recommended for those cases where longitudinal and vertical temperature, salinity, or constituent gradients occur. CE-QUAL-ELV2 generates time-varying velocity, temperature, salinity, and water quality constituent fields and surface elevations on a longitudinal and vertical grid. Both the spatial and temporal resolution can be varied by the user, within certain limits. Units of measure are expressed according to the International System of Units (SI), (meter-kilogram-second).

2. An application requires a considerable effort in planning and data assembly and computer resources. The user must modify a subroutine that supplies time-varying boundary condition data to CE-QUAL-ELV2 for each particular case. If the user intends to make use of the constituent transport computation option, he must be able to quantify the reaction rates for each constituent in terms of every other constituent and code these statements. The user must also be able to review results for reasonableness and applicability to his problem.

3. CE-QUAL-ELV2 in its present form can be applied to a single, continuous reach of an estuary. Carrying the computations into branches and tributaries is possible if the code is employed as a subroutine for each reach and boundary conditions between reaches are specified. This configuration has not been tested, however, and would require significant additional programming.

4. The code automatically increases the number of horizontal layers when water surface elevations increase and then adds segments as backwaters progress into the freshwater end of the estuary. Similarly, the grid contracts both vertically and longitudinally when surface elevations decrease.

5. Simulations of long periods are economically feasible. An eight-month simulation at a time step of 15 minutes for temperature and salinity on a grid that is 30 segments by 20 layers with 375 active cells would cost $300 on a commerical batch processing computer system. Each water quality constituent would add approximately $30 to this cost. These cost estimates are exclusive of any intermediate simulations and postprocessing of results. Experience has shown that ten intermediate simulations may be required for each final simulation obtained.

6. CE-QUAL-ELV2 has been tested against analytic solutions and has been applied to several cases. The program from which CE-QUAL-ELV2 is derived, the Laterally Averaged Reservoir Model, Version 2 (LARM2), has been successfully applied to approximately twenty cases.

PART II: THEORETICAL BASIS, ESTUARINE BOUNDARY CONDITIONS, AND VALIDATION TESTS

7. Details of the formulation of the governing partial differential equations and the subsequent casting of those equations into finite difference form are presented in Edinger and Buchak (1979 and 1980a). Seven equations (longitudinal momentum, vertical momentum, continuity, heat, salinity, and constituent balances, and state) are solved to obtain longitudinal and vertical velocity components, surface elevations, temperatures, salinities, constituent concentrations, and densities at a grid of points in space and time. The three-dimensional, time-varying partial differential equations are formally averaged over the estuary width and then cast into finite difference form after vertical averaging over a horizontal layer thickness h with the k^{th} layer boundaries at $z = k + \frac{1}{2}$ and $z = k - \frac{1}{2}$. The laterally averaged equations as vertically integrated over the layer thickness are presented below:

<u>longitudinal (x-direction) momentum</u>

$$\frac{\partial}{\partial t}(UBh) + \frac{\partial}{\partial x}(U^2Bh) + (u_b w_b b)_{k+\frac{1}{2}} - (u_b w_b b)_{k-\frac{1}{2}}$$

$$+ \frac{1}{\rho}\frac{\partial}{\partial x}(PBh) - A_x \frac{\partial^2}{\partial x^2}(UBh) + (\tau_z b)_{k+\frac{1}{2}} - (\tau_z b)_{k-\frac{1}{2}} = 0 \qquad (1)$$

with

$$\tau_z \text{ of the surface} = C^*(\rho_a / \rho) w_a^{\,2} \cos \phi$$

$$\tau_z \text{ of an interlayer} = A_z \, \partial U / \partial z$$

$$\tau_z \text{ of the bottom} = g\, U|U| / c^2$$

continuity

$$(w_b b)_{k-\frac{1}{2}} = (w_b b)_{k+\frac{1}{2}} + \frac{\partial}{\partial x}(UBh) - \frac{\partial Q}{\partial x} \qquad \text{(internal)} \tag{2a}$$

$$\frac{\partial (Zb)}{\partial t} - \frac{\partial}{\partial x}\int_H (UB)\,dz + \frac{\partial Q}{\partial x} = 0 \qquad \text{(over total depth)} \tag{2b}$$

vertical (z-direction) momentum

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

heat balance

$$\frac{\partial}{\partial t}(BhT) + \frac{\partial}{\partial x}(UBhT) + (w_b bT)_{k+\frac{1}{2}} - (w_b bT)_{k-\frac{1}{2}}$$

$$- \frac{\partial}{\partial x}\left(D_x \frac{\partial BhT}{\partial x}\right) - \left(D_z \frac{\partial BT}{\partial z}\right)_{k+\frac{1}{2}} + \left(D_z \frac{\partial BT}{\partial z}\right)_{k-\frac{1}{2}} = \frac{H_n \; Bh}{V} \tag{4}$$

salinity balance

$$\frac{\partial}{\partial t}(BhS) + \frac{\partial}{\partial x}(UBhS) + (w_b bS)_{k+\frac{1}{2}} - (w_b bS)_{k-\frac{1}{2}}$$

$$- \frac{\partial}{\partial x}\left(D_x \frac{\partial BhS}{\partial x}\right) - \left(D_z \frac{\partial BS}{\partial z}\right)_{k+\frac{1}{2}} + \left(D_z \frac{\partial BS}{\partial z}\right)_{k-\frac{1}{2}} = \frac{H_n \; Bh}{V} \tag{5}$$

constituent balance

$$\frac{\partial}{\partial t}(BhC) + \frac{\partial}{\partial x}(UBhC) + (w_b bC)_{k+\frac{1}{2}} - (w_b bC)_{k-\frac{1}{2}}$$

$$- \frac{\partial}{\partial x}\left(D_x \frac{\partial BhC}{\partial x}\right) - \left(D_z \frac{\partial BC}{\partial z}\right)_{k+\frac{1}{2}} + \left(D_z \frac{\partial BC}{\partial z}\right)_{k-\frac{1}{2}} = \frac{H_n \; Bh}{V} \tag{6}$$

state

$$\rho = \frac{1000\ P_0}{\lambda + 0.6980\ P_0} \tag{7}$$

where

$$\lambda = 1779.5 + 11.25T - 0.0745T^2 - (3.80 + 0.01T)S$$
$$P_0 = 5890 + 38T - 0.375T^2 + 3S$$

where

A_x	x-direction momentum dispersion coefficent (m^2/s)
A_z	z-direction momentum dispersion coefficent (m^2/s)
b	estuary width (m)
B	laterally averaged estuary width integrated over h (m)
c	Chezy resistance coefficient, $m^{\frac{1}{2}}/s$
C	laterally averaged constituent concentration integrated over h ($mg \cdot l^{-1}$)
C*	resistance coefficient
D_x	x-direction temperature and constituent dispersion coefficient (m^2/s)
D_z	z-direction temperature and constituent dispersion coefficient (m^2/s)
g	acceleration due to gravity (m/s^2)
h	horizontal layer thickness (m)
H	total depth (m)
H_n	source strength for heat balance ($C \cdot m^3 \cdot s^{-1}$), salinity ($PPT \cdot m^3 \cdot s^{-1}$), or consistuent balance ($mg \cdot l^{-1} \cdot m^3 \cdot s^{-1}$)
k	integer layer number, positive downward
P	pressure (N/m^2)
Q	tributary inflow and withdrawal rates (m^3/s)
S	salinity (ppt)

t	time (s)
T	laterally averaged temperature integrated over h (C)
U	x-direction, laterally averaged velocity integrated over h (m/s)
u_b	x-direction, laterally averaged velocity (m/s)
V	cell volume ($B \cdot h \cdot \Delta x$) (m^3)
W_1	wind speed (m/s)
w_b	z-direction, laterally averaged velocity (m/s)
x and z	Cartesian coordinates: x is along the estuary centerline at the water surface, positive downestuary, and z is positive downward from the x-axis (m)
Z	surface elevation (m)
ρ	density (kg/m^3)
ρ_a	air density (kg/m^3)
τ_z	z-direction shear stress (m^2/s^2)
ϕ	wind direction (rad)

8. The finite difference operation is applied to Equations (1) through (6) and introduces two additional variables, Δx , the x-direction spatial step (m) and Δt , the computation time step (s). This operation produces finite difference equation analogues of Equations (1) though (6). The solution technique is to substitute the forward time, longitudinal momentum term from Equation (1) into the vertically integrated continuity expression, Equation (2b), to give the free surface frictionally and inertially damped longwave equation. The latter is solved implicitly for the surface elevation Z , which eliminates the longwave speed time step restriction ($\Delta x/\Delta t > \sqrt{gH}$) . However, the computation time step Δt is still limited by the fundamental condition that

$$\Delta t < V/Q^* \tag{8}$$

for each cell, where Q^* is the flow into or out of the cell and V is the cell volume.

9. The computation proceeds as follows: 1) new water surface elevations are computed using the implicit equation combination (Equations 1 and 2b); 2) new longitudinal velocities on the grid are computed from the explicit Equation (1); 3) Equation (2a) is used to compute vertical velocities and Equation (2b) is used to check water balances prior to the implicit solution of Equations (4), (5), and (6) for temperature salinity and constituent concentrations; 4) densities are computed from Equation (7) (Leendertse 1973). Results are printed, and a new time step computation begins once again with the solution for water surface elevation.

10. The FORTRAN names of the variables introduced in Equations (1) through (7) are given below*:

variable	FORTRAN name	variable	FORTRAN name
A_x	AX	S	S1,S2
A_z	AZ		
b	B	T	T1,T2
B	B	U	U
c	CHZY	u_b	U
C	C1,C2	V	VOL
C*	CZ	W_a	WA
D_x	DX	w_b	W
D_z	DZ	Z	Z1,Z2
g	G	Δt	DLT
h	HIN,H1,H2	Δx	DLX
H	HIN,H1,H2	λ	LA
H_n	HN	ρ	RHO
k	K	ρ_a	RHOA
P	P	τ_z	ST
P_0	PO	Ø	PHI
Q	QTRIB,QWD		

* A glossary of the FORTRAN variables discussed in this report is presented in Appendix E.

11. The location of the variable on the finite difference grid is important in understanidng the FORTRAN coding of CE-QUAL-ELV2 and the output. Figure 1 shows the location of velocities and dispersion coefficients at cell boundaries. This convention permits boundary values of these variables to be exactly zero. Other variables are located at the cell center and represent averages for the entire cell.

12. Throughout the computation new values of variables replace old values. The solution technique requires that values of Z , H , T , S , and C be retained for two time steps. At the end of a time step, the contents of these variable arrays are exchanged so that the older values are placed in arrays with a "1" suffix and the newer values are placed in arrays with a "2" suffix.

Estuarine Boundary Conditions

13. The upstream boundary condition for an estuary is the same as for the reservoir case and consists of setting left-hand horizontal velocities based on known inflow rate and geometry. The estuarine or open boundary condition is more complex. Generally, the right-hand boundary water surface elevation is known and the right-hand horizontal velocities and net flow must be computed. The individual components of the x-momentum equation are computed prior to the solution of the implicit combination continuity and x-momentum Equations (1) and (2b). This solution uses the known boundary value of Z , the individual components of the x-momentum terms, and the previous values of Z to determine new values of Z . Following this solution, the horizontal velocities U are explicitly computed.

14. Because of limitations in the amount of information available beyond the right-hand boundary (only Z and the temperature, salinity, and constituent profiles, not velocities, are assumed), several of the components in Equation (1) cannot be computed at the right-hand boundary. This equation is reduced at the boundary to:

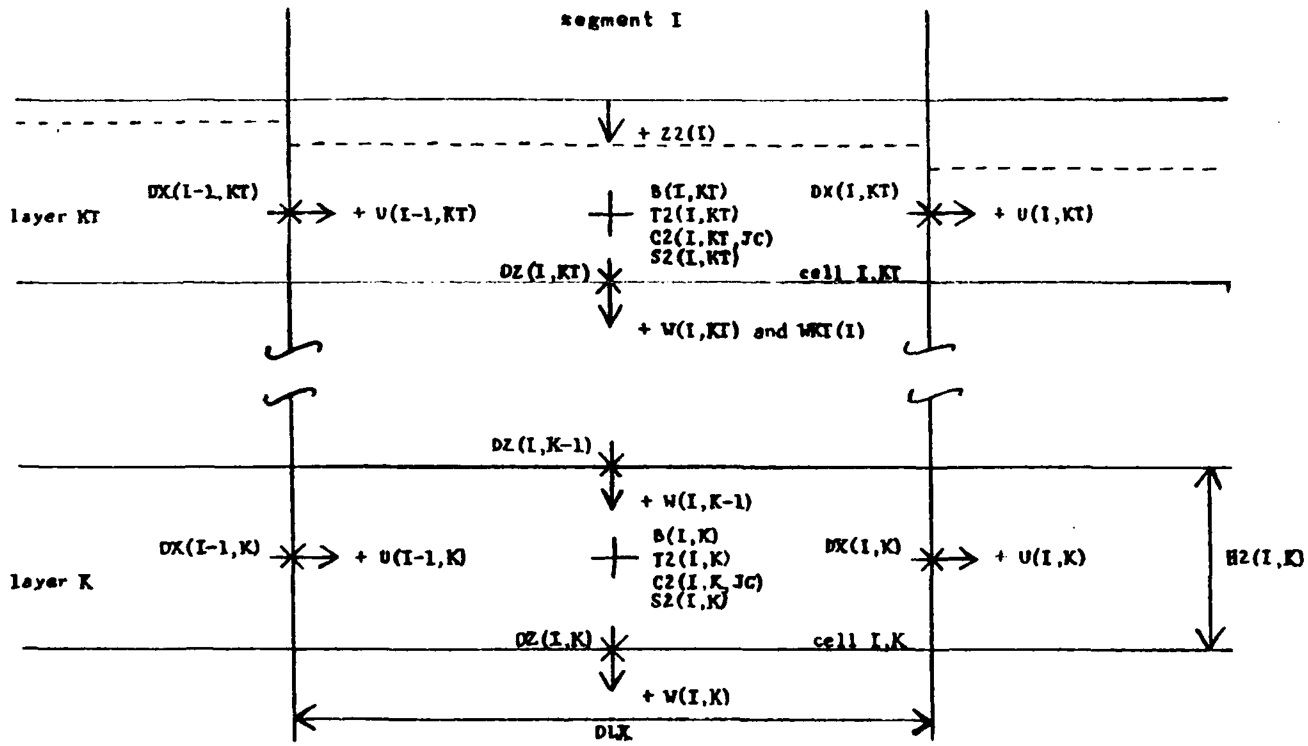

Figure 1. Location of major variables on finite difference grid

$$\frac{\partial}{\partial t}(UBh) + \frac{1}{\rho}\frac{\partial}{\partial x}(PBh) + (\tau_z b)_{k+\frac{1}{2}} - (\tau_z b)_{k-\frac{1}{2}} = 0 \qquad (9)$$

Only these terms at the right-hand boundary are used in the solution for Z and U . The net inflow or outflow at this boundary is then computed by integrating the U's over the depth.

15. Temperature, salinity, and constituent profiles are also needed at the boundary in order to solve Equations (4), (5), and (6). The right-hand boundary velocities computed from Equation (9) are used to transport these constituents into or out of the estuary. The FORTRAN names for these boundary profiles are TR , SR , and CR , which are a function of depth. The FORTRAN name for the boundary surface elevation is ZR .

Validation Tests

16. The codes from which CE-QUAL-ELV2 was derived have been validated and verified (Edinger and Buchak 1979, 1980a, and 1981). The validation tests were based on simulations of cases for which consistency and accuracy of water, heat, salinity, and constituent balances could be determined. Verification tests compared field observations with simulation results.

17. Validation tests made specifically for CE-QUAL-ELV2 focused on the newly-added Water Quality Transport Module. These tests separately exercised features of the program that handled the boundary conditions of inflow, outflow, and exchange at the open water boundary. Each test was deemed successfully completed if perfect temperature, salinity, and constituent balances were obtained. Evaluation of the results was simplified because each of the cases was run using uniform and constant temperatures, salinities, and constituents, with no sources or sinks other than at inflows, outflows, or the open boundary. The validation tests were as follows:

Case	Description
1	No motion. Constant and uniform temperature, salinity and constituent; no inflow or withdrawals; no head, temperature, or salinity gradient at open boundary.

Case	Description
2	Inflow, tributary, and withdrawal. Same as 1, with isothermal and isohaline inflow, tributary, and withdrawal.
3	Surge. Same as 1, with open boundary surface elevation higher than initial, internal elevations.
4	Convection. Same as 1, with boundary temperature less than initial, internal temperature and boundary salinity greater than initial, internal salinity.
5	Tide. Same as 1, with time-varying open water boundary elevation.

All these cases were successfully run.

18. Figure 2 shows the displacement vectors derived from the computed velocity field for day three of validation case 4.

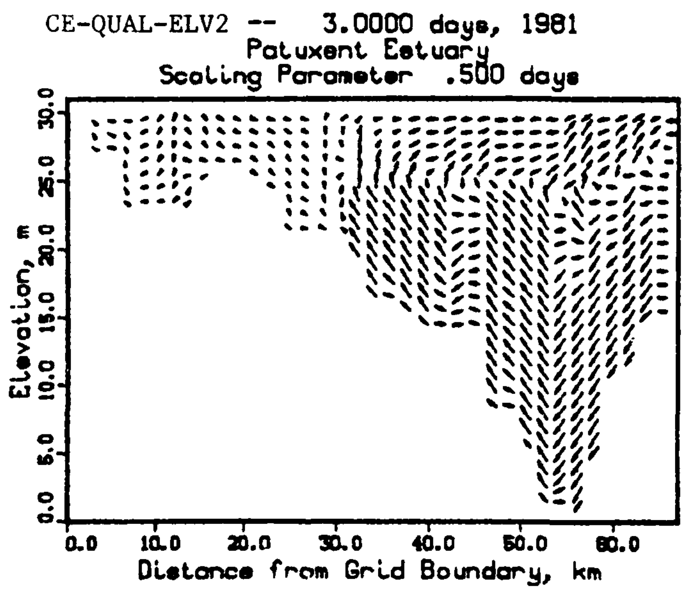

Figure 2. Displacement vectors for convection validation case

The displacements were obtained by multiplying the velocities by the scaling parameter (in this case, 0.5 day) to obtain distances which were then plotted on the finite difference grid. The figure shows movement up the estuary in the bottom and movement down the estuary in the surface layers in response to the density gradient at the open water boundary. Denser boundary water (i.e., colder and more saline) entered the estuary in the lower layers, and less dense estuary water left in the surface layers. This process continued as the density gradient moved up the estuary when colder, saltier water was advected in. By three days into the simulation, the salinity had reached segment 17 (km 32).

19. Validation case 1 showed that extremely small velocities ($< 1 \times 10^{-8}$ m/s) were generated at a large number of time steps for a case in which zero motion was expected. These spurious velocities were probably due to the accuracy limits of the computer and are dependent on the size of the grid considered. These velocities occurred because of a surface elevation gradient that was computed as the result of many secondary computations according to the recursive algorithm TRIDAG.

PART III: LATERALLY HOMOGENEOUS ESTUARIES

20. Estuaries have been classified by Pritchard (1956) on the basis of their dominant salinity gradients. An estuary which has salinity variations along its length, over its depth, and across its width is, of course, three-dimensional. A broad, shallow estuary which has predominately longitudinal and lateral salinity gradients but no vertical salinity gradient is considered a vertically homogeneous estuary. A long, narrow, and relatively deep estuary with little lateral variation in salinity but with longitudinal and vertical gradients is considered a laterally homogeneous estuary and is the type of estuary to which the CE-QUAL-ELV2 relationships apply. An estuary with little lateral and vertical variation in salinity but with a longitudinal gradient is considered to be a sectionally homogeneous estuary.

