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**Transport and Dispersion of
Pollutants in Surface
Impoundments: A Finite
Element Model**

G. T. Yeh

ENVIRONMENTAL SCIENCES DIVISION
Publication No. 1348

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TRANSPORT AND DISPERSION OF POLLUTANTS IN
SURFACE IMPOUNDMENTS: A FINITE ELEMENT MODEL

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LOW-LEVEL WASTE MANAGEMENT PROGRAM
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ABSTRACT

YEH, G. T. 1980. Transport and dispersion of pollutants in surface impoundments: A finite element model. ORNL-5222. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 120 pp.

A surface impoundment model in finite element (SIMFE) is presented to enable the simulation of flow circulations and pollutant transport and dispersion in natural or artificial lakes, reservoirs or ponds with any number of islands. This surface impoundment model consists of two sub-models: hydrodynamic and pollutant transport models. Both submodels are simulated by the finite element method. While the hydrodynamic model is solved by the standard Galerkin finite element scheme, the pollutant transport model can be solved by any of the twelve optional finite element schemes built in the program. Theoretical approximations and the numerical algorithm of SIMFE are described. Detailed instruction of the application are given and listing of FORTRAN IV source program are provided. Two sample problems are given. One is for an idealized system with a known solution to show the accuracy and partial validation of the models. The other is applied to Prairie Island for a set of hypothetical input data, typifying a class of problems to which SIMFE may be applied.

TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	iii
LIST OF TABLES	vi
LIST OF FIGURES	vii
I. INTRODUCTION	1
II. MODEL DEVELOPMENT	4
II.1 Hydrodynamic Model	4
II.2 Pollutant Model	17
III. COMPUTER IMPLEMENTATION	29
IV. RESULTS	32
IV.1 Ideal System Application	32
IV.2 Prairie Island Application	35
V. NOTATION	40
VI. REFERENCES	42
VII. APPENDICES	47
APPENDIX A. Applicability of the Model	48
APPENDIX B. Data Input Guide	53
APPENDIX C. Input and Output of an Ideally Hypothetical System	59
APPENDIX D. Input and Output at Prairie Island	67
APPENDIX E. Listing of FORTRAN Program	79

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1 Optional finite element schemes	28

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1 e-th finite element in global and local coordinates . . .	11
2 Application of dirichlet conditions	16
3 Subroutine of SIMFE	30
4 Finite element discretization of an ideal channel . . .	33
5 Velocity vector field in an ideal system	34
6 Normalized iso-concentration as predicted by SIMFE (—) and analytical solution (●)	35
7 Finite element directization of Prairie Island	37
8 Flow rate vectors as predicted by the model	38
9 Iso-concentration lines of Dissolved Oxygen (DO) at Prairie as predicted by the model	39

INTRODUCTION

Areas near surface impounding waters, either natural or man-made, have traditionally been the centers of industrial growth. A basic reason has been their capacity to receive, dilute, and assimilate all kinds of unwanted effluents. In recent years, however, the rapidly increasing quantities of such effluents and the growing concern over conservation of environmental quality have led to the necessity for rational planning of the utilization of impounding waters, instead of allowing uncontrolled expansion.

A major technical problem associated with such planning strategies is the prediction of how an effluent will spread in a given body of water. The answer to this question is by no means simple. It involves knowledge of the flow field on one hand and the characteristics and possible interactions of the pollutants on the other. The flow patterns in the surface waters are usually extremely complex and depend on meteorological conditions, bottom topography, boundary geometry, inflows and outflows. To gain insight into the processes that take place in nature, three approaches may be followed: (1) direct measurements, (2) hydraulic modeling, and (3) mathematical modeling.

Measurements in water bodies are normally very expensive and mostly site and time specific such that they rarely provide an adequate overview of the processes of interest. However, they are necessary in conjunction with models of categories (2) and (3), since they provide data required for input or verification. Hydraulic models can yield a very detailed picture of the phenomena, but considerable difficulties

are encountered in the proper scaling of all relevant factors, inevitably resulting in some degree of simplification of the representation. They are in general site specific and also are much more expensive than mathematical models. This last category consists essentially of the representation of the actual processes by mathematical equations, which are subsequently solved by some sort of analytical or numerical technique. The more complex the mathematical representation, the more difficult, but supposedly more accurate, the solution becomes. Mathematical models are relatively inexpensive and general enough so that they can be applied to different areas with only minor changes.

With the widespread use of high-speed computers, increasingly detailed mathematical formulations can be handled by various numerical methods. Several two-dimensional computational algorithms have been developed to describe the transient flow patterns in a water body (Leendertse 1970, Lee 1972, Liggett 1975, Abbott et al. 1975, Yeh 1976). However, there exists numerous occasions that do not warrant the application of the novel transient flow analysis. Furthermore, published transient flow models applied to a specific case often have the unfortunate characteristic of being inoperative when applied to a different problem. Thus more reliable steady state flow models coupled with transient pollutant transport models, which would yield adequate and convergent solution of the governing equations for a wide range of problems, are required.