21. The above classifications provide a basis for simplifying the hydrodynamic and transport relationships in an estuary to match its spatial variability. One-dimensional sectionally homogeneous hydrodynamics is simpler than two-dimensional vertically homogeneous hydrodynamics, which in turn is simpler than two-dimensional laterally homogeneous or three-dimensional hydrodynamics. Complexity of the relationships is determined by the number of variables being computed, the number of spatial dimensions, the number of boundary conditions, and the types of numerical computations that must be employed. The numerical hydrodynamics of all three classes of estuaries has been developed by Edinger and Buchak (1980a).

22. Salinity gradients alone may not dictate the proper classification of an estuary. An estuary that is considered sectionally homogeneous based on salinity can exhibit complex time-varying vertical velocity profiles, with surface velocities reversing before bottom velocities on each oscillatory reversal of the tide. Use of sectionally homogeneous relationships in this case results in mixing because the complex velocity shear is absorbed into the evaluation of one-dimensional

dispersion coefficients. Separate consideration of mixing in the vertical and longitudinal axes would permit more realistic evaluation of mixing coefficients.

23. Problems of oversimplifying an estuary to the sectionally homogeneous case can be overcome by use of the laterally homogeneous or CE-QUAL-ELV2 relationships. The amount of boundary data (including fresh water inflows, tide heights, and tidal salinity at the downestuary boundary) is simiiar for the two cases. The CE-QUAL-ELV2 geometry provides a more realistic representation of cross sections, including overbank areas, and a more accurate location of intakes and discharges. The CE-QUAL-ELV2 computations cost more than sectionally homogeneous relationships, but they overcome the problem of proper representation of mixing due to complex vertical velocity structure, and they provide detail about constituents that may mix slowly along the vertical axis.

Density Dynamics

24. Many estuaries exhibit a complex longitudinal and vertical salinity structure due to the intrusion of higher density salt water up the bottom and under the lighter freshwater inflow moving downestuary. There is mixing between the two layers due to tidal action, velocity shear, and wind shear, causing the salinity structure to vary within tidal cycles and over longer periods of time. The vertical velocity structure also varies and, when averaged over many tidal cycles, shows a characteristic upestuary flow along the bottom and a downestuary flow on the surface.

25. The characteristic dynamics of a laterally homogeneous estuary are determined by the variation of the horizontal pressure gradient with depth. The influence of the horizontal density gradient on the horizontal pressure gradient can be demonstrated algebracially beginning with the computation of pressure P from a free surface elevation η to a depth z. The vertical distribution of pressure is:

$$P = g\int_{\eta}^{z} \rho \, dz \qquad (10)$$

where ρ is the density. Since ρ and η vary horizontally, the horizontal pressure gradient is:

$$\frac{\partial P}{\partial x} = -g\int_{\eta}^{z} \frac{\partial \rho}{\partial x} \, dz + g\rho\frac{\partial \eta}{\partial x} \qquad (11)$$

The horizontal pressure gradient depends on the surface slope $\partial\eta/\partial x$ and varies vertically with the integral of the horizontal density gradient. For purposes of demonstration, assume that $\partial\rho/\partial x$ is constant with depth as would be the case for a sectionally homogeneous estuary. The horizontal pressure gradient then beomes:

$$\frac{\partial P}{\partial x} = -g\frac{\partial \rho}{\partial x} (z - \eta) + g\rho\frac{\partial \eta}{\partial x} \qquad (12)$$

The vertical variation of the horizontal pressure gradient is clear from the above equation. At the surface $z = \eta$, the horizontal pressure gradient follows the surface slope as $\partial P/\partial x = g\rho(\partial\eta/\partial x)$. At an intermediate depth of $z = \eta + (\rho\partial\eta/\partial x)\big/(\partial\rho/\partial x)$, the horizontal pressure gradient is zero and there is a level of no motion. Below this depth, the horizontal pressure gradient is opposite in direction to the surface slope due to the vertical integral of the horizontal density gradient. The level of no motion varies with time; η and $\partial\eta/\partial x$ change with propagation of the surface tidal wave.

26. Even a sectionally homogeneous estuary has both a horizontal density gradient due to the longitudinal salinity gradient and a horizontal pressure gradient that varies with depth. Velocities in a sectionally homogeneous estuary thus vary with depth. Over a tidal cycle, surface velocities can reverse direction before bottom velocities; the net result is a two-layered flow. An estuary may be sectionally

homogeneous based on salinity observations, but it may not be sectionally homogeneous for velocities and the important transport processes. A sectionally homogeneous estuary based on salinity would be well represented by laterally averaged estuarine hydrodynamics. Sectionally homogeneous estuaries are a special case of laterally averaged dynamics.

Tidal Dynamics

27. The tide is one of the main driving forces of an estuary. It governs the surface slope of the estuary to which the internal motions respond. Tidal force is exerted on the estuary in the rise and fall of the water surface at the estuary mouth and in the gravitational pull of the moon and sun along the length of the estuary. The latter is usually neglected in a tidal estuary computation because the estuary is dominated by the propagation of the tidal wave occurring at the mouth.

28. The tidal wave at the mouth propagates up the esutary at the gravity wave speed $C = \sqrt{gH}$, which varies with location depending on average cross-sectional depth. For an estuary with an average depth of 5 m, it has a speed of 7 m/s. The wave length L is dictated by the wave period T since for a wave $C = L/T$. For a tidal period of 12.45 hours, a typical wave length in an estuary would be 220 km. For an estuary with a length of 100 km a high tide may exist at the mouth while a low tide may exist at the head of tide. A typical estuary decreases in cross section and depth upestuary, which causes a tidal wave to slow down and increase in amplitude as it is "funneled" through the decreasing cross section.

29. Once geometry effects are accounted for, the time lag of a tidal wave peak and the increase in amplitude of the tide wave upestuary are controlled by bottom friction. Accurate tide height measurements along the length of an estuary give the tidally averaged surface slope, the tidal amplitude, and the wave time lag. All three are used to adjust model geometry and friction since they dictate the characteristics of the tide wave.

Wind Dynamics

30. Wind may be important in an estuary depending on the width, fetch length, and orientation of the estuary relative to prevailing winds.

Wind effects are exerted on an estuary (a) as a component of the water surface elevation record at the mouth of the estuary and (b) by direct wind shear on the estuarine water surface. Wind effects as exhibited by fluctuations in mean water levels have periods ranging from hours to days.

31. When determining the hydrodynamics of an estuary, the wind component of the water surface elevation recorded at the mouth and the surface shear within the estuary must be considered together. To impose wind surface stress within the estuary and tidal height variation at the mouth without the wind component would produce a model with an artificial estuarine circulation lacking a mass transport component at the mouth. Similarly, to impose an observed variation in water surface elevation at the mouth that does contain a wind component without considering a complimentary wind surface shear would produce a model (a) that propagates long-period internal oscillations not compensated for by surface shear and (b) with an artifical circulation.

32. For analysis, the wind component is often filtered out of the tide record at the estuary mouth, thus eliminating the need for internal parameterization of wind effects. When comparing model results to periods of real data, however, it should be determined if the data were filtered. Otherwise, internal parameters may be erroneously adjusted to compensate for a missing driving force.

33. Wind plays an important role in determining the motion or intensity of turbulence at spatial scales shorter than the Δx or Δz scales of the numerically computed mean motions.

Turbulent Transport

34. The source of turbulent transport terms is the temporal averaging of the hydrodynamic and transport relationships; temporal averaging gives time-smoothed results from fluctuating turbulent flows. The turbulent transport terms are derived from an instantaneous value of velocity u represented by a short-time averaged mean value U and the fluctuation about the mean u' as:

$$u = U + u' \qquad (13)$$

and similarly for the vertical velocity and salinity:

$$w = W + w' \qquad (14)$$

$$s = S + s' \qquad (15)$$

Averaging the horizontal and vertical advection of momentum terms $\partial\overline{uu}/\partial x$ and $\partial\overline{uw}/\partial z$ and the horizontal and vertical advection of salinity $\partial\overline{us}/\partial x$ and $\partial\overline{ws}/\partial z$ gives:

$$\overline{uu} = U\,U + \langle u'\,u' \rangle \qquad (16)$$

$$\overline{uw} = U\,W + \langle u'\,w' \rangle \qquad (17)$$

$$\overline{ws} = W\,S + \langle u'\,s' \rangle \qquad (18)$$

where the overbar (—) signifies a time average of the product terms. The momentum and constituent transport balances are for the mean values U, W, and S, and their averagings result in the average cross product fluctuation terms $\langle u'\,u' \rangle$, $\langle u'\,w' \rangle$, $\langle u'\,s' \rangle$, and $\langle w'\,s' \rangle$ which in turn represent the horizontal and vertical turbulent fluxes of momentum and salt.

35. A description of the turbulence processes in a numerical model is complicated by the relationship between the model integration time step Δt and the time period of averaging. Presumably, the mean values U, W, and S are an average over the integration time step, and the fluctuations about the mean u', w', and s' are measured many times within this time step. A short integration time step of a few seconds to one or two minutes approaches the frequency of the fluctuations, yet the model is not actually computing turbulent fluctuating velocities. Rather, the model is iterating between the time limits of the boundary data to the next solution point. One advantage of an implicit solution with long time steps is that the computed U, W, and S at the end of each time step represents a mean over a period for which the average of the fluctuations apply.

36. A second difficulty in describing the turbulent transport processes for use in a numerical model is relating them to the scale of the grid. Although the turbulent transport terms are properly multiplied by the width of lateral averaging, the mean velocity and salinity in the gradient terms $\partial U/\partial z$ and $\partial S/\partial z$ apply across a segment area $B\Delta x$ where B is of the order of hundreds of meters and Δx is of kilometres. The width average is implied when computing U, W, and S, but the length average is not. Thus, there is a component of spatial variation contained in $\langle u' w' \rangle$ and $\langle w' s' \rangle$ that varies over the computational grid length Δx.

Turbulence Models

37. The problem of relating the turbulent transport given by $\langle u' u' \rangle$ and $\langle u' w' \rangle$ for momentum and $\langle u' s' \rangle$ and $\langle w' s' \rangle$ for constituent transport to the mean flow field quantities of U, W, and S is known as the closure problem. There are two general classes of turbulent closure models that have been studied in recent years. One class of models relates the turbulent transport quantities to gradients of the mean flow field through dispersion coefficients; the other evaluates the turbulent transport quantities from higher order moments or averages of the momentum and transport balances. The dispersion coefficient formulation has a hierarchy of models that have developed over the years and that have an empirical basis. The higher order moments models have been applied successfully only to relatively simple problems and usually require an empirical closure relation.

Dispersion Relations

38. The dispersion description of the turbulent transport is based on an analogy to molecular diffusion. The turbulent transports are related to the mean flow field as:

$$\langle u' u' \rangle = -A_x \, \partial U/\partial x \qquad (19)$$

$$\langle u' w' \rangle = -A_z \, \partial U/\partial z \qquad (20)$$

$$\langle u' s' \rangle = -D_x \, \partial S/\partial x \qquad (21)$$

$$\langle w' s' \rangle = -D_z \, \partial S/\partial z \qquad (22)$$

The turbulent dispersion coefficients for momentum A_x and A_z are sometimes called eddy viscosities; those for constituent transport D_x and D_z

are sometimes called eddy diffusivities. They are simply proportionality coefficients between the turbulent transport quantities and the mean flow-field quantities and are not implied to be constant in time or space.

39. Rodi (1980) indicates that the dispersion coefficient description of the turbulent transport processes does not constitute a turbulence model but only provides the framework for constructing such a model, and the problem shifts to evaluating A_x , A_z , D_x , and D_z over space and time. The dispersion coefficient description of the turbulent transport process has been incorporated into the LARM2 and CE-QUAL-ELV2 hydrodynamics to be a function of time and space for independent evaluation by any formulation.

40. There is a hierarchy of models for evaluating the turbulent dispersion coefficients from characteristics of the mean flow field. They are: (a) the zero-equation models that use scaling velocities and lengths, (b) the one-equation models that utilize the transport of turbulent kinetic energy in the flow field and scaling lengths and, (c) the two-equation models that utilize the transport of turbulent kinetic energy and its dissipation in the flow field. The latter two models have only recently been tested for application in detailed estuarine hydrodynamic models.

Zero-Equation Models

41. The zero-equation models assume that the turbulent dispersion coefficients are proportional to a scaling velocity V and scaling length L as:

$$A \propto VL \qquad (23)$$

which shifts the burden to evaluating V and L . The scaling length L characterizes the large-scale turbulent motion related to the mean flow field. In finite numerical computations its evaluation is complicated by the fact that the mean flow field is computed over a finite Δx and Δz .

42. The Prandtl mixing length hypothesis relates the scaling velocity to the mean flow field as:

$$V = lm \mid \partial U/\partial z \mid \tag{24}$$

where lm is a mixing length related to boundary layer thickness. Pritchard (1960) has used a mixing length hypothesis to evaluate vertical momentum dispersion coefficients from field evaluations in the James River.

43. An extension of the Prandtl mixing length hypothesis is von Karman's evaluation of the mixing length as:

$$lm = k \mid (\partial U/\partial z)/(\partial^2 U/\partial z^2) \mid \tag{25}$$

which applies to relatively simple flows. Application of von Karman's relation directly to estuaries is limited by the fact that there are often zero vertical velocity gradients or curvature causing lm to extend from zero to infinity. The latter requires additional truncation hypotheses.

44. Zero-equation formulations of the dispersion coefficients are presently utilized in CE-QUAL-ELV2 because of the background of empirical information available for their evaluation in coastal plain estuaries.

<u>One-Equation Models</u>

45. The turbulent dispersion coefficients can be theoretically related to the turbulent kinetic energy of the mean flow field. The relationships take the form of:

$$A = Cu\ K^{\frac{1}{2}}\ L \tag{26}$$

where Cu is an empirical constant, K is the turbulent kinetic energy, and L is, as previously, a scaling length.

46. The turbulent kinetic energy is considered to be generated and transported by the mean flow and dissipated by viscosity. The transport of turbulent kinetic energy in laterally averaged flow is, as for any scalar constituent:

$$\frac{\partial BK}{\partial t} + \frac{\partial UBK}{\partial x} + \frac{\partial WBK}{\partial z} - \frac{\partial}{\partial x} BD_x \frac{\partial K}{\partial x} - \frac{\partial}{\partial z} BD_z \frac{\partial K}{\partial z} = SS(U,W,S) \tag{27}$$

where SS(U,W,S) are the sources and sinks as functions of the mean flow field. The transport of turbulent kinetic energy can be incorporated directly into the transport module of the LAEM code.

47. Leendertse and Liu (1977) have utilized the one-equation formulation of turbulent dispersion in a three-dimensional time-varying finite difference computation with some success. The formulation allows evaluation of the generation and decay of turbulent kinetic energy by wind shear at the water surface. The buoyancy component of the source-sink term allows evaluation of the dampening of turbulent kinetic energy under stratified conditions and the conversion of potential to kinetic energy by unstable density gradients.

48. The one-equation or K model requires an evaluation of a scale length for the particular flow problem being evaluated. The dissipation portion of the source-sink term is usually modeled as $\varepsilon = C_D K^{3/2}/L$ where C_D is another empirical constant. Often in simple flows, the length scale is evaluated from the von Karman formulation.

Two-Equation Models

49. Some of the empiricism of the one-equation or K model, such as scale lengths, can be removed by transporting K and ε as separate quantities, each with a separate mean flow transport. Both quantities can be formulated in the transport module of CE-QUAL-ELV2. The dispersion coefficient then becomes a function of both K and ε as:

$$A = Cu\ K^2/\varepsilon \tag{28}$$

and the length scale is eliminated.

50. Rodi (1980) points out that an exact dissipation or ε equation contains complex correlations whose behavior is little known and for which drastic modeling assumptions must be made. Carter (1981) has reported that numerical experiments by Blumberg in atmospheric stratified

flows using the $K-\varepsilon$ relationships did not improve flow-field predictions much beyond those given by the zero-equation models. The $K-\varepsilon$ relations are still in the experimental stage.

Moment Models

51. It is possible to formulate relationships for the turbulent transport terms $\langle u' u' \rangle$, $\langle u' w' \rangle$, $\langle u' s' \rangle$, and $\langle w' s' \rangle$ directly from the momentum and transport equations. For example, multiplying the salinity transport by $u = U + u'$ and averaging gives a relationship of the form:

$$\frac{\partial \langle u' s' \rangle}{\partial t} + \frac{\partial U \langle u' s' \rangle}{\partial x} - \frac{\partial \langle u' u' s' \rangle}{\partial x} + \cdots \tag{29}$$

which introduces higher moment terms such as $\langle u' u' s' \rangle$, $\langle u' w' s' \rangle$, and so on. Thus, introducing a relationship for direct evaluation of $\langle u' s' \rangle$ results in higher moments that need to be evaluated. The process can be continued to fourth-order and higher moments. However, eventual solution or closure requires truncation of the processes and empirical evaluation of the highest moment.

52. The higher moment relationships are often truncated by assuming that the turbulence has some mathematical property such as isotropy. The relationships have been evaluated for simple cases such as flows through grids but have yet to be applied in complex time-varying flows such as estuaries. Part of the reason is that more computations are required for the turbulent transports than for the mean flows.

Dispersion Relationships in CE-QUAL-ELV2

53. The turbulent transport relationships in CE-QUAL-ELV2 follow the zero-equation models and use dispersion relationships. The dispersion coefficients are written into all numerical expressions for general evaluation as functions of time and space. They can be evaluated from scaling relationships, as shown below, or they can eventually be evaluated from a K or $K-\varepsilon$ model. the scalar relationships rely on empirical evaluation from previous estuary studies and, where possible, field verification.

Vertical Transport Processes

54. The average cross-product fluctuation terms which make up the vertical turbulent process are related to the mean flow and concentration fields as:

$$\langle u' w' \rangle = -A_z \, \partial U/\partial z \qquad (30)$$

$$\langle w' s' \rangle = -D_z \, \partial S/\partial z \qquad (31)$$

The problem, therefore, is reduced to evaluating A_z and D_z in terms of the computed flow and density fields.

55. In an estuary that can stratify, the vertical dispersion coefficients are affected by the level of turbulence and the degree of stratification. They can be represented as:

$$A_z = A_{zo} \, F(Ri) \qquad (32)$$

where A_{zo} is a function describing the level of turbulence related to velocity, depth, wind stress, and Ri is the Richardson number related to stratification. Almost every formulation of A_z that is available can be examined in the above form.

56. The Richardson number is an important concept in describing vertical mixing in a stratified waterbody. It is defined as:

$$Ri = \frac{\frac{g}{\rho}\left(\frac{\partial \rho}{\partial z}\right)}{\left(\frac{\partial U}{\partial z}\right)^2} \qquad (33)$$

which is the ratio of the buoyant or potential energy to the kinetic energy being dissipated at a point in the water column. This Ri is called a "local" or gradient Richardson number as opposed to a "bulk" Richardson number applied to the whole water column. The stronger the stratification, as indicated by a large density gradient $\partial \rho/\partial z$, the more a given amount of kinetic energy $(\partial U/\partial z)^2$ is dissipated by the buoyancy and less by the turbulence generated. An increasing Ri, therefore, means a lower level of turbulence and a lower A_z and D_z.

57. In the absence of stratification, Ri = 0 and $A_z = A_{zo}$. These relationships as well as dimensional arguments led Munk and Anderson (1948) to the Richardson number function of:

$$F(Ri) = \left[1 + a(Ri)\right]^b \tag{34}$$

where they deduced for vertical momentum transport a = 10 and b = -1/2 and for vertical salinity transport a = 10/3 and b = -3/2. Since the exponent b is negative, a higher Ri leads to a lower A_z. The form of the Richardson number function given above appears in many studies. It tends to have a theoretical basis, as shown by the heuristic derivations given by Officer (1976).

58. Another form of the Richardson number function used by Leendertse and Liu (1975) is:

$$F(Ri) = e^{-r(Ri)} \tag{35}$$

which is an exponential form that has a value for negative Ri and can degenerate to zero. A negative Ri exists where an inverse density gradient occurs and mixing takes place by turnover or by vertical convection at a very rapid rate. It can be handled in numerical computations by using an algorithm that sets a large A_z where the density gradient is negative. A large Ri can lead to small A_z, the lower limit of which must be the molecular diffusivity and viscosity.

59. The most complete evaluation of A_{zo} and F(Ri) for an estuary has been given by Pritchard (1960). Based on data from the James River and using mixing length arguments, he deduced that:

$$F(Ri) = (1 + 0.276\ Ri)^{-2} \quad (36)$$

$$A_{zo} = 8.59 \times 10^{-3} U_t \left[z^2 (d - z)^2 / d^3 \right] \quad (37)$$

where U_t is the RMS tidal velocity and d is the total depth. The Richardson number was defined as $(g/\rho \cdot \partial\rho/\partial z)/(0.70U/h)$ where U is the mean velocity over the water column. The function A_{zo} is zero at the surface and bottom of the water column and has a maximum at middepth based on mixing length arguments. This shape is modified by $F(Ri)$ which reduces the middepth value because of stratification. The Ri is determined from the local gradient and bulk (water column) velocity and depth. It is clearly intended to be a local or depth-dependent evaluation of A_z by choice of the depth function.

60. The depth-dependent forms of A_z were tried in numerical models by Bowden and Hamilton (1975) and by Elliott (1976a). Both reported numerical instabilities that were apparently related to the evaluation of A_z using a Richardson number. Bowden and Hamilton (1975) resorted to using a bulk Richardson number, but with a vertical-shaped function. More recently, Bowden (1977) has discussed the difficulties of utilizing the local Richardson number in a numerical model and suggests that there is a theoretical rationale for the bulk Ri. Examination of the numerical form of the Elliott and the Bowden and Hamilton models suggests that the instabilities are a result of computational procedures rather than physical aspects of the mixing problem.

61. CE-QUAL-ELV2 presently uses a local Ri determined from the local velocity and density gradient. When computations are made for an estuary with a constant A_{zo}, an A_z is produced with a depth distribution as given by Pritchard (1960). This suggests that the distribution of A_z is a result of the interaction of the mean velocity and salinity fields with the vertical dispersion.

62. Wind is important in vertical mixing. Wind not only increases the mean velocity gradient and shear, but must also increase the turbulent

fluctuations about the mean. It is the fluctuating component over a given period of averaging that determines the vertical mixing. Pritchard (1960) assumed that the wind-induced turbulence is proportional to the orbital wave velocity resulting from the wind and is also affected by the vertical density gradient. The wind speed function deduced by Pritchard (1960) from the James River data is:

$$A_{zo} = 9.57 \times 10^{-3} \left[\frac{z(h-z)}{h} \left(\frac{H}{T} \right) e^{-2\pi z/L} \right] \tag{38}$$

where H is the wind wave height, T is the wave period, and L is the wave length. In the above relationship, the A_{zo} decreases exponentially with depth and shows a parabolic shape with depth. The exponential decay occurs because the wave orbital velocity decays with depth, as derived from elementary wave theory; the parabolic-shaped terms come from the mixing length theory used to scale to the total water column depth. Ford (1976) has examined the wind effects on A_{zo} primarily for lakes using the exponential decay, but no shape function with depth. The wind wave characteristics H, T, and L are functions of wind speed, duration, and fetch. The functional relationships among these variables are known to a limited extent for estuaries. Accurate representation of vertical mixing in estuaries will require performing wind wave analyses for significant wind events. The scale of the computational model grid relative to the waterbody has a significant effect on the magnitude of the dispersion coefficients. Increasing layer thickness from 0.5 m to 1 or 2 m reduces the resolution of the computations; the reduced resolution may mean larger values for A_{zo}. In principle, when the grid size decreases, values of A_{zo} approach molecular scales. However, the turbulence in the waterbody consists of random motions and still requires evaluation of the turbulent transport terms $\langle u' w' \rangle$ and $\langle w' s' \rangle$ to close the equations of motion and transport. In a unique experiment in model scales, CE-QUAL-ELV2 computations were performed on a very small grid where Δx = 5 ft and H = 3 in a hydraulic flume with a density underflow at laminar conditions (Edinger and Buchak 1979). The numerical model did not produce accurate results until the dispersion coefficients were reduced to molecular values, indicating that there is a strong interrelationship between grid size and the dispersion coefficients and turbulent characteristics of the waterbody.

Longitudinal Dispersion Formulations

63. The longitudinal dispersion of momentum and constituent concentrations results from the time averaging that produces the advection of momentum $\partial UU/\partial x$ in the momentum balance and the constituent $\partial US/\partial x$ in the transport balance. The average of the product fluctuations about the mean values are for momentum:

$$\langle u' u' \rangle = -A_x \, \partial U/\partial x \tag{39}$$

and for constituent

$$\langle u' s' \rangle = -D_x \, \partial S/\partial x \tag{40}$$

which relates the turbulent fluctuation to the average velocity U and constituent S . As discussed previously, there is a relationship between the time over which the fluctuation products are averaged and the time step of numerical integration that produces U and S .

64. Most formulations of longitudinal dispersion in estuaries have been derived in relation to one-dimensional sectionally homogeneous estuary models. They often come from analysis of steady channel flows and are dimensionally of the form:

$$D_x = a \, h^* u^* \tag{41}$$

where h^* and u^* are a characteristic depth and velocity. Harleman (1971) shows that when the Taylor formula is converted from pipe flow to a tidal case, the characteristic velocity translates from the boundary shear velocity to the maximum tidal velocity. Examples of the above relationships are given in Fischer et al. (1979).

65. Numerous evaluations of D_x have been made for specific estuaries using a one-dimensional model of the salinity distribution (Officer 1977). For the Potomac estuary, values of 10 to 20 m^2/s were found in the vicinity of Washington, D.C., increasing to 60 m^2/s toward the mouth. Using a dissolved oxygen model on the Delaware River, values ranged from 120 to 210 m^2/s over 135 km. The Thames exhibited values between 50 and 80 m^2/s at low river flows and up to 340 m^2/s at high river flows. The values, therefore, can range from 5 to 500 m^2/s and vary with river flow and salinity stratification. The latter can complicate results since the large D_x required in a one-dimensional model in the stratification region simply forces the model to fit a multilayered circulation, and a similarly large D_x would not be required for a laterally averaged model in the same region.

66. There have been few attempts to derive relationships for the use of A_x and D_x in laterally averaged hydrodynamics except to use relationships as if they applied to each layer. Experience with CE-QUAL-ELV2 has shown that changes in A_x and D_x of two orders of magnitude have not changed results significantly. Similar conclusions were reached by Elliott (1976a). The reason for this lack of sensitivity is that the contribution of vertical exchange to longitudinal mixing which is absorbed in D_x in one-dimensional models is explicitly included in the laterally averaged models. Thus, one of the spatial dimensions over which the turbulent transport is averaged in the one-dimensional model is relaxed in the two-dimensional model and becomes less important.

67. There still may be a scale relationship to the grid Δx for A_x and D_x as discussed previously for the flume studies at laminar flow conditions. Results suggest that in each computational grid it is necessary to satisfy the condition of:

$$D_{molecular} < D_x < U\Delta x \qquad (42)$$

which dimensionally states that a constituent (including momentum) should not be diffused out of a cell faster than it is advected inward. For an estuary like the Potomac where, computationally, Δx might be 9300 m (5 nm) and the average net non-tidal velocity is of the order of 0.02 m/s, maximum D_x would be 186 m^2/s.

Estuarine Characteristics

68. A laterally homogeneous estuary is usually identified by its geography, hydrography, and salinity distributions. A laterally homogeneous estuary is typically defined as exhibiting longitudinal and vertical gradients and lateral homogeneity of salinity. Velocity profiles may provide a more accurate basis for a dimensional description since an estuary may have vertically homogeneous salinity yet exhibit velocity reversals with depth. Salinity profiles are used as indicators because of the availability of salinity data. A laterally homogeneous estuary is characteristically a coastal plain estuary at the mouth of a drowned river valley. The estuary is much longer than it is wide, although there may be a bay at its mouth. Depths may be shallow and cross-sectional areas small near the head of tide, with both increasing in size toward the mouth.

69. Along the east coast of the United States, typical laterally homogeneous estuaries are the Connecticut River, the Hudson River, most of the tributaries to the Chesapeake Bay including the Severn, Patuxent, Potomac, and James Rivers. Long Island Sound and Chesapeake Bay can be approximated as laterally homogeneous estuaries, although there are significant lateral salinity and velocity gradients due to Coriolis acceleration. Many of the rivers along the North and South Carolina and Georgia coasts also have sections of estuary that are laterally homogeneous although they are tributary to shallow-water, vertically homogeneous coastal regions.

The Patuxent Estuary

70. CE-QUAL-ELV2 data requirements for simulation of a laterally homogeneous estuary are best illustrated by an example. The Patuxent Estuary was chosen because it shows a complete transition from a salinity-stratified laterally homogeneous estuary to a shallow, sectionally homogeneous estuary; it also has a single large heat source which allows the demonstration of the Water Quality Transport Module for excess heat.

71. The Patuxent Estuary is shown in Figure 3. It extends 70 km from Solomons Island to Hardesty, Md. Detailed hydrographic data is available for the Patuxent in numerical form (Cronin and Pritchard 1975). Freshwater inflows vary widely through the year, with high flows in the spring and low flows in the fall. Between 1970 and 1979 mean monthly flows have varied from 73 m^3/s to 2 m^3/s. Daily freshwater inflows at the head of the estuary and at major tributaries can be determined from the United States Geological Survey gage records.

72. The Patuxent Estuary is tributary to the Chesapeake Bay. The downestuary boundary salinity is determined by conditions in the bay. The temporal variation and stratification of salinity at the mouth of the Patuxent is due to processes within the Chesapeake Bay, including the influence of the Susquehanna River.

73. The salinity distributions within the Patuxent River estuary are dictated by the freshwater runoff, the estuarine geometry, and the salinity distribution at the mouth. Observed longitudinal and vertical distributions of salinity are given for high freshwater inflow period and a low flow period in Tables 1 and 2. In both cases, as shown by the vertical salinity profiles, the estuary is stratified at its mouth and significantly through its lower half. In the headwater reaches, the salinity is significantly lower during high-flow periods than during low-flow periods.

74. The spatial and temporal vertical distributions of salinity at the estuary mouth are necessary boundary conditions and should be recorded at daily intervals, if possible. Daily surface salinity data are available for the Patuxent at Solomons Island. For a few years there have

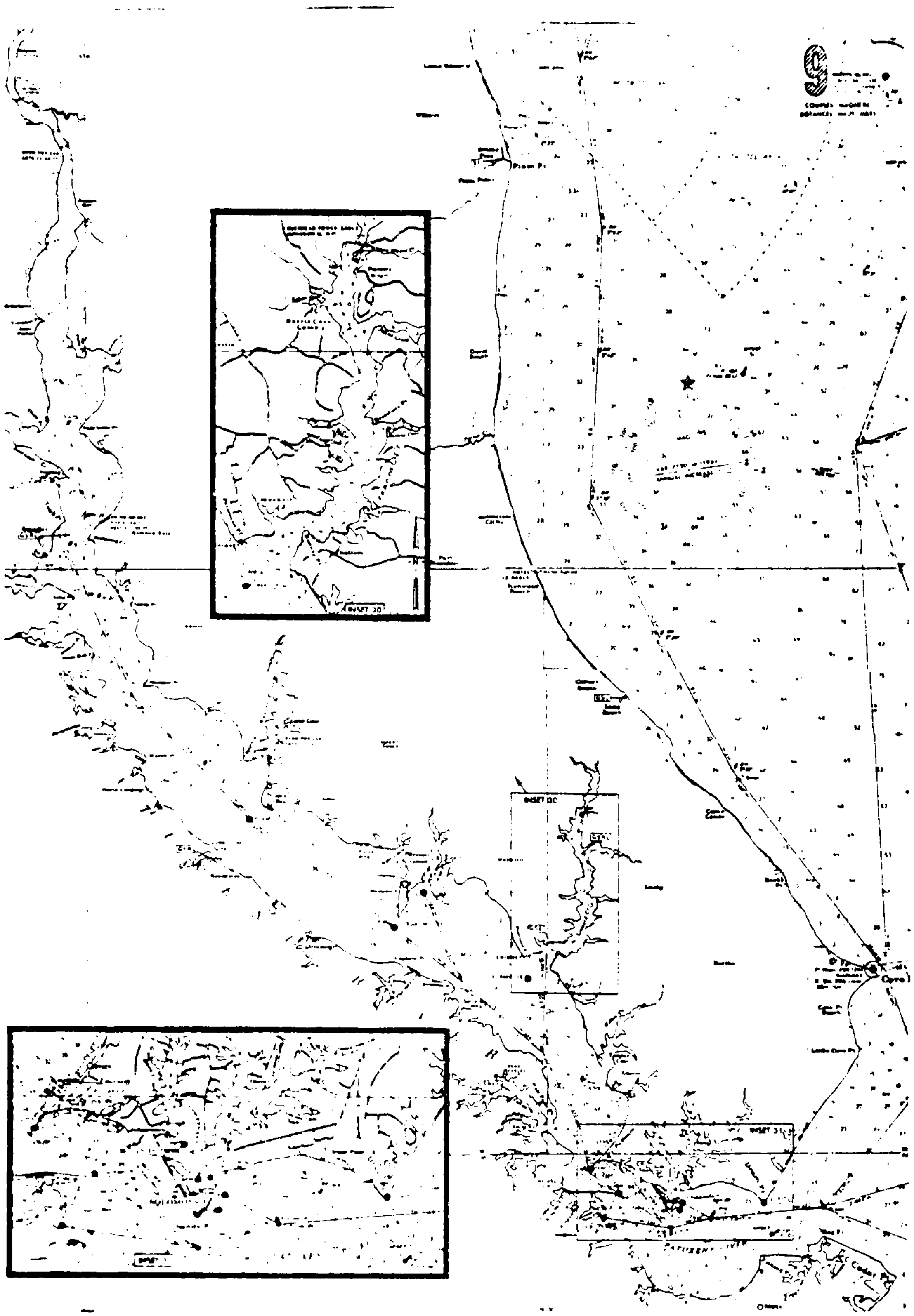

Figure 3. Patuxent Estuary

DEPTH (M)	RIVER MILE (NAUT MI)* 2.0	3.0	3.8	5.5	7.1	7.9	9.0	9.8	12.0	14.5	17.0	18.2	19.1	20.4	20.6
0.0	10.6	10.1	10.0	8.9	7.9	7.4	6.7	6.5	5.2	4.4	3.7	3.1	2.4	2.1	1.3
1.0	10.6	10.2	10.1	9.3	8.1	7.6	6.9	6.6	5.5	4.5	4.9	3.7	2.5	2.2	1.8
2.0	10.8	10.4	10.2	9.8	8.5	8.1	7.7	7.6	6.6	5.5	4.9	5.9	4.8	4.1	2.5
3.0	10.8	10.5	10.2	9.9	8.8	8.4	8.0	8.0	6.8	7.7	5.8	6.2	6.5	7.4	4.7
4.0	10.9	10.8	10.7	10.0	9.2	8.8	8.6	8.9	7.6		7.8	7.6	8.4	7.7	7.2
5.0											9.6				
6.0	11.4	11.6	11.4	11.3	10.8	9.6	9.3	9.8	10.8			9.9	10.3		8.9
7.0												11.0			
8.0	11.9	12.8	11.9	12.0	11.4	13.1	11.9	11.0	11.6				10.7		
10.0	12.3	12.9	12.3	12.5	13.1	13.3	12.8		13.0				11.0		
11.0		13.0													
12.0	12.4		13.0	12.8		13.5									
13.0			13.1			13.5									
14.0	12.0			12.8											
16.0	11.9														
	21.0	22.0	22.8	23.5	24.0	24.4	24.7	26.0	27.3	28.0	29.2	30.2	31.0	32.0	33.0
0.0 / 1.0	1.1 / 1.2	0.5 / 0.3	0.4 / 0.4	0.3	0.1 / 0.1	0.1 / 0.1	0.1 / 0.1	0.1 / 0.1	0.1 / 0.1	0.1 / 0.1					
2.0	1.3	0.6	0.5	0.2	0.1	0.1	0.1	0.1	0.1	0.1					
3.0	2.0	0.9	0.5	0.2	0.1	0.1	0.1	0.1	0.1	0.1					
4.0			0.5												

* A table for converting inch-pound units of measure to metric (SI) units is presented on page 4.

Table 1. Longitudinal and vertical salinity profiles in the Patuxent River for 17 May 1978, PPT

DEPTH (M)	RIVER MILE (NAUT MI) 2.0	3.0	3.8	5.5	7.1	7.9	9.0	9.8	12.0	14.5	17.0	18.2	19.1	20.4	21.0
0.0	10.1	10.1	10.3	10.1	9.4	8.5	8.6	8.2	7.8	7.7	7.4	6.9	6.5	6.2	6.3
1.0	10.2	10.1	10.4	10.1	9.6	8.6	8.7	8.3	7.8	7.8	7.4	7.1	6.8	6.1	6.6
2.0	10.3	10.3	10.3	10.1	9.8	8.6	8.8	8.4	7.9	7.8	7.7	7.7	6.9	6.2	7.2
3.0	10.4	10.3	10.4	10.2	9.8	8.8	9.0	8.5	8.0	8.2	7.8	8.4	6.9	6.3	7.5
4.0	10.5				9.9				8.6						
6.0	10.8				10.0				10.5						
8.0	11.0				10.1				10.6						
10.0	11.1				10.3										
12.0	11.3														
14.0	11.4														
16.0															

DEPTH (M)	22.0	22.8	24.0	24.4	26.0	27.3	28.0	29.2	30.2	31.0	32.0	33.0
0.0	5.9	5.5	4.9	4.5	3.5	2.5	1.6	1.5	1.3	0.4	0.2	0.3
1.0	6.1	5.8	5.0	4.8	4.0	2.6	2.2	1.6	1.3	0.4	0.3	0.3
2.0	6.1	5.8	5.3	4.8	3.9	2.6	2.5	1.7	1.3	0.4	0.4	0.3
3.0	6.1	5.8	5.3	4.8	3.9	2.9	2.7	1.7	1.4	0.7	0.5	

Table 2. Longitudinal and vertical profiles in the Patuxent River for 17 July 1978, PPT

existed monthly vertical salinity profiles that must be interpolated to daily values. Such an interpolated boundary record presents the possibility that large, short-term fluctuations in salinity due to storm events will be missing from the boundary data and will not be reflected in the computed results.