Finite difference techniques have traditionally been used for simulating the hydrodynamic equations, but lately finite element models

have emerged (Wang and Connor 1975, Christodoulo et al. 1976). Finite element methods offer two great advantages: (1) flexibility in the representation of complex geometries and (2) ease in the treatment of Neumann or third type boundary conditions. This report presents the development of an algorithms of the surface impoundment model by finite element (SIMFE).

From a practical viewpoint, the main interest is not the flow field, but rather the transport and dispersion of some substance due to a given flow field. Therefore, the information obtained from the hydrodynamic model of SIMFE is subsequently used as input to the transport model. The latter normally solves some form of the advective-diffusion equation, expressing the mass balance of the constituent of interest. The standard Galerkin finite element method is used for the hydrodynamic model while twelve optional finite element techniques are used for the pollutant transport model.

II. MODEL DEVELOPMENT

The spatial variations of the velocity from discharges, intakes inflows and outflows are simulated with a two-dimensional steady state hydrodynamic model. This is a modified version of the model developed previously (Yeh et al. 1973). The temporal and spatial variations of a pollutant constituent are calculated with the aid of numerical solution of mass transport equation. The solution method for both the hydrodynamic and pollutant models are the finite element method.

II.1 Hydrodynamic Model

II.1.1 Governing Equations

The characteristics in a shallow impoundment can be fairly approximated by the following assumptions: (1) the velocity distribution in the vertical direction is fairly uniform, (2) the pressure distribution in the vertical direction is hydrostatic, (3) the fluctuation of the water surface is much smaller than the water depth, (4) the flow is steady state, (5) the nonlinear convection is very small compared to the bottom frictional force and (6) the bottom stress is proportional to the velocity. A discussion on the validity of these assumption has been presented in a previous report (Yeh 1979). It is recapitulated in Appendix A.

Under the above assumptions, the vertically integrated form of the conservation equations of mass and momentum in a Cartesian coordinate system with x and y on the horizontal plane can be reduced to (Yeh et al. 1973):

$$\frac{\partial^2 \Psi}{\partial x^2} + \frac{\partial^2 \Psi}{\partial y^2} - \left(\frac{2}{h} \frac{\partial h}{\partial x} + \frac{f}{K} \frac{\partial h}{\partial y} \right) \frac{\partial \Psi}{\partial x} - \left(\frac{2}{h} \frac{\partial h}{\partial y} - \frac{f}{K} \frac{\partial h}{\partial x} \right) \frac{\partial \Psi}{\partial y} = \frac{h^2}{\rho K} \frac{\partial}{\partial x} \left(\frac{\tau_y^w}{h} \right) - \frac{h^2}{\rho K} \frac{\partial}{\partial y} \left(\frac{\tau_x^w}{h} \right) \quad (1)$$

where Ψ is the stream function; ρ is the water density; f is the coriolis coefficient; K is the linear bottom stress coefficient; h is the water depth; and τ_x^w and τ_y^w are the wind stress components in the x - and y -directions, respectively. Equation (1) represents the balance between three forces. The first two terms and the third and fifth terms are the bottom frictional forces. The fourth and sixth terms are the coriolis force. The last two terms on the right hand side are the wind driven forces. Another important driving force which is not appearing explicitly in the equation is the inflow and outflow of the region, which resemble the pressure gradient force.

After Eq. (1) is solved for the stream function, the flow rate components, U and V , can be computed as follows:

$$U = \bar{u}h = - \frac{\partial \Psi}{\partial y} ; \quad V = \bar{v}h = \frac{\partial \Psi}{\partial x} \quad (2)$$

where $\bar{u}$ and $\bar{v}$ are the vertically averaged velocity components in the x - and y -directions, respectively. The flow rate components, U and V , along with the topography and the bathymetry of the water body, will serve as inputs to the pollutant model.

Boundary conditions to complete the solution of Eq. (1) are determined by the requirements that every water-land interface is a streamline whose values can be prescribed from the information of inflows and outflows. The conditions at open boundaries such as intake channel, discharge cannal, influx and efflux lines are determined by assuming the normal flow to the lines prevailing. To write these conditions in mathematical terms, they are described by the following equations:

$$\Psi = \Psi_L(x,y) \quad \text{at} \quad L(x,y) = 0 \quad (3)$$

and

$$\frac{\partial \Psi}{\partial x} n_x + \frac{\partial \Psi}{\partial y} n_y = f_s(x,y) = 0 \quad \text{at} \quad S(x,y) = 0 \quad (4)$$

where $L(x,y) = 0$ is the curve of water-land interface; $S(x,y) = 0$ is the curve of open water boundaries; and n_x and n_y are directional cosines of a unit vector normal to the curve, $S(x,y) = 0$. An option is also given that

$$\Psi = \Psi_S \quad \text{on} \quad S(x,y) = 0 \quad (4a)$$

In Eqs. (3) and (4a) Ψ_L and Ψ_S are two known functions describing boundary values of Ψ .