75. Tide height data at the estuary mouth are a necessary boundary condition. Tide height measurements at the estuary mouth should be made accurately and taken hourly, if possible. Hourly records should include the effects due to wind setup as well as the solilunar harmonics. For the Patuxent at Solomons Island, only daily high and low tide heights were available, and many data were missing from the tide record. Therefore, tide heights at Solomons Island were reconstructed for a simulation period using the following data sources: observed tide heights upestuary at Benedict, the National Oceanic and Atmospheric Administration (NOAA) predicted tidal amplitudes for the estuary at Benedict and Solomons Island, and an assumed sinusoidal tide at the mouth. Deviations of observed and predicted tidal amplitudes at Benedict were superimposed on predicted tidal amplitudes at Solomons Island in order to create a tidal boundary record. The reconstructed tide record at Solomons Island does not accurately reflect the effects due to wind setup either along the Chesapeake Bay or on the estuary. Tidal amplitudes are among the most important types of boundary data for hydrodynamic simulations, yet for most estuarine applications tide height data at the mouth is sparse or nonexistant. It must be emphasized that the accuracy of a hydrodynamic model is no greater than that of the boundary data used.

76. A major heat source on the Patuxent located 38 km upestuary from the mouth is the Chalk Point Power Plant, which withdraws high-salinity water downestuary and then discharges it upestuary at a temperature increase of 7° C. The plant pumps at a rate of approximately 47 m^3/s, representing many times the fall low flow and a large fraction of the springtime freshwater flow. The more saline discharged waters are warmer and less dense than the receiving waters, so they float on the

surface near the discharge. As they mix and cool, however, their density increases relative to the receiving waters and they sink. These types of details should be part of the boundary data for a limited region of an estuary.

77. There have been a number of intensive surveys of the Patuxent River, including the monthly salinity and water quality profiling presented above, that provide data for verification of simulations. Velocity comparisons present one of the most stringent verifications. In August 1978, extensive water current surveys were made in a region that extended between 35 km and 45 km from the estuary mouth (Academy of Natural Sciences of Philadelphia and J. E. Edinger Associates, Inc. 1981). At one particular section of interest at Benedict, four surface current meters and four bottom current meters placed across the estuary made it possible to determine laterally averaged velocities at two depths and compare them to computed results.

78. Another verification compares longitudinal variations in tidal amplitude and mean tide height. Except for the Benedict gage these are known from the NOAA-predicted tide ranges along the estuary, and the comparison is between two different methods of computation. Salinity profiles within the period can also be compared; either long time intervals (30-60 days) or a unique storm event was required to produce a uniquely different salinity profile. The Patuxent simulations were initialized from an observed salinity distribution.

PART IV: APPLICATION PROCEDURE AND EXAMPLE

79. Applying CE-QUAL-ELV2 to a particular case requires five steps: (1) assembling the necessary data, (2) schematizing the estuary geometry, (3) modifying a subroutine for the input of time-varying boundary condition data, (4) determining site-dependent hydraulic constants and constituent reaction rates, and (5) executing the code and evaluating the results. These steps are described below

Required Data

80. The initial task in applying CE-QUAL-ELV2 to a specific case (after deciding that the problem requires a two-dimensional, time-varying simulation for its solution) is assembling the necessary data. Estuary geometry is of immediate usefulness and should include bathymetric cross sections (y-z plane). A plan (x-y plane), an elevation (x-z plane), and an elevation-area-volume table are useful, but not necessary, adjunct information. These data are used to construct the computational grid.

81. Initial and boundary condition data are required. The former are measurements of water surface elevation and temperature and salinity fields for the starting day of the simulation. Boundary condition data in their most general form consist of time-varying inflow rates, temperatures, and salinities for the upstream inflow and each significant tributary; time-varying release and withdrawal rates; and time-varying meteorological data for wind shear, evaporation, and surface heat exchange calculations. As CE-QUAL-ELV2 is now coded, surface heat exchange is computed using equilibrium temperature, the coefficient of surface heat exchange, and solar radiation. These parameters are computed separately from air temperature; dew point temperature; wind speed; and observed solar radiation, percent of possible sunshine, or cloud cover data (Edinger, Brady, and Geyer 1974). In their simplest form, the boundary condition data are constants. For each water quality constituent to be computed,

initial and boundary condition data and reaction rates are needed. Hydraulic properties--Chezy and dispersion coefficients--and solar radiation absorption and attenuation characteristics are also required.

Geometric Schematization

82. The geometric data are organized into a grid like the one shown in Figure 4 for the Patuxent Estuary. The basic parameters to be selected in defining the grid are the longitudinal spacing Δx (FORTRAN DLX) in meters and the vertical spacing h (FORTRAN HIN) in meters. These parameters are constant throughout the grid and define two of the three dimensions of each cell. The third dimension, the cell widths (FORTRAN B), are most easily taken from cross-section drawings and represent an average width for each cell. The vertical columns defined by Δx are called segments, and the horizontal rows defined by h are called layers.

83. A more sophisticated procedure for obtaining cell widths involves the use of the Hydrologic Engineering Center code GEDA and the preprocessor GIN, the user notes for which are included as Appendix F of this guide. GEDA utilizes cross-sectional data from ranges at irregular intervals and produces estuary widths as functions of elevation at regular intervals. GEDA also computes areas and volumes as functions of elevation. Cross-sectional data may be modified using GEDA procedures in order to fit the computed elevation-area-volume table to published information. GEDA allows several Δx's and h's to be tried with very little additional effort. GIN uses GEDA output as input and produces the geometry (BA) cards read by CE-QUAL-ELV2. GIN also may be manipulated to change the computed elevation-area-volume table to more closely match the given table. GIN produces an active/inactive cell map to allow screening of illegal geometric features.

84. Implicit in the geometric schematization is the identification of the waterbody centerline. This may be defined as the dominant flow path, with its origin at the upstream boundary and it may follow a path that coincides with the thalweg. All longitudinal distances are measured along the selected centerline.

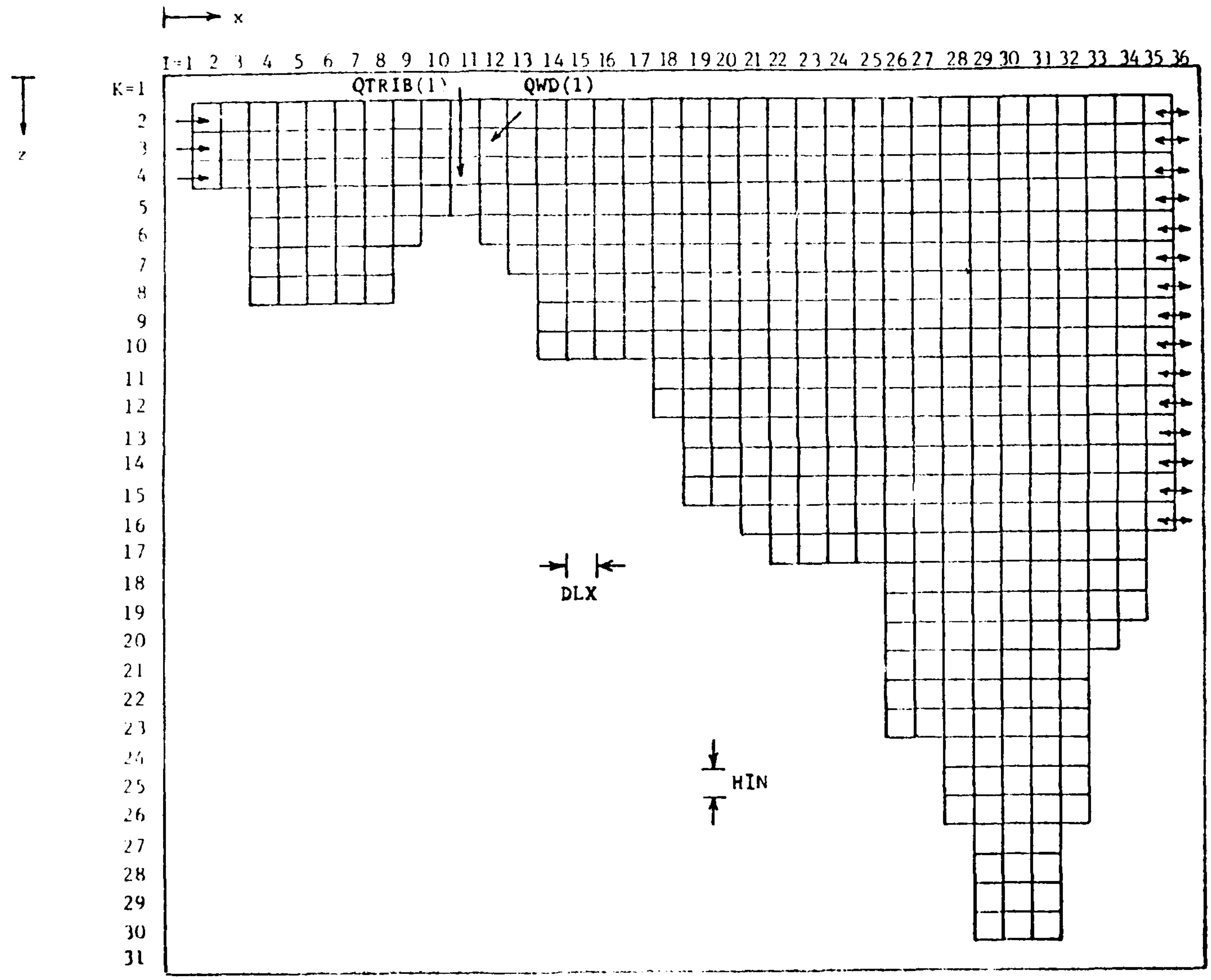

Figure 4. Patuxent Estuary finite difference grid

85. The choice of Δx and h is important to the success of the simulation. By selecting the ratio $h/\Delta x$ to match the overall estuary bottom slope, the user will find that the estuary bottom topography may be modeled more accurately. While relatively small values of Δx and h permit finer resolution, the resulting large number of grid cells requires more computation and storage. A second consideraion in the choice of Δx and h is the basic stability criterion that Δt , the integration time step, be smaller than the volume of each cell divided by the flow through the cell (Equation (8)). This criterion also affects economy by forcing smaller Δt's as cell dimensions are decreased.

86. In practice, Δt can be changed for a particular simulation, while the geometry established initially remains fixed. Surprises from an implicit choice of Δt can be avoided by anticipating the limiting Δt dictated by geometry. In most cases, this limiting Δt will occur at tributary or upstream inflows, withdrawals, or downstream outflows. Equation (8) can be evaluated using the smallest cell volume and largest anticipated flow at these inflow or outflow segments.

87. The code automatically expands the grid to accommodate rising and falling water surfaces, so the selected grid should be large enough to contain the largest anticipated volume. The grid consists of active and inactive cells, the former being those at which velocities, temperatures, salinities, and constituent concentrations are computed; and the latter being those at which no computations are done. Inactive cells are identified by inputing their widths as zero. The grid must satisfy the following rules:

a. It must be at least two active cells deep at every segment.
b. It must be at least three active cells long at every layer.
c. Steps in the waterbody bottom profile are permitted as long as each continuous layer produced is at least three cells long.
d. The grid must include a layer of inactive cells at the top and bottom and a segment of inactive cells at the left and

right, such that those cells representing the waterbody are surrounded on all sides by a layer or segment of inactive cells.

e. Cell widths must not decrease from bottom to top in any segment.

Active cells are those which may contain water, or may not at various times because of flood events, drawdown, or tidal changes. The current boundaries of the computation on the grid are defined by the parameters IL and IMAXM1 in the longitudinal and KT and KMAXM1 in the vertical. The minimum values of the parameters IL and KT are each two, indicating the waterbody is at its maximum volume. As drawdown occurs, KT increases, so that the water surface is located near layer KT . If necessary, CE-QUAL-ELV2 also decreases IL so that segment I = IL is always at least two cells deep.

88. Layers are identified by the layer number K , with a range of 1 to KMAX . Each of these has an elevation associated with it, so that

$$EL = h \cdot (KMAX - KT + 1) - Z + DTM \tag{43}$$

is the water surface elevation, where DTM is the distance from some reference datum to the bottom of the grid. CE-QUAL-ELV2 computes water surface elevations in terms of the layer number K and the local elevation Z , which is a deviation from the top of that layer rather than an actual elevation. Longitudinal distances are given in terms of the segment number I . Mapping these segments and layers back onto the plan and elevation of the estuary will help to relate CE-QUAL-ELV2 results to specific estuary locations.

89. This mapping will also be useful in establishing the locations of inflows and outflows. CE-QUAL-ELV2 uses the following definitions:

a. Upstream inflows occur only at I = IL (left boundary) and are defined by the variables QIN , TIN , and CIN .

b. Downstream outflows occur only at I = IMAXM1 (right boundary) and are defined by the variable QOUT .

c. There must always be an inflow specified, although the associated flow may be zero.

d. Tributaries can occur in any segment from I = IL to I = IMAXM1 ; each tributary must have an associated flow, temperature, salinity, and constituent concentration.

e. Withdrawals can be located in any segment and layer, and each must have an associated flow.

90. The estuary orientation may be specified if wind speed and direction data are available and if wind stress computations are desired. The general estuary direction is determined by the angle the centerline (x-axis, positive to the right downstream) makes with north.

91. As presently coded, CE-QUAL-ELV2 will handle grid sizes up to 40 segments long and 50 layers deep. Larger sizes require changes in dimension statements. These statements are marked "DIMENS" in columns 73 to 80, and instructions for changing them are located in comment statements proceeding each dimension statement. Dimension statements are found in the main program and in subroutines TRIDAG, GRIDG, GRID, GRIDC, and GRIDX.

Time-Varying Boundary Condition Data

92. In order to model water, heat, and salinity budgets accurately through the simulation period, it is necessary to consider heat exchange at the water surface and mass, heat, and salinity advected in or out of the waterbody. Information necessary to compute these fluxes is provided to the main code through the subroutine TVDS, which is an acronym for time-varying data selector. This subroutine performs two tasks. It is called once in order to read the time-varying data. On each succeeding call, TVDS receives from the main code the current simulation time and returns to the main code the value of each of the parameters specified in its call. TVDS must be modified by the user to accommodate his particular data. Minimum data requirements are flows, temperatures,

and salinities for the upstream inflow (QIN, TIN, SAIN) and each tributary (QTRIB, TTRIB, STRIB); flow rates for each withdrawal (QWD); and the surface heat exchange parameters CSHE , SRO , and ET . If evaporation is to be computed, the dew point temperature (TD) is required; wind speed (WA) and direction (PHI) are needed if wind stress computations are to be performed. For each constituent being simulated, inflow (CIN) and tributary (CTRIB) concentrations are also required. These parameters can be supplied at any time interval (including irregular intervals). Daily or more frequent data is recommended, although in some cases steady-state simulations made with constant parameters are useful.

93. Right-hand (open) boundary values for elevation (ZR), temperature (TR), salinity (SR), and constituent concentration (CR) profiles are required and are also provided to the main code through TVDS. The profile boundary condition data may be observations and are therefore handled in a manner similar to the inflow or meteorological records. The elevations may also be observations but must be converted to the system used in the program; i.e., the elevations must be in terms of a deviation from the current top layer KT . Paragraphs 82 through 91 include a discussion of the elevation convention, and Equation 43 gives the relationship of KT and Z to an elevation relative to mean sea level.

94. The right-hand boundary elevation ZR may be computed more conveniently from the tidal amplitude and period as:

$$AZ = A \sin (2\pi t/t_0) + ZI \tag{44}$$

where A is the amplitude (one half the range), t_0 is the tidal period (usually 12.45 hours), and ZI is the initial or reference elevation.

95. The subroutine TVDS is given the simulation time (variable ELTM) which is measured in Julian days and fractions thereof. ELTM is computed in CE-QUAL-ELV2 as TMSTRT + N * DLT/86400 , where N is the current iteration number. Note that an ELTM of 1.75 means January 1, 6 p.m. and that an ELTM of 72.0 is midnight March 12/March 13. A Julian data calendar is given in Appendix H.

96. In the most general case, TVDS has available from its first call several arrays, each one of which contains time-varying data from a separate disk or tape file. In the example for the Patuxent Estuary, one array contains all the flow data and a second array contains the right-hand boundary salinity profile data. The first array contains daily data, and the second one contains data taken at irregular intervals. These files are chronological, which is essential for the TVDS algorithm. Pairs of times associated with each data file are examined sequentially and compared to ELTM , beginning with the previously located line of data. When the correct line is located, the data is extracted from the array and set equal to the proper subroutine arguments. In the example shown, both data arrays are examined in this manner before the time-varying boundary condition data are returned to the main code. The subroutine also contains error-checking routines.

97. It is important that the prospective user study the TVDS subroutine. Difference in data availability and format make it easier for the user to tailor TVDS to his data than to attempt to create a generalized TVDS able to handle all cases.

Initial Conditions, Hydraulic Parameters, and Constituent Reactions

98. Once the user has established a grid to represent the estuary and assembled time-varying data for the simulation period, initial conditions to start each simulation must be selected. These consist of a water surface elevation, temperature, and salinity corresponding to the simulation starting time. This information is coded on the IC input card.* If the water quality constituent computation option is used, initial conditions for each constituent are required. These are specified on the CC card.

99. The initial value for the temperature and for each of the constituent computations is a single number, so that homogeneous temperature and constituent fields are the initial conditions at which the simulation begins. With some reprogramming, temperature and constituent fields that

* Each of the cards or card images used as input to CE-QUAL-ELV2 is described in Appendix A of this report.

vary longitudinally and vertically may be used. This option is already programmed for the case of salinity. A single value may be used to initialize the salinity field (IC card), or a separate salinity for each active cell in the grid may be input (SI cards). Appendix A gives instructions for selecting these options. Although the simultaneous, implicit solution of the combined momentum and continuity equations establishes a consistent flow field within a few wave travel times down the estuary, the establishment of a salinity field consistent with the applied boundary conditions will take an amount of time equal to at least a residence time. For this reason, it is recommended that a longitudinally and vertically varying salinity field be used for the initial condition. There are two ways to obtain this field: (a) using observations or (b) computing a steady-state field and using the resulting salinities as the initial condition for the simulation period of interest.

100. The foregoing comments may also be applied to the initial temperature and constituent conditions. However, surface heat exchange can reduce substantially the amount of time required to damp out the initial condition and establish a temperature field consistent with the boundary conditions. The same may be said of any constituents that have a decay term on the right-hand side of the transport equation.

101. Hydraulic parameters consist of A_x , A_z , and the Chezy coefficient. These parameters are defined in Part II and discussed in Part III of this guide, and suggested values are coded in DATA statements. A_x and A_z may be varied by several orders of magnitude, with the following exception. A_z , the vertical dispersion of momentum coefficient, has the limits of the molecular value (1.5×10^{-6} m^2/s) as a minimum and a value related to the horizontal layer thickness and the time step as a maximum ($A_z < h^2/2\Delta t$). The latter limit is derived from the computation time step limit, Equation (8). The value of A_z varies spatially and temporally within these limits and is computed by the code from the Richardson number, which is the local ratio of buoyancy to shear. The value of A_z used in the computation is a function of a base value for this parameter A_{zo} and the Richardson number, so that

$$A_z = A_{zo} (1 + 10Ri)^{-\frac{1}{2}} \tag{45}$$

where Ri is the Richardson number. It is necessary to set only A_{zo}, as the code automatically keeps the value of A_z within the molecular and computational limits. A_x is presently set at a single value that is constant over time and space, but the numerical formulation allows it to vary spatially and temporally with additional coding.

102. The Chezy coefficient is also space- and time-invariant, but it can be made variable with some reprogramming. Boundary friction varies spatially with the amount of side and bottom area exposed, as well as temporally with the flow field. Chezy may be varied by a factor of four from the value given in the CE-QUAL-ELV2 DATA statement.

103. The temperature equation dispersion parameters may be varied. These parameters are D_x and D_z, the longitudinal and vertical dispersion coefficients. Like A_x, D_x is temporally and spatially invariant, and its value is controlled by the FORTRAN variable DXI. D_z varies over time and space and is also computed from the Richardson number and a base value D_{zo}. Like the momentum equation parameter A_z, D_z operates within a range from a minimum molecular value to a computational maximum of $h^2/2\Delta t$.

104. The distribution of solar radiation in the vertical is controlled by the parameters β and γ (FORTRAN BETA and GAMMA) as follows:

$$H_s(z) = (1 - \beta) H_s(z = 0)^{-\gamma z} \tag{46}$$

where

H_s	solar radiation rate at a depth z ($^{\circ}C\ m^3 \cdot s^{-1}/m$)
β	fraction of H_s absorbed at the water surface
γ	attenuation rate

Note that these parameters control only the distribution of solar radiation in the vertical and that overall surface heat exchange, including solar radiation, is summarized in the parameters CSHE and ET. If $\beta = 1$, all the solar radiation is absorbed in the current top layer (K = KT), and the value of γ is arbitrary.

Constituent Reactions

105. For each constituent specified, constituent reaction rates and internal sources and sinks need to be coded. For the user who desires only hydrodynamic and temperature simulations, this section of the user guide may be skipped. For a detailed description of the constituent transport computations, the user may refer to LARM2 Developments 1979-1980 (Edinger and Buchak 1980b).

106. The variable RR(JC,M) is the rate at which constituent JC is transferred to constituent M and may be dependent on a number of spatially and temporally varying variables, such as temperature. For the case of M = JC , RR is negative and is the linear decay rate. RR is expressed in units of s^{-1} .

107. The variable HN (I,K) is the spatially and temporally varying source and sink term for constituent JC . HN (I,K) has the units $mg\ l^{-1} \cdot m^{3} \cdot s^{-1}$. The user is required to augment this array by the amount of material added to or subtracted from constituent JC due to the reactions specified by RR .

108. The user must examine DO loop 1840 in the CE-QUAL-ELV2 code and modify it to compute RR and HN as required for his constituents. The user may also specify different sources and sinks in the surface or bottom layers by separate statements for layers K = KT or K = KB . The computation for each constituent concentration (DO loop 1820) begins with an initialization of the HN array. Then, for each location I,K the reaction rate (RR) array is computed, one FORTRAN statement for each constituent JC is transferred to or from constituent M . The remainder of the computation requires no user changes and includes the augmenting of HN by external sources and sinks, the retrieving of the transport coefficient vectors, and the call to the subroutine TRIDAG for layer-by-layer solution of the transport equation.

Input, Output, and Computer Resource Requirements

109. The input data stream is described in Appendix A, and an example data set for the Patuxent Estuary is given in Appendix B. CE-QUAL-ELV2

output for this data set is given in Appendix C. The output shown there is for IFORM = 0 , that is, compressed and shortened for 80-character-width printers. The normal form of the output is for 132-character-width printers. Although an example of this more complete output is not given, the user may quickly make his own by changing the IFORM parameter (PR card, field 1) from 0 to 1. The additional information generated by the longer output is as follows:

a. Three geometry tables: a grid showing active and inactive cells, a grid showing cell widths as augmented by CE-QUAL-ELV2 (widths assigned to inactive cells), and a elevation-area-volume table.

b. The initial conditions for Z2 , U , W , and S2 (and C2): the velocity fields are always initialized to zero at the start of the computation, Z2 and T2 are initialized through the IC card, C2 through the CC card, and S2 through the IC or SI cards.

c. Eight additional segment results for Z2 , V , W , and S2 (and C2), using the additional columns available on 11- by 14-inch paper.

110. A second type of output is available from the CE-QUAL-ELV2 code, and it is useful in postprocessing applications such as the vector plotting code VV . Cell coordinate positions are written unformatted to TAPE61, followed by Z2 , U , and W fields at times selected on the PL card (see Appendix A). This information is used by VV to plot displacement vectors on a scaled grid. However, by saving additional information on TAPE61, time series plots of other variables may be obtained, as well as statistical analyses of, for example, outflow temperatures or velocity records at a particular estuary location.

111. The code and test data as supplied requires 320,000 octal words of storage on a Controled Data Corporation 175. This storage requirement depends on both the grid size and the amount of time-varying boundary condition data stored. CE-QUAL-ELV2 requires 0.00023s of cpu* time for each time

* central processor unit.

step iteration for each active cell at a high level of compiler optimization. The Patuxent Estuary example uses 124.72s of cpu time for its 452 active cells for simulation of 1200 steps, plus 11.5s for compilation.

Patuxent Estuary Example

112. The problem here was to determine how to distribute heat from the Chalk Point Power Plant within the longitudinal-vertical structure of the Patuxent Estuary. The characteristics of the estuary and the rationale for applying CE-QUAL-ELV2 to this particular problem are presented in Part III of this report. This application presented the opportunity to verify the computations with observed velocities, temperature, and salinities.

113. This section of the report describes the steps in applying CE-QUAL-ELV2, with particular emphasis on the coding involved. This application is typical because some features of this problem could not be handled by the general boundary condition routines of CE-QUAL-ELV2. TVDS was rewritten to supply the particular time-varying boundary condition data to the main code; however, the user will find elements of many applications in this Patuxent Estuary example and is encouraged to study it.

114. Figure 3 shows the Patuxent Estuary. Cronin and Pritchard (1975) present dimensional data for the Patuxent, including average widths for each nautical mile in the longitudinal direction and for each metre in the vertical. These data were used directly in creating a finite difference representation of the Patuxent, with a Δx of one nautical mile (1852 m) and an h of one metre; therefore the preprocessors GEDA and GIN were not needed in this application. The resulting grid with IMAX = 36 and KMAX = 31 is shown in Figure 4. The segments are also mapped onto the Patuxent Estuary plan in Figure 5.

115. The level of zero depth in the tables given by Cronin and Pritchard is mean low water. The parameter DTM was assigned a value of -30 m so that the computation of EL (Equation (43)) yields 0 m when KT is 2 and Z is 0 m. EL , therefore, becomes the deviation from mean low water at the open-water (Chesapeake Bay) boundary.

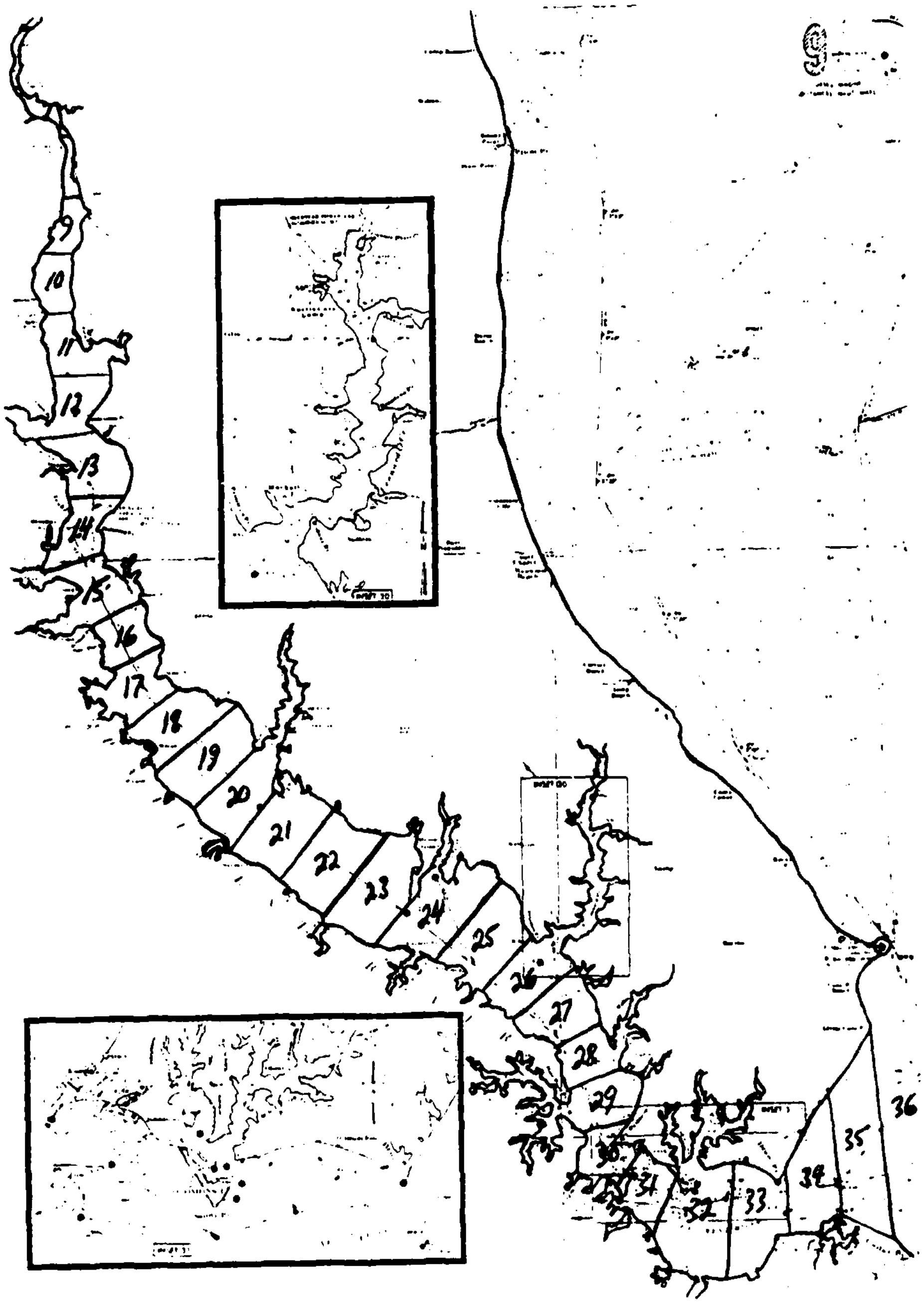

Figure 5. Patuxent Estuary map of segments

116. Following the establishment of the finite difference grid, inflows, tributaries, withdrawals, and the open-water boundary were identified and located on the grid. These are as follows:

a. Patuxent River: QIN , TIN , SAIN --upstream inflow

b. Chalk Point Power Plant intake: QWD(1) --segment 13, layer 2

c. Chalk Point Power Plant discharge: QTRIB(1) , TTRIB(1) , STRIB(1) --segment 11

c. Chesapeake Bay: ZR , TR , SR --open-water boundary.

The discharge temperature and salinity are dependent on the temperature and salinity adjacent to the intake, as well as on the amount of heat added by condenser cooling. This dependency can be handled in a number of ways; for example, the temperature and salinity at the Chalk Point Power Plant intake could be passed to TVDS through the call parameters, with TTRIB(1) and STRIB(1) set in TVDS. A simpler method was adopted. TVDS supplied the main code with the plant temperature rise, and the following two statements were added to the main code following the call to TVDS:

$$\mathrm{TTRIB(1)} = \mathrm{TTRIB(1)} + \mathrm{T2}\left(\mathrm{IWD(1)},\ \mathrm{KWD(1)}\right) \quad (47)$$

$$\mathrm{STRIB(1)} = \mathrm{S2}\left(\mathrm{IWD(1)},\ \mathrm{KWD(1)}\right) \quad (48)$$

The variable TTRIB(1) on the right-hand side of the first statement is the plant temperature rise assigned in TVDS. This code is the only modification required in CE-QUAL-ELV2 for the Patuxent Estuary application, other than the rewriting of TVDS.

117. The time-varying data consist of two tapes: observed inflows and boundary salinities and generated boundary tide. The observations of daily QIN values were recorded for July and August 1978, and five right-hand boundary salinity profiles were made for a period beginning 17 July and ending 18 September. The boundary tide was synthesized as follows using a period of 12.45 hours and an extrapolated amplitude for Solomons, Md.:

$$ZR = -0.24 * SIN(12.1122 * ELTM) + ZI \qquad (49)$$

where ZI is the initial water surface elevation relative to layer two.

118. All other boundary condition data were assumed to be constant. Note that this simulation was designed to obtain excess temperatures above a base of $20^{O}C$. These were obtained by setting the inflow and open-water boundary temperatures to $20^{O}C$ as well as the equilibrium temperature ET to $20^{O}C$. The coefficient of surface heat exchange CSHE was set to a nominal value of 120 $Btu/(ft^2 \cdot day \cdot {}^{O}F)$.

119. Initial conditions for the simulation correspond to the values of the boundary condition data for the selected starting date, Julian day 205 (24 July 1978). Initial salinities were taken from the same set of observations that produced the boundary salinities. These data permitted the salinity field to be initialized with vertical and longitudinal gradients. The initial temperature was set to $20^{O}C$ to be consistent with the excess temperature computations on the $20^{O}C$ base.

120. An initial series of simulations was made to check all the boundary condition data as supplied to the main code by TVDS and to help select a Δt . An acceptable value for Δt proved to be 747s, which was large enough for economical simulations, yet small enough to resolve the tidal cycle that drives the computation (747s is 1/60 of the tidal period of 12.45 hours). The final simulation included a long period of initialization (1080 time steps, or 9.3 days) followed by two entire tidal cycles (120 additional steps), during which results were printed every five time steps.

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APPENDIX A: INPUT DATA DESCRIPTION FOR CE-QUAL-ELV2

General

Description for each of the cards (or card images) used as input to CE-QUAL-ELV2 are presented on the following pages. There are three data types:

alphanumeric

real (may be left- or right-justified)

integer (must be right-justified)

There are eleven data fields per card:

Field	Length	Columns
0	2	1-2
1	6	3-8
2	8	9-16
3	8	17-24
4	8	25-32
5	8	33-40
6	8	41-48
7	8	49-56
8	8	57-64
9	8	65-72
10	8	73-80

This format is similar to that used in the Hydrologic Engineering Center codes.

Title Card (Required)

Title cards may be used to identify applications, simulations, or other parameters as required. These cards do not otherwise affect the computation.

CARD T1

The text input with this card appears in the header with each velocity, temperature, salinity, and constituent field snapshot, as well as in the overall header printed once for each simulation.

Field	Parameter	Value	Description
0	AID	T1	alphanumeric: card identification
1-9	TITLE(1,J), J=1,18		alphanumeric: simulation identification text

CARD T2

The text input using this card always appears in the overall simulation header and appears in the first snapshot header if IFORM = 1 .

Field	Parameter	Value	Description
0	AID	T2	alphanumeric: card identification
1-9	TITLE(2,J), J=1,18		alphanumeric: simulation identification text

CARD T3

The text input using this card always appears in the overall simulation header and appears in the first snapshot header if IFORM = 1 .

Field	Parameter	Value	Description
0	AID	T3	alphanumeric: card identification
1-9	TITLE(3,J), J=1,18		alphanumeric: simulation identification text

CARD T4

The text input using this card always appears in the overall simulation header and appears in the first snapshot header if IFORM = 1 .

Field	Parameter	Value	Description
0	AID	T4	alphanumeric: card identification
1-9	TITLE(4,J), J=1,18		alphanumeric: simulation identification text

Note: The variable TITLE is dimensioned to accommodate 18 four-character words per line. This configuration will allow CE-QUAL-ELV2 to run on machines that have at least four characters per word, such as IBM computers.

Geometry Card (Required)

CARD GE

The geometry card specifies the grid size (number of segments and layers), the length and height of the individual cells, and the location of the grid relative to a reference datum.

Field	Parameter	Value	Description
0	AID	GE	alphanumeric: card identification
1	IMAX	≥ 5	integer: number of segments
2	KMAX	≥ 4	integer: number of layers
3	DLX	+	real: Δx , cell length, m
4	HIN(1,1)	+	real: h , cell height, m
5	DTM	-,0,+	real: distance from reference datum to lower grid boundary, m

Note: CE-QUAL-ELV2 requires a grid with IMAX$\geq$5 and KMAX$\geq$4 . A typical grid has IMAX in the 10-to-36 range, KMAX in the 15-to-31 range. Grid sizes larger than 36 × 31 require changing the code's dimension statements. Instructions for doing so are given in comment cards preceding each dimension statement, each of which is marked "DIMENS" in columns 73-80.

Typical cell sizes are DLX in the 0.5-to-10-km range and HIN(1,1) in the 0.5-to-30-m range. HIN(1,1) is read as the cell height for cell I = 1 , K = 1 , which is then applied to all other cells. DLX likewise is the length of each cell.

Time Card (Required)

CARD TM

This card determines the simulation length by specifying the temporal iteration size and the number of iterations.

Field	Parameter	Value	Description
0	AID	TM	alphanumeric: card identification
1	DLT	+	real: Δt computation time step, s
2	NSTEPS	+	integer: number of iterations

Note: The simulation length is NSTEPS * DLT , in seconds. The value of DLT may be determined approximately from Equation 8. However, some experimentation may be necessary to determine a value of DLT at which the computation is stable. Also, to accurately model a tidal boundary condition with a period of 12.45 hours, a DLT of no more than 15 minutes should be used.

Plot Card (Required)

CARD PL

This card specifies whether, and at what frequency, elevation and velocity fields are saved for postprocessing by VVE, the vector plotting code.

Field	Parameter	Value	Description
0	AID	PL	alphanumeric: card identification
1	IPLOT	0	integer: no postprocessing information written to TAPE61
		1	integer: postprocessing information written to TAPE61
2	M1	0,+	integer: information is written beginning at iteration M1 ; if IPLOT = 0 , this parameter has no effect
3	M2	0,+	integer: information is written every M2 iterations; if IPLOT = 0 , this parameter has no effect

Note: If IPLOT = 1 , M1 = 960 , and M2 = 96 , for example, the elevation and velocity fields are written to TAPE61 every 96 iterations, beginning at iteration 960.

Print Card (Required)

CARD PR

This card specifies the form of the printed output, as well as the frequency of the velocity, temperature, salinity, and constituent field snapshots.

Field	Parameter	Value	Description
0	AID	PR	alphanumeric: card identification
1	IFORM	0	integer: output shortened (cell widths and volume-area-elevation table suppressed) and compressed to fit an 8½-inch page width; snapshot output is for 9 segments specified on I0 card
		1	integer: normal output using entire 132-column page width (14 inches); snapshot output is for 17 segments specified on I1 and I2 cards
2	N1	0,+	integer: snapshots are printed beginning at iteration N1
3	N2	0,+	integer: snapshots are printed every N2 iterations
4	IDIAG	0	integer: the printing of the individual terms in the momentum equation is suppressed
		1	integer: the printing of the individual terms in the momentum equation occurs according to the control parameters IFORM, N1, N2, I0, I1, and I2

Note: The parameters N1 and N2 are used like the parameters and M2 on the PL card. The segments for which elevations, velocities, temperatures, salinities, and constituents are printed in the snapshots are specified on the I0, I1, and I2 cards. Very few simulations will run with IDIAG = 1.

Segment Print Selector Cards (Required)

These cards permit the user to select which segment results are to be printed for IFORM = 0 and IFORM = 1 . Nine segments may be selected for IFORM = 0 (short form) and 17 segments for IFORM = 1 (long form).