II.1.2 Finite Element Approximations

The method that will be used in the integration of Eq. (1) is a special case of the broad category called weighted residual methods. These methods, in their classical form, approximate the solution to the differential equations and satisfy the boundary conditions exactly. The differential equation may be written in the general form:

$$L(\phi) = 0 \quad (5)$$

where L is a differential operator and ϕ is the dependent variable. The weighted residual approximate solution $\hat{\phi}$ over the region R is obtained from the equation

$$\int_R W_i \cdot L(\hat{\phi}) dR = 0 \quad \text{for } i = 1, 2, \dots, n \quad (6)$$

The W_i 's comprise a set of n weighting functions, and the trial solution, $\hat{\phi}$, has the form

$$\hat{\phi} = \sum_{j=0}^n \phi_j \cdot N_j \quad (7)$$

where N_j 's are the base functions (interpolating functions); ϕ_j 's are unknown values of the trial solution at the nodal points, j 's, and $L(\phi) \neq 0$ is the residual. Since Eq. (1) is an elliptic type, the weighting function will be chosen as the interpolating function and the method is thus called Galerkin method. In fact, the equation for the Galerkin method

$$\int_R N_i L \left(\sum_{j=1}^n N_j \phi_j \right) dR = 0, \quad i = 1, 2, \dots, n \quad (8)$$

requires that the residual of the differential equation be made orthogonal to each term in the trial solution. Coefficients of ϕ_j 's

are obtained by integrating Eq. (8). The integration yields a set of n -algebraic equations, whose solution gives ϕ_j 's.

In the classical Galerkin method, each of the interpolating functions, N_i , extends over the entire domain R and must satisfy all boundary conditions. Hence, the method is restricted to simply shaped, simply connected regions with homogeneous material properties. However, the power and generality of the Galerkin method can be extended considerably by combining it with a finite element discretization in which the region of integration is represented by an assemblage of sub-domains. These sub-domains are called elements, and their corners, or connection points, are called nodes. In this approach, the family of the base functions consists of subfamilies of very simple functions. The ϕ_j 's satisfy boundary conditions, and not the base functions, N_j 's, which are non-zero on only one of the subdomains. The coefficients, ϕ_j 's become the amplitudes of the unknown function at the nodes. This finite element approach, in effect, is a piecewise Galerkin approximation which permits the application of the Galerkin method to complex geometries and non-homogeneous media. A more detailed discussion of the Galerkin finite element method is given by Hutton and Anderson (1971).

The Galerkin method applied to a quadrilateral element e may be written as:

$$\int_{R_e} N_i \cdot L \left(\sum_{j=1}^4 \phi_j N_j \right) dR, \quad i = 1, 2, 3, 4 \quad (9)$$

Substituting the differential operator in Eq. (1) into (9) and integrating the second order derivatives by parts, one obtains:

$$[S_{ij}]\{\psi_j\} + \{D_i\} + \{Q_i\} = 0 \quad (10)$$

where

$$\begin{aligned} S_{ij} = \int_{R_e} \{ & (\frac{\partial N_i}{\partial x} \frac{\partial N_j}{\partial x} + \frac{\partial N_i}{\partial y} \frac{\partial N_j}{\partial y}) + N_i (\frac{2}{h} \frac{\partial h}{\partial x} + \frac{f}{\rho K} \frac{\partial h}{\partial y}) \frac{\partial N_j}{\partial x} \\ & + N_i (\frac{2}{h} \frac{\partial h}{\partial y} - \frac{f}{\rho K} \frac{\partial h}{\partial x}) \frac{\partial N_j}{\partial y} \} dR \end{aligned} \quad (11)$$

$$D_i = \int_{R_e} \{ \frac{h^2}{\rho K} N_i \frac{\partial N_j}{\partial x} (\frac{\tau_y^w}{h})_j - \frac{h^2}{\rho K} N_i \frac{\partial N_j}{\partial y} (\frac{\tau_x^w}{h})_j \} dR \quad (12)$$

and

$$Q_i = - \int_{B_e} (N_i \frac{\partial \psi}{\partial x} n_x + N_i \frac{\partial \psi}{\partial y} n_y) dB \quad (13)$$

in which $(\tau_x^w/h)_j$ and $(\tau_y^w/h)_j$ are the values of (τ_x^w/h) and (τ_y^w/h) evaluated at point j ; R_e and B_e are the region and boundaries of the element e , respectively. Equation (13) applies to only those elements having one or more sides on the global boundary, $S(x,y) = 0$.

II.1.3 Numerical Implementation

Quadrilateral bilinear element are used to discretize the region of interest. The base function for the i -th node may be written in terms of local normalized coordinates as:

$$N_i = \frac{1}{4} \cdot (1 + \xi_i \xi) \cdot (1 + \eta_i \eta) \quad i = 1, 2, 3, 4 \quad (14)$$

where ξ_i and η_i are the local coordinates of the corner nodes, which are numbered 1 to 4 progressing around the element in a counterclock-wise direction as shown in Fig. 1. In the local coordinate system the element is square regardless the shape of the quadrilateral element in global coordinates. The global coordinates at any point within element e are given in terms of local coordinates by the following transformation:

$$x = \sum_{j=1}^4 x_j N_j$$

and

(15)

$$y = \sum_{j=1}^4 y_j N_j$$

where x_j and y_j are the global coordinates of the nodes of the e -th element. N_j 's are function of the local coordinates of ξ and η as in Eq. (14).