CARD I0

Field	Parameter	Value	Description
0	AID	I0	alphanumeric: card identification
1-9	I0(I), I=1,9	1≤I0≤IMAX	integer: segment number

CARD I1

Field	Parameter	Value	Description
0	AID	I1	alphanumeric: card identification
1-10	I1(I), I=1,10	1≤I1≤IMAX	integer: segment number

CARD I2

Field	Parameter	Value	Description
0	AID	I2	alphanumeric: card identification
1-7	I1(I), I=11,17	1≤I1≤IMAX	integer: segment number

Note: If IMAX < 9 or IMAX < 17 , segment numbers may be repeated to complete the card requirements.

Initial Condition Card (Required)

CARD IC

This card defines the starting time in Julian days and the corresponding initial water surface elevation and temperature.

Field	Parameter	Value	Description
0	AID	IC	alphanumeric: card identification
1	TMSTRT	$0 \le TMSTRT \le 366$	real: simulation starting time, Julian days
2	KT	$KMAX-2 \le KT \le 2$	integer: layer number for initial water surface elevation
3	ZI	$-0.8*HIN(1,1) \le ZI \le 0.25*HIN(1,1)$	real: initial water surface elevation relative to layer KT , m (positive down)
4	TI	$0 \le TI \le 100$	real: initial temperature, C
5	SI	-1	real: initial salinity is specified on SI cards which follow BA cards
		$0 \le SI \le 40$	real: initial salinity of SI applied to all active cells, ppt

Note: KT and ZI give the water surface elevation, TI the temperature, and SI the salinity for corresponding to the time TMSTRT . Values of 3 for KT and 0.1 m for ZI , for example, place the initial water surface elevation 0.1 m below the top layer 3. The initial temperature field is isothermal at TI and isohaline at SI unless SI = -1 . The simulation begins at TMSTRT and ends at TMSTRT + NSTEPS * DLT/86400 , days.

Constituent Definition Card (Required)

CARD CD

This card specifies the number of water quality constituents to be simulated and also permits these transport computations to be turned off for a particular simulation.

Field	Parameter	Value	Description
0	AID	CD	alphanumeric: card identification
1	NC	$0 \le NC \le 10$	integer: number of constituents to be simulated; if NC > 0 , the following card, Constituent Initial Concentration Card, is required
2	ICC	0	integer: constituent transport computations suppressed
		1	integer: constituent transport computations performed

Note: The user generally will complete a hydrodynamic, temperature, and salinity simulation to his satisfaction (ICC = 0) before going on to the water quality constituent computations (ICC = 1).

Water quality reaction-iteration rates also must be specified for each water quality constituent. Since these rates are usually a function of temperature, they must be computed in CE-QUAL-ELV2. The location for the user to insert this computation is discussed in paragraph 108 of this guide.

Constituent Initial Concentration Card (Optional)

CARD CC

This card contains the initial concentration for each of the NC constituents and is required if NC > 0 .

Field	Parameter	Value	Description
0	AID	CC	alphanumeric: card identification
1-10	CI(JC) JC=1,NC	CI(JC)≥0	real: initial concentrations for each of the NC constituents

Note: CE-QUAL-ELV2 initializes the entire estuary to CI(JC) .

Meteorological Parameter Card (Required)

CARD MP

This card specifies the estuary orientation for wind stress computations and also whether evaporation is included in the water budget computations.

Field	Parameter	Value	Description
0	AID	MP	alphanumeric: card identification
1	PHIO	$0 \leq PHIO \leq 2\pi$	real: the angle between the positive x-axis (estuary centerline in the flow direction) and north, radians
2	IEVAP	0	integer: evaporation rates not computed and not included in water budget computations
		1	integer: evaporation rates computed and included in water budget computations

Note: For an estuary flowing from east to west, PHIO = $\pi/2$; the southwest to northeast, PHIO = $5\pi/4$. The convention is similar to the meteorologist's convention for wind direction.

Evaporation rates are sometimes given in the inflow record as QIN_{net} = QIN-QET . This is the case for which IEVAP should be set to 0. The contribution of evaporation to surface heat exchange is always considered, regardless of the value of IEVAP .

Tributary Card (Required)

CARD TR

This card specifies the number of estuary tributaries.

Field	Parameter	Value	Description
0	AID	TR	alphanumeric: card identification
1	NTRIB	$0 \le NTRIB \le 10$	integer: number of estuary tributaries; if NTRIB > 0 , then the following card, Tributary Location Card, is required

Note: For each tributary, an inflow and inflow temperature and salinity need to be supplied by the subroutine TVDS.

Tributary Location Card (Optional)

CARD TL

This card gives the estuary segment numbers at which tributary inflows enter and is required if NTRIB > 0 .

Field	Parameter	Value	Description
0	AID	TL	alphanumeric: card identification
1-10	ITRIB(J), J=1,NTRIB	$2 \le$ ITRIB(J) $\le$ IMAX-1	integer: segment number at which each tributary enters

Note: Tributary flows are entered in the segment specified here and at a layer that corresponds to their density, which is computed by CE-QUAL-ELV2 and which is shown on the output as KTRIB . Tributaries above the current upstream boundary segment IL on any particular time step are combined with the upstream inflow.

Withdrawal Card (Required)

CARD WD

This card specifies the number of withdrawals from the estuary.

Field	Parameter	Value	Description
0	AID	WD	alphanumeric: card identification
1	NWD	$0 \leq NWD \leq 10$	integer: number of estuary withdrawals; if NWD > 0 , then the following cards, WI and WK, are required

Note: For each withdrawal, an outflow rate needs to be supplied by subroutine TVDS.

Withdrawal Segment Card (Optional)

CARD WI

The card specifies the longitudinal location (segment) for each withdrawal and is required if NWD > 0 .

Field	Parameter	Value	Description
0	AID	WI	alphanumeric: card identification
1-10	IWD(J), J=1,NWD	2≤IWD(J) ≤IMAX-1	integer: segment number for each of NWD withdrawals

Note: The layer number for each withdrawal is specified on the WK card, which follows.

Withdrawal Layer Card (Optional)

CARD WK

This card specifies the vertical location (layer) for each withdrawal and is required if NWD > 0 .

Field	Parameter	Value	Description
0	AID	WD	alphanumeric: card identification
1-10	KWD(J), J=1,NWD	$2 \le KWD(J)$ $\le KMAX-1$	integer: layer number for each of NWD withdrawals

Note: The segment number for each withdrawal is specified on the preceding card. Each individual withdrawal must have its segment and layer specified in the same field on the WI and WK cards, respectively.

A single withdrawal spanning a number of layers may be specified by breaking it into several. Withdrawals above the current upstream boundary segment IL or above the current water surface layer KT are ignored.

Bathymetry Cards (Required)

CARDS BA

These cards contain the cell widths for each of the IMAX × KMAX cells, which are taken from cross-section drawings and represent an average value for each cell. GEDA produces widths as a function of elevation. GIN (see Appendix F) uses GEDA output and produces BA cards used by CE-QUAL-ELV2.

Field	Parameter	Value	Description
0	AID	BA	alphanumeric: card identification
1-10	B(I,K)	B(I,K)≥0	real: cell widths, m (left to right, top to bottom, filling each BA card)

Note: For the grid boundary segments (I = 1 and I = IMAX) and boundary layers (K = 1 and K = KMAX), B must be set to zero; inactive cells also are identified by setting their widths to zero.

The read statement for these cards is
READ(5,550) ((B(I,K),K=1,KMAX),I=1,IMAX).

Salinity Cards (Optional)

CARDS SI

These cards specify the initial salinity field and are required if the SI parameter on the IC card is -1.

Field	Parameter	Value	Description
0	AID	SI	alphnanumeric: card identification
1-10	SI(I,K)	$0 \le SI(I,K) \le 40$	real: initial salinities for each active cell (0 for inactive cells), ppt (left to right, top to bottom, filling each SI card)

Note: The read statement for these cards is
IF(SI.EQ.-1.) READ(5,550) ((SI(I,K),K=1,KMAX),I=1,IMAX).

TVDS Data Cards (Optional)

These cards contain the time-varying boundary condition data for the simulation. Since they are read by the user-written subroutine TVDS, no format is specified here. A discussion of the time-varying boundary condition data and TVDS can be found in paragraphs 92-97.

APPENDIX B: EXAMPLE CE-QUAL-ELV2 INPUT DATA

T1USER GUIDE EXAMPLE -- PATUXENT ESTUARY, MARYLAND -- 10/14/81
T2UPSTREAM INFLOW, POWER PLANT INTAKE AND DISCHARGE, AND TIDAL
T3BOUNDARY CONDITION
T4IFORM=0 FOR SHORTENED AND COMPRESSED OUTPUT

GE	35	31	1653.25	1.	-30.					
TM	747.	60								
PL	4	0	60							
PR	0	0	60	0						
IN	2	5	11	12	13	30	31	32	36	
I1	1	4	7	8	9	10	11	12	13	14
I2	15	16	19	22	26	30	36			
IC	205.	2	-.24	20.	-1.					
CB	1	0								
CC	5.									
MF	0.	0								
TR	1									
TL	11									
WO	1									
WI	13									
WK	2									
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	570.	430.	330.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	480.	320.	240.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	160.	150.	140.	120.	120.	110.
BA	40.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	180.	170.	160.	150.	140.
BA	130.	110.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	210.	290.	180.	170.
BA	150.	110.	110.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	330.	250.	210.
BA	[illegible]	170.	140.	110.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	410.	270.
BA	[illegible]	200.	140.	150.	110.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	530.
BA	350.	250.	200.	[illegible]	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	[illegible]	500.	720.	230.	0.	0.	0.	0.	0.	0.
BA	[illegible]	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	1120.	470.	420.	270.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	1450.	1260.	[illegible]	530.	90.	0.	0.	0.
BA	0.	0.	[illegible]	0.	0.	0.	0.	[illegible]	0.	0.
BA	0.	0.	[illegible]	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.
BA	0.	0.	0.	[illegible]	0.	0.	[illegible]	0.	0.	0.
BA	0.	0.	[illegible]	[illegible]	0.	[illegible]	0.	0.	0.	0.

BA	0.	0.	0.	0.	1370.	1100.	690.	550.	450.	370.
BA	180.	90.	90.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	1660.	1160.	680.	550.	460.
BA	400.	320.	170.	90.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	1940.	1160.	730.	550.
BA	430.	360.	280.	200.	90.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	1910.	1330.	980.
BA	770.	600.	480.	370.	270.	90.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	2230.	1850.
BA	1600.	1110.	900.	690.	500.	350.	170.	140.	110.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	2860.
BA	2530.	2280.	1600.	1150.	760.	600.	490.	430.	360.	290.
BA	150.	120.	80.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	2700.	2340.	2080.	1670.	1230.	900.	770.	490.	420.	350.
BA	300.	260.	220.	160.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	2490.	2100.	1870.	1700.	1550.	1430.	1100.	650.	530.
BA	370.	300.	270.	240.	190.	130.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	2790.	2320.	2030.	1840.	1670.	1540.	1190.	800.
BA	640.	500.	420.	370.	330.	280.	240.	130.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	3040.	2290.	1860.	1570.	1360.	1200.	1020.
BA	790.	680.	630.	580.	520.	470.	410.	350.	270.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	2870.	2070.	1660.	1420.	1250.	1120.
BA	960.	770.	670.	600.	550.	500.	450.	370.	310.	250.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	2540.	1980.	1670.	1520.	1390.
BA	1290.	1160.	950.	800.	650.	530.	440.	370.	290.	230.
BA	200.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	2640.	2250.	2030.	1910.
BA	1790.	1650.	1470.	1180.	880.	660.	530.	450.	390.	330.
BA	290.	270.	170.	160.	160.	140.	120.	70.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	2140.	1840.	1660.
BA	1550.	1450.	1320.	1160.	910.	670.	550.	490.	470.	430.
BA	390.	360.	270.	170.	160.	160.	140.	120.	70.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	1930.	1670.
BA	1570.	1420.	1330.	1250.	1200.	1140.	1080.	1030.	820.	670.
BA	600.	530.	450.	340.	230.	220.	190.	180.	170.	150.
BA	140.	120.	80.	0.	0.	0.	0.	0.	0.	1620.
BA	1390.	1350.	1250.	1200.	1150.	1120.	1090.	1040.	1010.	810.
BA	680.	620.	550.	490.	460.	430.	410.	380.	360.	340.
BA	320.	290.	260.	210.	130.	120.	110.	100.	0.	0.
BA	1050.	790.	710.	660.	640.	590.	570.	550.	520.	510.
BA	480.	470.	450.	420.	370.	360.	350.	340.	330.	320.
BA	310.	300.	280.	260.	260.	240.	210.	190.	170.	0.
BA	0.	1690.	1390.	1220.	1110.	1030.	960.	900.	850.	800.
BA	770.	750.	730.	700.	680.	630.	620.	610.	590.	590.
BA	440.	320.	300.	270.	260.	250.	110.	90.	80.	70.
BA	0.	0.	2900.	2520.	2300.	2130.	2000.	1880.	1760.	1660.
BA	1550.	1340.	1180.	1050.	920.	850.	800.	750.	690.	630.
BA	530.	310.	190.	170.	150.	140.	130.	0.	0.	0.
BA	0.	0.	0.	2610.	2300.	2070.	1920.	1820.	1730.	1650.

BA	1560.	1480.	1280.	1130.	1000.	890.	820.	780.	510.	330.
BA	260.	130.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	2660.	2320.	1980.	1770.	1590.	1490.
BA	1390.	1280.	1050.	970.	920.	870.	820.	770.	690.	230.
BA	90.	70.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	5300.	4790.	4430.	4160.	3870.
BA	3610.	3330.	2720.	1710.	930.	430.	390.	350.	310.	240.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BA	0.	0.	0.	0.	0.	0.				
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.4	0.4	0.4	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.4	0.4	0.4	0.7	0.7	0.7
SI	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	1.3	1.3	1.3	1.4	1.4
SI	1.4	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	1.5	1.6	1.7	1.7
SI	1.7	1.7	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	2.2	2.5
SI	2.7	2.7	2.7	2.7	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	2.6
SI	2.6	2.9	2.9	2.9	2.9	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5
SI	4.0	4.0	4.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	4.5	4.8	4.8	4.8	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	4.9	5.0	5.3	5.3	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	5.5	5.8	5.8	5.8	5.8	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	5.9	6.1	6.1	6.1	6.1	6.1	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	6.3	6.6	7.2	7.5	7.5	7.6
SI	7.8	7.9	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	6.3	6.6	7.2	7.5	7.6
SI	7.7	7.8	7.9	8.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	6.5	6.8	7.2	7.5
SI	7.6	7.8	7.9	8.0	8.1	0.0	0.0	0.0	0.0	0.0

SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.9	7.1	7.7
SI	8.4	8.4	8.4	8.4	8.5	8.6	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.4	7.4
SI	7.7	8.4	8.4	8.5	8.5	8.6	8.7	8.7	8.7	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.5
SI	7.5	7.7	8.4	8.4	8.6	8.6	8.7	8.8	8.8	8.8
SI	8.8	8.8	8.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	7.6	7.7	7.8	8.4	8.4	8.8	8.8	8.8	8.9	8.9
SI	8.9	8.9	8.9	8.9	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	7.7	7.8	7.8	8.4	8.4	9.0	9.2	9.3	9.3
SI	9.3	9.3	9.3	9.3	9.3	9.3	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	7.7	7.8	7.9	8.4	8.5	9.2	9.4	9.5
SI	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	7.8	7.8	7.9	8.4	8.6	9.6	9.6
SI	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	8.0	8.1	8.2	8.4	8.6	9.6
SI	9.6	9.6	9.6	9.8	9.9	9.9	9.9	9.9	9.9	9.9
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	8.2	8.3	8.4	8.5	8.6
SI	9.7	9.7	9.7	9.8	9.9	10.0	10.0	10.1	10.2	10.4
SI	10.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	8.6	8.7	8.8	9.0
SI	9.1	9.8	9.9	9.9	10.0	10.1	10.2	10.3	10.4	10.5
SI	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.6	8.7	8.8
SI	9.0	9.2	9.9	10.0	10.0	10.1	10.2	10.3	10.4	10.5
SI	10.6	10.7	10.7	10.7	10.7	10.7	10.7	10.7	10.7	0.0
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.4	9.6
SI	9.8	9.8	9.9	10.0	10.0	10.1	10.1	10.2	10.3	10.5
SI	10.6	10.7	10.8	10.8	10.8	10.8	10.8	10.8	10.8	10.8
SI	10.8	10.8	10.8	0.0	0.0	0.0	0.0	0.0	0.0	9.8
SI	9.9	10.0	10.0	10.0	10.0	10.0	10.1	10.1	10.2	10.3
SI	10.6	10.6	10.8	10.9	10.9	10.9	10.9	10.9	10.9	10.9
SI	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	0.0	0.0
SI	10.1	10.1	10.1	10.2	10.2	10.2	10.3	10.4	10.5	10.5
SI	10.6	10.8	10.8	10.9	11.0	11.0	11.0	11.0	11.0	11.0
SI	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	0.0
SI	0.0	10.2	10.2	10.3	10.3	10.3	10.3	10.4	10.5	10.6
SI	10.6	10.7	10.9	10.9	11.0	11.1	11.1	11.1	11.1	11.1
SI	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1
SI	0.0	0.0	10.3	10.4	10.4	10.4	10.4	10.4	10.5	10.6
SI	10.7	10.7	10.8	11.0	11.0	11.0	11.1	11.1	11.1	11.1
SI	11.1	11.1	11.1	11.1	11.1	11.1	11.1	0.0	0.0	0.0
SI	0.0	0.0	0.0	10.3	10.4	10.4	10.4	10.4	10.5	10.6
SI	10.7	10.8	10.9	11.0	11.1	11.2	11.3	11.4	11.4	11.4
SI	11.4	11.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	10.3	10.4	10.4	10.4	10.5	10.7
SI	10.8	10.9	11.0	11.0	11.1	11.2	11.3	11.3	11.4	11.4
SI	11.4	11.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SI	0.0	0.0	0.0	0.0	0.0	10.3	10.4	10.4	10.4	10.5
SI	10.7	10.8	10.9	11.0	11.0	11.1	11.2	11.3	11.3	11.4
SI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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SI   0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
SI   0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
SI   0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
SI   0.0      0.0      0.0      0.0      0.0      0.0
G 78.    182.     178.
G 78.    183.     187.
G 78.    184.     565.
G 78.    185.     1810
G 78.    186.     1450.
G 78.    187.     1010.
G 78.    188.     261.
G 78.    189.     196.
G 78.    190.     177.
G 78.    191.     177.
G 78.    192.     205.
G 78.    193.     152.
G 78.    194.     136.
G 78.    195.     134.
G 78.    196.     139.
G 78.    197.     145.
G 78.    198.     163.
G 78.    199.     144.
G 78.    200.     235.
G 78.    201.     250.
G 78.    202.     148.
G 78.    203.     116.
G 78.    204.     112.
G 78.    205.     106.
G 78.    206.     107.
G 78.    207.     200.
G 78.    208.     132.
G 78.    209.     129.
G 78.    210.     146.
G 78.    211.     115.
G 78.    212.     227.
G 78.    213.     988.
G 78.    214.     986.
G 78.    215.     525.
G 78.    216.     220.
G 78.    217.     436.
G 78.    218.     423.
G 78.    219.     250.
G 78.    220.     321.
G 78.    221.     227.
G 78.    222.     229.
G 78.    223.     223.
G 78.    224.     539.
G 78.    225.     703.
G 78.    226.     455.
G 78.    227.     232.
G 78.    228.     194.
G 78.    229.     162.
G 78.    230.     143.
G 78.    231.     130.
G 78.    232.     124.
G 78.    233.     118.
G 78.    234.     114.
G 78.    235.     107.
G 78.    236.     103.
G 78.    237.     102.
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G	78.	238.	104.							
G	78.	239.	105.							
G	78.	240.	169.							
G	78.	241.	152.							
G	78.	242.	123.							
G	78.	243.	363.							
S	78.	198.	10.3	10.4	10.4	10.4	10.5	10.7	10.8	10.9
S	78.	198.	11.0	11.0	11.1	11.2	11.3	11.3	11.4	
S	78.	212.	10.5	10.5	10.5	10.5	10.6	10.8	10.9	11.0
S	78.	212.	11.0	11.0	11.1	11.2	11.3	11.4	11.5	
S	78.	226.	10.6	10.6	10.6	10.6	10.7	10.8	10.9	11.0
S	78.	226.	11.0	11.0	11.1	11.2	11.3	11.4	11.5	
S	78.	240.	10.7	10.7	10.7	10.7	10.8	10.9	10.9	11.0
S	78.	240.	11.0	11.0	11.1	11.2	11.3	11.4	11.5	
S	78.	251.	10.8	10.8	10.8	10.8	10.9	10.9	10.9	11.0
S	78.	251.	11.0	11.0	11.1	11.2	11.3	11.4	11.5	

APPENDIX C: EXAMPLE CE-QUAL-ELV2 OUTPUT DATA

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L A E M -- LATERALLY AVERAGED ESTUARY MODEL

VERSION TWO -- OCTOBER 1981 -- WAYNE, PENNSYLVANIA

USER GUIDE EXAMPLE -- PATUXENT ESTUARY, MARYLAND -- 10/14/81
UPSTREAM INFLOW, POWER PLANT INTAKE AND DISCHARGE, AND TIDAL
BOUNDARY CONDITION
IFORM=0 FOR SHORTENED AND COMPRESSED OUTPUT


CONTROL PARAMETERS

IMAX= 36  KMAX= 31  DLX= 1853.25 M  HIN(1,1)= 1.00 M  DTM= -30.00 M
DLT=  747.00 S  NSTEPS=        60
IPLOT=0  M1=          0  M2=        60
IFORM=0  N1=          0  N2=        60  IDIAG=0
ID=   2   8  11  12  13  30  31  32  36
I1=   1   4   7   8   9  10  11  12  13  14
I1 (I2 CARD)=  15  16  19  22  26  30  36
TMSTRT=  205.00 DAYS  KT=  2  ZI=  -.2400 M  TI=20.00 C  SI=-1.00 PPT
NC=    1  ICC=     0 WITH INITIAL VALUES OF     5.000
PHI0=    0.00 RAD  IEVAP=0
NTRIB=    1 AT I=   11
NWD=     1 AT I=   13
      AND AT K=    2


INTERNALLY-SET PARAMETERS

AX= .1500E-03 M*M/S
AZMIN= .1400E-06 M*M/S
AZ0= .2000E-03 M*M/S
AZMAX= .0689E-03 M*M/S
BETA=     1.0000
CHZY=    35.0000 SQRT(M)/S
DXI= .1000E+02 M*M/S
DZMIN= .1400E-06 M*M/S
DZ0= .2000E-03 M*M/S
DZMAX= .0689E-03 M*M/S
GAMMA=      .4900 1/M

NWAC=  452  NLC=   32
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LAEM 10/81 WES: USER GUIDE EXAMPLE -- PATUXENT ESTUARY, MARYLAND -- 10/14/81

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ELTM= 205.51875 DAYS (N=     60)  1978
GIN=   3.00 CMS  TIN=    20.0 C  SAIN=     0.0 PPT
GOUT=  -2628.57 CMS
QTRIB (CMS)=  46.90
TTRIB (C)=     26.7
STRIB (PPT)=      6.1
ITRIB=            11
KTRIB=             2
Q-D (CMS)=  46.90
I-D=             13
K-D=              2
CSHE=  .58E-05 M/S  SRO= 0.       (C M*M*M)/(S M*M)  ET=     20.0 C
TD= 20.0 C  WA=  0.0 M/S  PHI= 3.14 RAD
ZR= -.4554 M
RATIO OF SPACE TO TIME INTEGRATED VOLUME= 100.246 PER CENT

IL=    2  KT=    2  EL=    .46 M
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ZZ (M)

2	8	11	12	13	30	31	32	36
-.4544	-.4526	-.4606	-.4616	-.4621	-.4647	-.4635	-.4619	-.4584

U (M/S)

	2	8	11	12	13	30	31	32	36
2	-.0309	-.0908	-.0955	-.0916	-.1144	-.0838	-.0795	-.0830	0.0000
3	-.0253	-.1075	-.0608	-.0712	-.0797	-.0981	-.0784	-.0824	0.0000
4	-.0228	-.1235	-.0646	-.0744	-.1019	-.1189	-.0873	-.0889	0.0000
5	0.0000	-.1168	-.0522	-.0608	-.0996	-.1381	-.0961	-.0977	0.0000
6	0.0000	-.1290	0.0000	-.0476	-.0882	-.1426	-.1057	-.1058	0.0000
7	0.0000	0.0000	0.0000	0.0000	-.0590	-.1582	-.1104	-.1107	0.0000
8	0.0000	0.0000	0.0000	0.0000	0.0000	-.1676	-.1168	-.1098	0.0000
9	0.0000	0.0000	0.0000	0.0000	0.0000	-.1640	-.1140	-.1008	0.0000
10	0.0000	0.0000	0.0000	0.0000	0.0000	-.1938	-.1032	-.0661	0.0000
11	0.0000	0.0000	0.0000	0.0000	0.0000	-.1793	-.1014	-.0864	0.0000
12	0.0000	0.0000	0.0000	0.0000	0.0000	-.1943	-.1049	-.0899	0.0000
13	0.0000	0.0000	0.0000	0.0000	0.0000	-.1758	-.1055	-.0935	0.0000
14	0.0000	0.0000	0.0000	0.0000	0.0000	-.1745	-.1180	-.1086	0.0000
15	0.0000	0.0000	0.0000	0.0000	0.0000	-.1584	-.1243	-.1119	0.0000
16	0.0000	0.0000	0.0000	0.0000	0.0000	-.1897	-.1297	-.0836	0.0000
17	0.0000	0.0000	0.0000	0.0000	0.0000	-.2150	-.1296	-.0718	0.0000
18	0.0000	0.0000	0.0000	0.0000	0.0000	-.2046	-.1224	-.0718	0.0000
19	0.0000	0.0000	0.0000	0.0000	0.0000	-.1907	-.1052	-.0623	0.0000
20	0.0000	0.0000	0.0000	0.0000	0.0000	-.1306	-.0749	-.0562	0.0000
21	0.0000	0.0000	0.0000	0.0000	0.0000	-.1068	-.0537	0.0000	0.0000
22	0.0000	0.0000	0.0000	0.0000	0.0000	-.1209	-.0723	0.0000	0.0000
23	0.0000	0.0000	0.0000	0.0000	0.0000	-.1231	-.0904	0.0000	0.0000
24	0.0000	0.0000	0.0000	0.0000	0.0000	-.1362	-.0918	0.0000	0.0000
25	0.0000	0.0000	0.0000	0.0000	0.0000	-.1350	-.0899	0.0000	0.0000
26	0.0000	0.0000	0.0000	0.0000	0.0000	-.0847	-.0646	0.0000	0.0000
27	0.0000	0.0000	0.0000	0.0000	0.0000	-.0801	0.0000	0.0000	0.0000
28	0.0000	0.0000	0.0000	0.0000	0.0000	-.0784	0.0000	0.0000	0.0000
29	0.0000	0.0000	0.0000	0.0000	0.0000	-.0678	0.0000	0.0000	0.0000
30	0.0000	0.0000	0.0000	0.0000	0.0000	-.0350	0.0000	0.0000	0.0000

USER GUIDE EXAMPLE -- PATUXENT ESTUARY, MARYLAND -- 10/14/81
ELTM= 205.51875 DAYS

W (MM/S)

	2	8	11	12	13	30	31	32	36
2	-.0186	.0128	-.0001	-.0266	-.0347	-.0233	.0015	-.0002	0.0000
3	-.0098	.0402	.0048	-.0186	-.0484	-.0405	.0209	.0099	0.0000
4	0.0000	.0497	.0031	-.0234	-.0646	-.0582	.0414	.0207	0.0000
5	0.0000	.0548	0.0000	-.0239	-.0552	-.0770	.0620	.0332	0.0000
6	0.0000	.0608	0.0000	0.0000	-.0367	-.1010	.0890	.0470	0.0000
7	0.0000	.0252	0.0000	0.0000	0.0000	-.1303	.1150	.0629	0.0000
8	0.0000	0.0000	0.0000	0.0000	0.0000	-.1519	.1421	.0770	0.0000
9	0.0000	0.0000	0.0000	0.0000	0.0000	-.1749	.1692	.0885	0.0000
10	0.0000	0.0000	0.0000	0.0000	0.0000	-.1722	.1735	.1017	0.0000
11	0.0000	0.0000	0.0000	0.0000	0.0000	-.1538	.1734	.1191	0.0000
12	0.0000	0.0000	0.0000	0.0000	0.0000	-.1228	.1659	.1358	0.0000
13	0.0000	0.0000	0.0000	0.0000	0.0000	-.1011	.1630	.1546	0.0000
14	0.0000	0.0000	0.0000	0.0000	0.0000	-.0755	.1652	.1739	0.0000
15	0.0000	0.0000	0.0000	0.0000	0.0000	-.0592	.1806	.1855	0.0000
16	0.0000	0.0000	0.0000	0.0000	0.0000	-.0348	.1874	.1788	0.0000
17	0.0000	0.0000	0.0000	0.0000	0.0000	.0116	.1760	.1599	0.0000
18	0.0000	0.0000	0.0000	0.0000	0.0000	.0555	.1635	.1393	0.0000
19	0.0000	0.0000	0.0000	0.0000	0.0000	.0964	.1439	.1246	0.0000
20	0.0000	0.0000	0.0000	0.0000	0.0000	.1023	.1458	.1421	0.0000
21	0.0000	0.0000	0.0000	0.0000	0.0000	.0618	.1728	.1871	0.0000
22	0.0000	0.0000	0.0000	0.0000	0.0000	.0606	.1775	.2346	0.0000
23	0.0000	0.0000	0.0000	0.0000	0.0000	.0489	.1590	.1663	0.0000
24	0.0000	0.0000	0.0000	0.0000	0.0000	.0488	.1336	.1126	0.0000
25	0.0000	0.0000	0.0000	0.0000	0.0000	.0544	.1026	.0499	0.0000
26	0.0000	0.0000	0.0000	0.0000	0.0000	.0485	.1173	0.0000	0.0000
27	0.0000	0.0000	0.0000	0.0000	0.0000	.0349	.1356	0.0000	0.0000
28	0.0000	0.0000	0.0000	0.0000	0.0000	.0192	.0848	0.0000	0.0000
29	0.0000	0.0000	0.0000	0.0000	0.0000	.0056	.0503	0.0000	0.0000

USER GUIDE EXAMPLE -- PATUXENT ESTUARY, MARYLAND -- 10/14/81
ELTM= 205.51875 DAYS

T2 (C)

	2	8	11	12	13	30	31	32	36
2	20.0	20.2	21.6	20.3	20.1	20.0	20.0	20.0	20.0
3	20.0	20.0	20.4	20.3	20.1	20.0	20.0	20.0	20.0
4	20.0	20.0	20.1	20.1	20.0	20.0	20.0	20.0	20.0
5	0.0	20.0	20.1	20.0	20.0	20.0	20.0	20.0	20.0
6	0.0	20.0	0.0	20.0	20.0	20.0	20.0	20.0	20.0
7	0.0	20.0	0.0	0.0	20.0	20.0	20.0	20.0	20.0
8	0.0	20.0	0.0	0.0	0.0	20.0	20.0	20.0	20.0
9	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	20.0
10	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	20.0
11	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	20.0
12	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	20.0
13	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	20.0
14	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	20.0
15	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	20.0
16	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	20.0
17	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	0.0
18	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	0.0
19	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	0.0
20	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	0.0
21	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	0.0
22	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	0.0
23	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	0.0
24	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	0.0
25	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	0.0
26	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	0.0
27	0.0	0.0	0.0	0.0	0.0	20.0	20.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	20.0	20.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	20.0	20.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	20.0	20.0	0.0	0.0

USER GUIDE EXAMPLE -- PATUXENT ESTUARY, MARYLAND -- 10/14/81
ELTM= 205.51875 DAYS

S2 (PPT)

	4	8	11	12	13	30	31	32	35
2	.3	4.2	5.4	5.7	6.1	10.0	10.2	10.3	10.3
3	.3		5.3	5.7	6.1	10.0	10.2	10.3	10.4
4	.3		5.4	6.0	6.5	10.1	10.2	10.3	10.4
5	0.0	3.4	5.4	6.2	6.8	10.1	10.2	10.3	10.4
6	0.0	3.3	0.0	6.4	7.1	10.2	10.3	10.4	10.5
7	0.0	3.2	0.0	0.0	7.1	10.3	10.3	10.4	10.7
8	0.0	3.1	0.0	0.0	0.0	10.4	10.4	10.5	10.8
9	0.0	0.0	0.0	0.0	0.0	10.5	10.5	10.6	10.9
10	0.0	0.0	0.0	0.0	0.0	10.6	10.5	10.6	11.0
11	0.0	0.0	0.0	0.0	0.0	10.6	10.6	10.7	11.0
12	0.0	0.0	0.0	0.0	0.0	10.7	10.6	10.8	11.1
13	0.0	0.0	0.0	0.0	0.0	10.8	10.7	10.9	11.2
14	0.0	0.0	0.0	0.0	0.0	10.8	10.8	10.9	11.3
15	0.0	0.0	0.0	0.0	0.0	10.9	10.9	11.0	11.3
16	0.0	0.0	0.0	0.0	0.0	10.9	10.9	11.0	11.4
17	0.0	0.0	0.0	0.0	0.0	11.0	11.0	11.1	0.0
18	0.0	0.0	0.0	0.0	0.0	11.0	11.0	11.1	0.0
19	0.0	0.0	0.0	0.0	0.0	11.0	11.0	11.1	0.0
20	0.0	0.0	0.0	0.0	0.0	11.0	11.0	11.1	0.0
21	0.0	0.0	0.0	0.0	0.0	11.0	11.0	11.1	0.0
22	0.0	0.0	0.0	0.0	0.0	11.0	11.1	11.1	0.0
23	0.0	0.0	0.0	0.0	0.0	11.0	11.1	11.1	0.0
24	0.0	0.0	0.0	0.0	0.0	11.0	11.1	11.1	0.0
25	0.0	0.0	0.0	0.0	0.0	11.0	11.1	11.1	0.0
26	0.0	0.0	0.0	0.0	0.0	11.0	11.1	11.1	0.0
27	0.0	0.0	0.0	0.0	0.0	11.0	11.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	11.0	11.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	11.0	11.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	11.0	11.0	0.0	0.0

APPENDIX D: ERROR MESSAGES FOR CE-QUAL-ELV2

General

CE-QUAL-ELV2 identifies two types of errors: (1) fatal errors which stop the computation, (2) non-fatal errors which permit the computation to continue. The messages written on the detection of these errors are discussed below.

1. "FATAL INPUT ERROR"

This error occurs when the input stream is missing a required card or the deck is out of order (see Appendix A). The code checks the card identifiers (field 0) and stops the computation when an error is detected. An input error also occurs when too few or too many tributaries or withdrawals are specified. In both cases, CE-QUAL-ELV2 writes an error message, repeats the offending card, and stops the computation.

2. "NON-FATAL ERROR: AZ0 EXCEEDS AZMAX"
   and
   "NON-FATAL ERROR: DZ0 EXCEEDS DZMAX"

The variables AZ0 and DZ0 are set by the user and represent base values of vertical dispersion coefficients for the x-momentum and for temperature, salinity, and constituent equations. These variables are used with the Richardson number to compute spatially and temporally varying dispersion coefficients. The upper limits on the latter, however, are values based on the horizontal layer thickness h and the time step Δt (see Appendix E). The values of AZ0 and DZ0 should always be less than these maximum values. This error is not serious enough to stop the computation, however, since the code always insures that the computed values of AZ and DZ do not exceed their computational limits.

3. "FATAL TVDS ERROR AT _ DAYS"

This error message should be coded in the TVDS subroutine to detect the case where CE-QUAL-ELV2 asks for time-varying data that is not available--for example, if a simulation were set up for a 370-day run, with only one year of data available. The illegal time request is printed with the error message and the computation is stopped.

APPENDIX E: GLOSSARY OF IMPORTANT FORTRAN VARIABLES

The glossary lists only those FORTRAN variables found on the CE-QUAL-ELV2 printed output, in the FORTRAN statements labelled CHANGE, in the TVDS arguments, and in this report. Those variables discussed in the card descriptions (Appendix A) are not repeated here.

A: vector containing subdiagonal (backward) coefficients for the tridiagonal algorithm solutions of Z, T, and C

ADMX: ADvection of Momentum in the X-direction: $\frac{\partial}{\partial x}(U^2Bh)$, m^3/s^2

ADMZ: ADvection of Momentum in the Z-direction: $(u_b w_b b)_{k-\frac{1}{2}}$, m^3/s^2

AR: waterbody area by layer, m (vector)

AS: A Storage: array for storing A vectors for use in constituent concentration computations

AX: A_x, m^2/s: x-direction momentum dispersion coefficient

AZ: A_z, m^2/s: dispersion coefficient, z-direction, x-momentum equation (array)

AZMAX: maximum permitted value of A_z $(0.85 \cdot \frac{1}{2} \cdot h^2/\Delta t)$, m^2/s

AZMIN: minimum value of A_z (molecular value), m^2/s (scalar)

AZ0: base value for A_z computation, m^2/s (scalar)

B: B, m: cell width (array)

BETA: β, fraction of incident solar radiation absorbed at the water surface

BH1: B·h, m^2: cross-sectional area of a cell at the previous time step

BH2: B·h, m^2: cross-sectional area of a cell at the current time step

C: vector containing superdiagonal (forward) coefficients for the tridiagonal algorithm solutions of Z and T

CHZY: CHeZY resistance coefficient, $m^{\frac{1}{2}}/s$

CIN: upstream inflow constituent concentration, mg l^{-1} (vector)

CR: Constituent Right, mg l^{-1}: right-hand (open-water) boundary constituent profile (array)

CS: C Storage: array for storing C vectors for use in constituent concentration computations

CSHE: k, kinematic coefficient of surface heat exchange, mg s^{-1}

CTRIB: array containing tributary constituent concentrations, mg l^{-1}

CZ: C*, wind resistance coefficient (varies with wind speed)

C1: array containing constituent concentrations at the previous time step, mg l^{-1}

C2: array containing constituent concentrations at the current time step, mg l^{-1}

D: vector containing right-hand side for the tridiagonal algorithm solution of Z and T

DG: Density Gradient: $\frac{1}{\rho}\frac{\partial}{\partial x}$ (PBh), m^3/s^2 (This gradient term in the x-momentum equation includes only that portion of hydrostatic pressure due to density differences and does not include that portion due to changes in elevation.)