ORNL- DWG 78-19276

Fig. 1. e -th finite element in global and local coordinates.

The shape function, N_i 's, of the coordinate transformation in Eq. (15) is the same as the base function, N_j 's of Eq. (7); hence this element formulation is termed isoparametric. The Jacobian for the transformation from global to local coordinates is expressed as:

$$[J] = \begin{bmatrix} \frac{\partial x}{\partial \xi} & \frac{\partial y}{\partial \xi} \\ \frac{\partial x}{\partial \eta} & \frac{\partial y}{\partial \eta} \end{bmatrix} \quad (16)$$

Substitution of Eq. (15) into the determinant of this expression yields:

$$J = \text{Det}[J] = (x_j \frac{\partial N_j}{\partial \xi}) \cdot (y_k \frac{\partial N_k}{\partial \eta}) - (y_j \frac{\partial N_j}{\partial \xi}) \cdot (x_k \frac{\partial N_k}{\partial \eta}) \quad (17)$$

Equation (17) is used for numerical evaluation of the determinant of the Jacobian. The integrals of Eq. (11) and (12) taken over the area of the e-th element may now be written in local coordinates using the determinant of the Jacobian to transform the element area:

$$S_{ij} = \int_{-1}^1 \int_{-1}^1 \left\{ \left(\frac{\partial N_i}{\partial x} \frac{\partial N_j}{\partial x} + \frac{\partial N_i}{\partial y} \frac{\partial N_j}{\partial y} \right) + N_i \left(\frac{2}{h} \frac{\partial h}{\partial x} + \frac{f}{k} \frac{\partial h}{\partial y} \right) \cdot \frac{\partial N_j}{\partial y} \right. \\ \left. + N_i \left(\frac{2}{h} \frac{\partial h}{\partial y} - \frac{f}{k} \frac{\partial h}{\partial x} \right) \cdot \frac{\partial N_j}{\partial x} \right\} J \, d\xi d\eta \quad (18)$$

and

$$D_i = \int_{-1}^1 \int_{-1}^1 \left\{ \frac{h^2}{\rho k} \cdot N_i \cdot \frac{\partial N_j}{\partial x} \left(\frac{\tau_j^w}{h} \right)_j + \frac{h^2}{\rho k} \cdot N_i \cdot \frac{\partial N_j}{\partial y} \left(\frac{\tau_x^w}{h} \right)_j \right\} J \, d\xi d\eta \quad (19)$$

Integration of these equations is easily carried out using 2X2 Gaussian points. A linear algebraic equation, Eq. (9), results.

In order to evaluate $[S_{ij}]$ and $\{D_i\}$, expression for the spatial derivative of the interpolation function with respect to x and y in terms of ξ and η are necessary. The chain rule:

$$\begin{Bmatrix} \frac{\partial}{\partial \xi} \\ \frac{\partial}{\partial \eta} \end{Bmatrix} = [J] \cdot \begin{Bmatrix} \frac{\partial}{\partial x} \\ \frac{\partial}{\partial y} \end{Bmatrix} \quad (20)$$

may be inverted to yield

$$\begin{Bmatrix} \frac{\partial}{\partial x} \\ \frac{\partial}{\partial y} \end{Bmatrix} = J^{-1} \cdot \begin{Bmatrix} \frac{\partial y}{\partial \eta} & \frac{\partial y}{\partial \xi} \\ \frac{\partial x}{\partial \eta} & \frac{\partial x}{\partial \xi} \end{Bmatrix} \begin{Bmatrix} \frac{\partial}{\partial \xi} \\ \frac{\partial}{\partial \eta} \end{Bmatrix} \quad (21)$$

using the definition of $[J]$ in Eq. (16).

When the top row of Eq. (21) is applied to the base function, N_i , the following is obtained:

$$\frac{\partial N_i}{\partial x} = \frac{1}{J} \left[(y_j \frac{\partial N_j}{\partial \eta}) \cdot \frac{\partial N_i}{\partial \xi} - (y_j \frac{\partial N_j}{\partial \xi}) \cdot \frac{\partial N_i}{\partial \eta} \right] \quad (22)$$

where $(\partial N_i / \partial \xi)$ and $(\partial N_i / \partial \eta)$ are given as:

$$\frac{\partial N_i}{\partial \xi} = \frac{1}{4} \xi_i (1 + \eta_i \eta)$$

and

(23)

$$\frac{\partial N_i}{\partial \eta} = \frac{1}{4} \eta_i (1 + \xi_i \xi)$$

by taking the derivatives of Eq. (14) with respect to ξ and η , respectively. Similarly, applying the bottom row of Eq. (21) to the base function, one obtains:

$$\frac{\partial N_i}{\partial y} = \frac{1}{J} \left[- \left(x_j \frac{\partial N_j}{\partial \eta} \right) \cdot \left(\frac{\partial N_i}{\partial \xi} \right) + \left(x_j \frac{\partial N_j}{\partial \xi} \right) \cdot \left(\frac{\partial N_i}{\partial \eta} \right) \right] \quad (24)$$

Equations (23) and (24) are in a form suitable for numerical evaluation. These equations are used to evaluate the integrands of Eqs. (18) and (19).

II.1.4 Assembling of Element Matrix

Equations (10) through (13) are developed for an element. Direct stiff matrix procedure is then used to assume over all the elements to form a system of algebraic equations as:

$$[T_{ij}]\{\psi_j\} = \{X_i\} - \{B_i\} = \{Y_i\} \quad (25)$$

where $[T_{ij}]$ and $\{Y_i\}$ are the global matrix and load vector, respectively. The matrix $[T_{ij}]$ is a singular matrix if the boundary conditions are not incorporated.

II.1.5 Incorporation of Boundary Conditions

At nodes where Dirichlet boundary conditions, Eq. (3), are imposed, an identity equation is then generated for each of such nodes and included in the matrix of Eq. (26) (Wang and Connor 1975). Computationally, this is done as sketched in Fig. 2. If the k -th variable is prescribed, the k -th column in the coefficient matrix $[T_{ij}]$ is stored, then the k -th row and column in $[T_{ij}]$ are set to zero and the diagonal entry set equal to one. Finally, the stored column matrix is multiplied by the prescribed value Y^* and subtracted from the right hand side of Eq. (26). This procedure effectively replace the k -th equation by the prescribed constant.

At nodes where the Neumann boundary conditions are applied, a surface integral term, B_i , must be subtracted from the vector, X_i . In this case, nothing should be done since the normal derivative on S is zero.

On the island nodal points, special care should be made. Recall that, each island is a streamline but its stream function value is not prescribed. Therefore, for each island, the stream function at a designated nodal point, say the first point encountered, should be considered unknown. Those at all other points on the same island are set equal to the designated one. Hence, for each island, one equation corresponding to the designated nodal point has to be modified because

$$\begin{bmatrix}
 T_{11} & \dots & T_{1,k-1} & 0 & T_{1,k+1} & \dots & T_{1n} \\
 \cdot & & \cdot & \cdot & \cdot & & \cdot \\
 \cdot & & \cdot & \cdot & \cdot & & \cdot \\
 \cdot & & \cdot & \cdot & \cdot & & \cdot \\
 T_{k-1,1} & \dots & T_{k-1,k-1} & 0 & T_{k-1,k+1} & \dots & T_{k-1,n} \\
 0 & \dots & 0 & 1 & 0 & \dots & 0 \\
 T_{k+1,1} & \dots & T_{k+1,k-1} & 0 & T_{k+1,k+1} & \dots & T_{k+1,n} \\
 \cdot & & \cdot & \cdot & \cdot & & \cdot \\
 \cdot & & \cdot & \cdot & \cdot & & \cdot \\
 \cdot & & \cdot & \cdot & \cdot & & \cdot \\
 T_{n,1} & \dots & T_{n,k-1} & 0 & T_{n,k+1} & \dots & T_{nn}
 \end{bmatrix}
 \begin{Bmatrix}
 h_1 \\
 \cdot \\
 \cdot \\
 \cdot \\
 h_{k-1} \\
 h_k \\
 h_{k+1} \\
 \cdot \\
 \cdot \\
 \cdot \\
 h_n
 \end{Bmatrix}
 =
 \begin{Bmatrix}
 y_1 \\
 \cdot \\
 \cdot \\
 \cdot \\
 y_{k-1} \\
 0 \\
 y_{k+1} \\
 \cdot \\
 \cdot \\
 \cdot \\
 y_n
 \end{Bmatrix}$$

$$- \begin{bmatrix}
 0 & \dots & 0 & T_{1k} & 0 & \dots & 0 \\
 \cdot & & \cdot & \cdot & \cdot & & \cdot \\
 \cdot & & \cdot & \cdot & \cdot & & \cdot \\
 \cdot & & \cdot & \cdot & \cdot & & \cdot \\
 0 & \dots & 0 & T_{k-1,k} & 0 & \dots & 0 \\
 0 & \dots & 0 & -1 & 0 & \dots & 0 \\
 0 & \dots & 0 & T_{k+1,k} & 0 & \dots & 0 \\
 \cdot & & \cdot & \cdot & \cdot & & \cdot \\
 \cdot & & \cdot & \cdot & \cdot & & \cdot \\
 \cdot & & \cdot & \cdot & \cdot & & \cdot \\
 0 & \dots & 0 & T_{nk} & 0 & \dots & 0
 \end{bmatrix}
 \begin{Bmatrix}
 0 \\
 \cdot \\
 \cdot \\
 \cdot \\
 0 \\
 y^* \\
 0 \\
 \cdot \\
 \cdot \\
 \cdot \\
 0
 \end{Bmatrix}$$

Fig. 2. Application of dirichlet conditions.

the boundary integral, $\{B_i\}$, are no longer zero but are depending on the stream function. Substituting Eq. (7) into Eq. (13), one obtains:

$$\{Q_i\} = [E_{ij}]\{\Psi_j\} \quad (26a)$$

where

$$E_{ij} = - \int_{B_e} N_i \left(\frac{\partial N_j}{\partial x} n_x + \frac{\partial N_j}{\partial y} n_y \right) dB \quad (26b)$$

The surface integral, $[E_{ij}]$, after assembly over all elements having the designated point as one of their nodal points, is added to the matrix, $[T_{ij}]$.