DM: Diffusion of Momentum: $A_x \frac{\partial}{\partial x}$ (UBh), m^3/s^2

DX: D_x, m^2/s: dispersion coefficient, x-direction, heat and constituent balance equation (array)

DXI: base value of DX, m^2/s (scalar)

DZ: D_z, m^2/s: dispersion coefficient, z-direction, heat and constituent balance equation (array)

DZMAX: maximum permitted value of D_z $(0.85\cdot\frac{1}{2}\cdot h^2/\Delta t)$, m^2/s (scalar)

DZMIN: minimum value of D_z (molecular value), m^2/s (scalar)

DZO: base value of DZ computation, m^2/s (scalar)

EL: water surface elevation, m

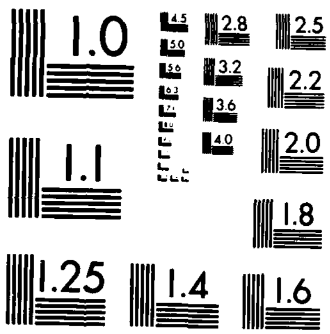
ELTM: ELapsed TiMe, days: sum of NΔt and TMSTRT, time since beginning of calendar year

ET: E, equilibrium temperature of surface heat exchange, C

G: g, m/s^2: gravitational constant

AD-A125 713 USER GUIDE FOR CE-QUAL-ELV2: A LONGITUDINAL-VERTICAL TIME-VARYING ESTUARI..(U) EDINGER (J E) ASSOCIATES INC WAYNE PA E M BUCHAK ET AL. DEC 82 WES/IR/EL-82-1 2/2

UNCLASSIFIED DACW39-81-M-2788 F/G 9/2 NL


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

GAMMA: γ, m^{-1}: exponential decay constant for absorption of solar radiation with depth

HIN: H INitial, m; retains original value of h (layer thickness) for computation of varying h in top layer of cells from Z and also used in reinitializing a layer of cells immediately after a layer has been added or subtracted due to estuarine volume changes

HN: Hn, $^{o}C\ m^3 s^{-1}$ or $mg\ l^{-1} m^3 s^{-1}$: net rate of heat or constituent addition, source term for heat balance or constituent equation

HPG: Horizontal Pressure Gradient: $\frac{1}{\rho}\frac{\partial}{\partial x}$ (PBh), m^3/s^2

H1: h, m: vertical slice thickness at the current or previous time step (Only the top layer of cells has varying thickness due to elevation changes; however, the location of the top layer of cells may vary due to extreme elevation changes.)

H2: h, m: vertical slice thickness at the current or previous time step

I: counter for sweeping across (longitudinally) the estuary grid in x-direction DO-loops

IB: I Begin: variable locating the first active cell in each line for use in the tridiagonal solution of the heat balance equation; IB is found in an initial program step and stored in the array LC

IE: I End: variable locating the last active cell in each line for use in the tridiagonal solution of the heat balance equation; IE is found in an initial program step and stored in the array LC

IFLAG: logic flag for subroutine TVDS; if IFLAG = 0 , instruct TVDS to read time-varying boundary condition data; if IFLAG = 1 , instruct TVDS to provide boundary condition data for a particular time; if IFLAG = -1 , TVDS error and computation stopped

IFORM: control variable; if IFORM = 0 , terminal-oriented display is produced (80-character width); if IFORM = 1 , full width (132-character) display is produced

IL: I Left: I-index of current left-hand segment

IMAX: I MAXimum: I-index of the rightmost segment

IMAXM1: I MAXimum Minus 1: I-index of the next-to-rightmost segment

IMAXM2: I MAXimum Minus 2: I-index of the second-to-rightmost segment

ISC: Integer Segment Coordinates: vector containing K-index of bottom active cell of each segment

IY: Integer Year: year number

JC: constituent counter

K: counter for sweeping down (vertically) the estuary grid in z-direction DO-loops

KB: K Bottom: K-index of bottom active cell in a particular segment; KB is found in array ISC

KMAX: K-MAXimum: K-index of the bottom layer of cells

KMAXM1: K-MAXimum Minus 1: K-index of the next to bottom layer of cells

KOUT: computed layer number at which each tributary enters the LAEM2 grid (vector)

KT: K-Top: K-index of the currently active top layer of cells

L: integer variable denoting active cells (L-1) or inactive cells (L = 0)

LA: λ

LC: Layer Coordinates: array containing (1) layer number (K), (2) IB, and (3) IE for each active layer of cells

MNAC: Maximum Number of Active Cells (This variable may be used to more accurately estimate the amount of computer time required by a simulation, see paragraphs 109-111.)

N: counter for time steps

NLC: Number of Layer Coordinates (This variable is equal to the number of separate layers in a grid and may be used to set the first dimension in the array LC .)

P: pressure, $N/m^2 = kg \cdot m/s^{-2}/m^2$

PO: P_0

PHI: ϕ, degrees: wind direction

QET: Q Evaporation Total, m^3/s: evaporation rate

QIN: upstream inflow rate, $m^3 s^{-1}$

QOUT: vector containing downstream outflow rates

QTRIB: Q TRIButary, m^3/s: vector containing tributary inflow rates

QWD: Q WithDrawal, m^3/s: vector containing withdrawal rates

RHO: ρ, kg/m^3: density of water

RHOA: ρ_a, kg/m^3: density of air (used in wind stress computation and assumed constant at 1.25 kg/m^3)

RR: constituent reaction rate, s^{-1}

S: Stress: $(\tau_z b)_{k+\frac{1}{2}}$, m^3/s

SAIN: upstream inflow salinity, ppt

SR: Salinity Right, ppt: right-hand (open-water) boundary temperature salinity profile (vector)

SRO: Solar Radiation, $(^{\circ}C \cdot m^3/s)/m^2$

STRIB: Salinity of TRIButary, ppt: vector containing tributary salinities

S1: S, ppt: array containing salinities at the previous time step

S2: S, ppt: array containing salinities at the current time step

T: vector containing the results of the layer-by-layer solution of the implicit temperature equation

TAPE5: read device

TAPE6: write device

TAPE61: binary write device

TD: Td, D: dew point temperature, $^{\circ}C$

TIN: upstream inflow temperature, $^{\circ}C$

TMSTRT: time of year in Julian days when simulation starts, read in as days, converted internally to seconds

TR: Temperature Right, $^{\circ}C$: right-hand (open-water) boundary temperature profile (vector)

TTRIB: Temperature of TRIButary, $^{\circ}C$: vector containing tributary temperature

T1: T, ^{o}C: array containing temperatures at the previous time step

T2; T, ^{o}C: array containing temperatures at the current time step

U: U, m/s: array containing x-direction velocity components

UM: cell average x-direction velocity, m/s^{-1}

V: vector containing main diagonal (centered) coefficients for the tridiagonal algorithm solution of Z and T

VOL: estuary volume based on initial volume and sum of inflows and outflows, m^3

VOLE: cumulative waterbody volume by layer, m^3 (vector)

VOLP: estuary volume, m^3 (computed from geometry and water surface elevations)

VRATIO: ratio of VOLP to VOL, %

VS: V Storage: array for storing V vectors for use in constituents concentration computations

W: w_b, m/s: array containing vertical velocities

WA: W_a, m/s: wind speed

WKT: vector containing a corrected vertical velocity for the top layer of cells that permits a perfect water balance in that layer

WM: cell average z-direction velocity, m/s^{-1}

ZR: Z Right, m: right-hand (open-water) boundary water surface deviation

Z1: Z, m: vector containing deviation of water surface from datum (top of active layer of cells) for each column, positive downwards (The "1" denotes a particular time level.)

Z2: Z, m: vector containing deviation of water surface from datum (top of active layer of cells) for each column, positive downwards (The "2" denotes a particular time level.)

APPENDIX F: USER NOTES FOR PREPROCESSOR GIN

GIN is a preprocessor code that prepares bathymetry (BA) cards for use by CE-QUAL-ELV2. GIN uses GEDA output as input and may be used to preview the grid geometry prior to creating the BA cards. The code is short and is documented internally with comment cards. Following are the most important features of GIN:

a. The basic grid parameters Δx and h are selected during the GEDA run. Output from the final GEDA run is modified, eliminating all output lines preceding "GEOMETRIC MODEL FOR UNSTEADY FLOW PROGRAMS." This modified GEDA output is the only input to GIN.

b. The variable IFORM can be set to 0 or 1 in line 27 of GIN. If IFORM = 0, the grid geometry is previewed in a form similar to that presented by CE-QUAL-ELV2. If IFORM = 1, the BA cards are written. The user will generally run GIN with IFORM = 0 until a satisfactory grid is established, then with IFORM = 1 as a final step before working with CE-QUAL-ELV2.

c. The segment order may be reversed by changing the variable IMAGE.

d. GIN may be used to modify a grid geometry by changing some lines of the code. The example shows some lines marked "CHANGE" in columns 73-80 in DO-loop 170 that modify widths to fit better the given elevation-area-volume table. The best compromise in fitting such tables may be to match areas in the surface layers and volumes elsewhere.

e. The user is responsible for obtaining a legal geometry as outlined in paragraphs 27-29 of this report.

f. GIN used GEDA output in feet and converts all dimensions to metres.

APPENDIX G: POSTPROCESSOR VVE

VVE is a postprocessor code that uses the velocity fields generated by CE-QUAL-ELV2 to produce vector plots like those shown in Figures G1 and G2. VVE uses DISSPLA, a proprietary software package created by Integrated Software Systems Corporation of San Diego and available on many time-sharing systems. VVE uses a file created by CE-QUAL-ELV2 when the IPLOT parameter on the PL card is set to one. The code is short and documented internally with comment cards. However, familiarity with DISSPLA subroutines is required to use VVE. Following are some of the most important features of VVE.

a. CE-QUAL-ELV2 writes the contents of the TITLE and GE cards to TAPE61 in binary prior to writing the coordinates of all the CE-QUAL-ELV2 cells and the velocity fields. VVE reads this information on TAPE51.

b. VVE computes all the scaling parameters and axis labels from information written by CE-QUAL-ELV2. The user can change the axis sizes and the location of the plot on the paper by changing the value of XAXIS, ZAXIS, XSTART, and ZSTART (all in inches).

c. The velocity components are translated to a displacement from the cell center by multiplying each component by DLT, a time in seconds. Different applications yield different velocity magnitudes, so the user may need to change the value of DLT. It is converted to days and identified as the scaling parameter on each plot.

d. The velocity components used by VV are averaged to the cell center so that $\overline{U}(I,K) = (U(I-1,K) + U(I,K))/2$ and $\overline{W} = (W(I,K-1) + W(I,K))/2$. This averaging process may result in stepped velocity profiles adjacent to vertical boundaries.

e. The user may select the number of velocity plots by manipulating the PSTART and PEND parameters.

f. VVE also writes all the plot definition variables and title information to TAPE6 as a debugging aid.

g. The previous cycle shown in Figure 62 is created by inserting the equation for ZR in TVDS into VVE.

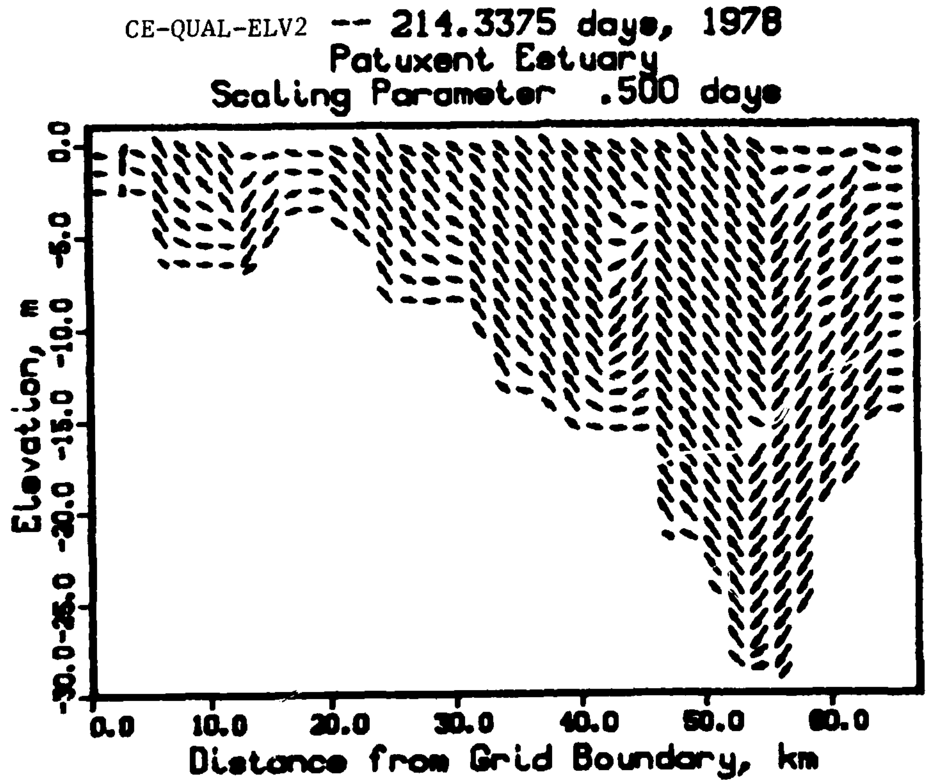


Figure G1. Velocity vectors, first of two plots produced by VVE for each time step

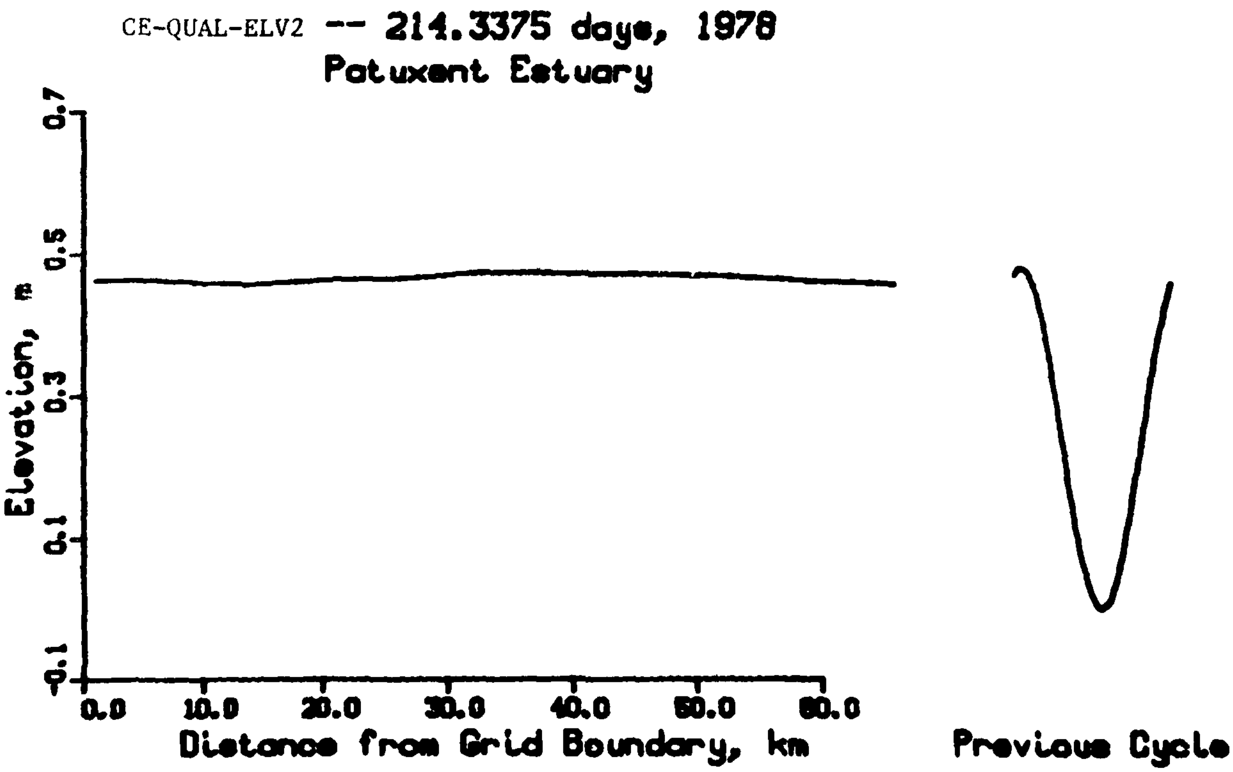


Figure G2. Water surface profile, second of two plots produced by VVE for each time step

APPENDIX H: JULIAN DATE CALENDAR

Day	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Day
1	001	032	060	091	121	152	182	213	244	274	305	335	1
2	002	033	061	092	122	153	183	214	245	275	306	336	2
3	003	034	062	093	123	154	184	215	246	276	307	337	3
4	004	035	063	094	124	155	185	216	247	277	308	338	4
5	005	036	064	095	125	156	186	217	248	278	309	339	5
6	006	037	065	096	126	157	187	218	249	279	310	340	6
7	007	038	066	097	127	158	188	219	250	280	311	341	7
8	008	039	067	098	128	159	189	220	251	281	312	342	8
9	009	040	068	099	129	160	190	221	252	282	313	343	9
10	010	041	069	100	130	161	191	222	253	283	314	344	10
11	011	042	070	101	131	162	192	223	254	284	315	345	11
12	012	043	071	102	132	163	193	224	255	285	316	346	12
13	013	044	072	103	133	164	194	225	256	286	317	347	13
14	014	045	073	104	134	165	195	226	257	287	318	348	14
15	015	046	074	105	135	166	196	227	258	288	319	349	15
16	016	047	075	106	136	167	197	228	259	289	320	350	16
17	017	048	076	107	137	168	198	229	260	290	321	351	17
18	018	049	077	108	138	169	199	230	261	291	322	352	18
19	019	050	078	109	139	170	200	231	262	292	323	353	19
20	020	051	079	110	140	171	201	232	263	293	324	354	20
21	021	052	080	111	141	172	202	233	264	294	325	355	21
22	022	053	081	112	142	173	203	234	265	295	326	356	22
23	023	054	082	113	143	174	204	235	266	296	327	357	23
24	024	055	083	114	144	175	205	236	267	297	328	358	24
25	025	056	084	115	145	176	206	237	268	298	329	359	25
26	026	057	085	116	146	177	207	238	269	299	330	360	26
27	027	058	086	117	147	178	208	239	270	300	331	361	27
28	028	059	087	118	148	179	209	240	271	301	332	362	28
29	029		088	119	149	180	210	241	272	302	333	363	29
30	030		089	120	150	181	211	242	273	303	334	364	30
31	031		090		151		212	243		304		365	31

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Buchak, Edward M.
User guide for CE-QUAL-ELV2 : A longitudinal-vertical, time-varying estuarine water quality model / by Edward M. Buchak, John Eric Edinger (J.E. Edinger Associates, Inc., Wayne, Pennsylvania). -- Vicksburg, Miss. : U.S. Army Engineer Waterways Experiment Station ; Springfield, Va. : available from NTIS, 1982.
101 p. in various pagings ; ill. ; 27 cm. -- (Instruction report ; EL-82-1)
Cover title.
"December 1982."
Final report.
"Prepared for Office, Chief of Engineers, U.S. Army under Purchase Order No. DACW39-81-M-2788."
"Monitored by Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station."
Bibliography: p. 57-58.

Buchak, Edward M.
User guide for CE-QUAL-ELV2 : A longitudinal : ... 1982.
(Card 2)

1. CE-QUAL-ELV2 (Computer program). 2. Computer programs. 3. Estuarine ecology. 4. Patuxent River Estuary (Md.) 5. Water quality. I. Edinger, John Eric. II. United States. Army. Corps of Engineers. Office of the Chief of Engineers. III. U.S. Army Engineer Waterways Experiment Station. Environmental Laboratory. IV. Title V. Series: Instruction report (U.S. Army Engineer Waterways Experiment Station) ; EL-82-1.
TA7.W34i no.EL-82-1