II.1.6 Solution of Assembled Equations

Gaussian elimination algorithm is used to solve the matrix equation, Eq. (26).

II.2 Pollutant Model

II.2.1 Governing Equations

The variations of pollutants with space and time are simulated with a transient two-dimensional advective-dispersion equation. The model is developed according to the mass conservation relationship:

$$\frac{\partial hc}{\partial t} + \frac{\partial Uc}{\partial x} + \frac{\partial Vc}{\partial y} = \frac{\partial}{\partial x} \left(hK_x \frac{\partial c}{\partial x} \right) + \frac{\partial}{\partial y} \left(hK_y \frac{\partial c}{\partial y} \right) + \frac{M}{\rho} - (K_m + \lambda)hc \quad (27)$$

where c is the concentration; K_m is the first order reaction rate of pollutants with water; λ is the decay constant, if the pollutant is radioactive; K_x and K_y are the dispersion coefficient in the x - and y -directions, respectively; ρ is the water density; M is the source or sink term, which may result from the discharge, intake, river inflows and outflows. In Eq. (27), the first term represents the time rate of change of the pollutant in a differential volume. The second and third terms represent the flux by the advection. The first two terms on the right hand side represent the dispersive fluxes by ambient turbulence and shear forces. Pollutant degeneration by chemical reaction or biological action is characterized by K_m .

Variables involved in Eq. (27) are U , V , K_x , K_y , K_m , h , λ and c . c is the unknown to be determined. Among those variables, h , and K_m are input variables. U and V are flow rate components which are obtained from the output of hydrodynamic model. K_x and K_y are related to the hydrodynamic variables, U and V , as follows:

$$hK_x = a_T W + (a_L - a_T)U^2/W + hD_m \quad (28a)$$

and

$$hK_y = a_T W + (a_L - a_T)V^2/W + hD_m \quad (28b)$$

where a_L and a_T are the longitudinal and transverse eddy diffusivities, respectively; $W = \sqrt{U^2 + V^2}$; and D_m is the molecular diffusion coefficient.

To complete the description of the concentration distribution, initial and boundary conditions are required in addition to Eq. (27). Three types of boundary conditions are considered in the present formulation. The first one is the Dirichlet boundary where the concentration is given:

$$c = c_1(x,y,t) \quad \text{on} \quad B_1 \quad (29)$$

where c_1 is a known function of time, t , and the spatial coordinates, (x,y) , on the curve B_1 . The second one is the Neumann boundary where the normal gradient of the concentration is zero, thus yielding the concentration dependent conditions and can be written as:

$$(-hK_x \frac{\partial c}{\partial x} + Uc) \cdot n_x + (-hK_y \frac{\partial c}{\partial y} + Vc) \cdot n_y = Ucn_x + Vcn_y \quad \text{on} \quad B_2 \quad (30)$$

where n_x and n_y are the directional cosines of the outward unit vector normal to the curve B_2 . The last one is the mixed boundary where the normal flux is prescribed:

$$(-hK_x \frac{\partial c}{\partial x} + Uc) \cdot n_x + (-hK_y \frac{\partial c}{\partial y} + Vc) \cdot n_y = q_1(x,y,t) \quad \text{on} \quad B_3 \quad (31)$$

II.2.2 Finite Element Approximations

It may be expected that in a surface impoundment, the advection may be as important as the dispersion. Under such circumstances, it is advantageous to use weighting functions different from the base

functions. For example, the upstream weighting function is one of such candidates (Huyakorn 1976). In the present finite element formulation, two options are provided: one is the standard Galerkin finite element described in the section of hydrodynamic model, the other is the upstream weighting finite element. The detailed derivation of the upstream weighting function for a quadrilateral bilinear element can be found elsewhere (Huyakorn 1976). Thus, the method of the weighted residual applied to the mass transport equation for an element e may be written as:

$$\int_{R_e} W_i \cdot L \left(\sum_{j=1}^4 N_j \phi_j \right) dR = 0, \quad i = 1, 2, 3, 4 \quad (32)$$

Substituting the differential operator in Eq. (27) into Eq. (32), and integrating the second order derivatives by part, one obtains:

$$[M_{ij}]\{\dot{c}_j\} + [S_{ij}]\{c_j\} + \{D_i\} + \{Q_i\} = 0 \quad (33)$$

where

$$\dot{c} = \frac{dc}{dt} \quad (34)$$

and

$$M_{ij} = \int_{-1}^1 \int_{-1}^1 W_i h N_j d\xi d\eta \quad (35)$$

$$\begin{aligned}
S_{ij} = & \int_{-1}^1 \int_{-1}^1 \left\{ \frac{\partial W_i}{\partial x} \left(K_x \frac{\partial N_j}{\partial x} - U N_j \right) + \frac{\partial W_i}{\partial y} \left(K_y \frac{\partial N_j}{\partial y} - V N_j \right) \right\} J \, d\xi d\eta \\
& + \int_{-1}^1 \int_{-1}^1 (K + \lambda) W_i h N_j \, J \, d\xi d\eta
\end{aligned} \quad (36)$$

$$D_i = - \int_{-1}^1 \int_{-1}^1 W_i M J \, d\xi d\eta \quad (37)$$

$$Q_i = \int_{B_e} W_i \left\{ (-h K_x \frac{\partial C}{\partial x} + U c) n_x + (-h K_y \frac{\partial C}{\partial y} + V c) n_y \right\} dB \quad (38)$$

in which B_e is the side or sides of the element e . It should be noted that Eq. (38) appears only for those elements having one or more sides on B_2 . The application of this boundary equation will be discussed later.

The weighting function, W_i 's, for the Galerkin option is given by

$$W_i = N_i, \quad i = 1, 2, 3, 4 \quad (39)$$

and for the upstream weighting option is given by (Huyakorn 1976),

$$\begin{aligned}
W_1 &= \frac{1}{16} [(1+\eta)(3\beta_2\eta - 3\beta_2 - 2) + 4][(1+\xi)(3\alpha_1\xi - 3\alpha_1 - 2) + 4] \\
W_2 &= \frac{1}{16} [(1+\eta)(3\beta_1\eta - 3\beta_1 - 2) + 4][(1+\xi)(-3\alpha_1\xi + 3\alpha_1 + 2)] \\
W_3 &= \frac{1}{16} [(1+\eta)(-3\beta_1\eta + 3\beta_1 + 2)][(1+\xi)(-3\alpha_2\xi + 3\alpha_2 + 2)] \\
W_4 &= \frac{1}{16} [(1+\eta)(-3\beta_2\eta + 3\beta_2 + 2)][(1+\xi)(3\alpha_2\xi - 3\alpha_2 - 2) + 4]
\end{aligned} \quad (40)$$

where α_1 , α_2 , β_1 and β_2 are weighting factors for the bottom, top, right and left sides, respectively, of the element e .

The derivatives of W_i 's with respect to x and y in terms of local coordinates are given by Eqs. (22) and (23) replacing N_i 's with W_i s. The derivatives of W_i 's with respect to ξ and η are given by the following equations (Huyakorn 1976):

$$\frac{\partial W_1}{\partial \xi} = \frac{1}{8} [(1+\eta)(3\beta_2\eta-3\beta_2-2) + 4] (3\alpha_1\xi-1)$$

$$\frac{\partial W_2}{\partial \xi} = -\frac{1}{8} [(1+\eta)(3\beta_1\eta-3\beta_1-2) + 4] (3\alpha_1\xi-1)$$

$$\frac{\partial W_3}{\partial \xi} = -\frac{1}{8} [(1+\eta)(-3\beta_1\eta+3\beta_1+2)] (3\alpha_2\xi-1)$$

$$\frac{\partial W_4}{\partial \xi} = \frac{1}{8} [(1+\eta)(-3\beta_2\eta+3\beta_2+2)] (3\alpha_2\xi-1)$$

$$\frac{\partial W_1}{\partial \eta} = \frac{1}{8} [(1+\xi)(3\alpha_1\xi-3\alpha_1-2) + 4] (3\beta_2\eta-1)$$

$$\frac{\partial W_2}{\partial \eta} = \frac{1}{8} [(1+\xi)(-3\alpha_1\xi+3\alpha_1+2)] (3\beta_1\eta-1)$$

$$\frac{\partial W_3}{\partial \eta} = -\frac{1}{8} [(1+\xi)(-3\alpha_2\xi+3\alpha_2+2)] (3\beta_1\eta-1)$$

$$\frac{\partial W_4}{\partial \eta} = -\frac{1}{8} [(1+\xi)(3\beta_2\xi-3\beta_2-2) + 4] (3\alpha_2\eta-1)$$

Referring to the mass matrix $[M_{ij}]$ in Eq. (33), one notes that this is a unit matrix if the finite difference formulation is used in the spatial discretization. Hence by suitable scaling, the mass matrix

may be reduced to a finite differences equivalent if it is lumped (Clough 1971). The lumping of mass matrix in many instances results in more accurate solution than no lumping, especially when it is used in conjunction with central or backward time marching (Gureghian et al. 1978). Therefore, an option is provided for the lumping of the mass matrix, $[M_{ij}]$. More explicitly, $[M_{ij}]$ will be lumped according to the following formulae:

$$M_{ii} = \sum_{j=1}^4 \int_{-1}^1 \int_{-1}^1 w_i h N_j dA \quad (42)$$

$$M_{ij} = 0 \quad \text{if } i \neq j$$

II.2.3 Time Marching Methods

Two most important advantages in finite element approximation over the finite difference approximation are its easiness to handle the complex boundaries and the normal derivatives therein. In the time dimension, none of these advantages is evident. Thus, the simple and easy finite difference methods are normally used in approximating the time derivative and in marching the solution. Three optional time marching methods are used in this report. The first one is the central or Crank-Nicolson formulation:

$$[M_{ij}]({c_j}_{t+\Delta t} - {c_j}_t)/\Delta t + \frac{1}{2} [S_{ij}]({c_j}_{t+\Delta t} + {c_j}_t) + {D_i} + {Q_i} = 0 \quad (43)$$

where $[M_{ij}]$, $[S_{ij}]$, $\{D_i\}$ and $\{Q_i\}$ are evaluated at time, $t + \Delta t/2$.

The second option is the backward difference formulation:

$$[M_{ij}]\{c_j\}_{t+\Delta t} - \{c_j\}_i/\Delta t + [S_{ij}]\{c_j\}_{t+\Delta t} + \{D_i\} + \{Q_i\} = 0 \quad (44)$$

where $[M_{ij}]$, $[S_{ij}]$, $\{D_i\}$ and $\{Q_i\}$ are evaluated at time, $t + \Delta t$.

The third option is the mid-difference formulation (Gureghian et al. 1978) in which the value of the unknown c_j 's are assumed to vary linearly with time in the time interval, Δt . The recurrence formula for this method is:

$$(2[M_{ij}]/\Delta t + [S_{ij}])\{c_j\}_{t+\Delta t/2} - \frac{2}{\Delta t}[M_{ij}]\{c_j\}_t + \{D_i\} + \{Q_i\} = 0 \quad (45)$$

and

$$\{c_j\}_{t+\Delta t} = 2\{c_j\}_{t+\Delta t/2} - \{c_j\}_t \quad (46)$$

where $[M_{ij}]$, $[S_{ij}]$, $\{D_i\}$ and $\{Q_i\}$ are evaluated at time, $t + \Delta t/2$.

In fact, Eqs. (43) through (45) can be written in a general form as:

$$[C_{ij}]\{c_j\} = \{R_i\} - \{Q_i\} \quad (47)$$

II.2.4 Assembling of the Element Matrices

Equation (47) is written for an element and then assembled over all the elements in the region of interest to yield a global matrix equation:

$$[T_{ij}]\{c_j\} = \{X_i\} - \{B_i\} = \{Y_i\} \quad (48)$$

During the assembling process, the column matrix $\{Q_i\}$ resulting from the boundary conditions is ignored since they would cancelled each other except on the boundary elements. After the assembling, the boundary conditions are then incorporated in Eq. (48) to be discussed in the following.

II.2.5 Application of Boundary Conditions

At nodes where Dirichlet boundary conditions are applied, an identity equation is generated for each node and included in the matrices of Eq. (48). The generation of identity equation follows the procedure described in the section of hydrodynamics.

Boundaries on which the Neumann boundary conditions are imposed are either the flow-through boundaries or the water-land interfaces. For the latter case, the entries $\{B_i\}$ is zero and no boundary conditions have to be applied. For the former case, the corresponding entries in $\{B_i\}$ are then linear function of the unknown concentration. Such terms must therefore be incorporated into the $[T_{ij}]$ matrix in Eq. (48). Substituting Eq. (30) into Eq. (38), one obtains:

$$\{Q_i\} = [E_{ij}]\{c_j\} \quad i = 1,2 \quad \text{and} \quad j = 1,2 \quad (49)$$

where

$$E_{ij} = \int_{B_e} W_i (U_{n_x} + V_{n_y}) N_j \, dB \quad (50)$$

For the backward difference and mid-difference time marching algorithm, $[E_{ij}]$ after assembly over all boundary elements of B_2 is added to the matrix $[T_{ij}]$. For the central difference time marching algorithm, half of $[E_{ij}]$ after assembly over the boundary elements is added to the matrix $[T_{ij}]$ while the other half is multiplied by $\{c_j\}$ of the previous time and then subtracted from $\{X_i\}$.

Boundaries on which the mixed type boundary conditions, Eq. (31), are imposed, of course, yield concentration-independent entries in the column matrix $\{Q_i\}$. These entries are evaluated by direct application of substituting Eq. (31) into Eq. (38) to yield normal element fluxes. This is then followed by assembling over all boundary elements of B_3 to yield a global column matrix $\{B_i\}$. The results are then subtracted from the $\{X_i\}$ to form $\{Y_i\}$.

II.2.6 Solution of Assembled Equation

Gaussian elimination algorithm is used to solve the matrix equation, Eq. (48).

II.2.7 Optional Numerical Schemes

Depending on the type of weighting functions (Galerkin or upstream weighting), the methods of time marching (Crank-Nicolson, or backward difference, or mid-difference), and the treatment of the mass matrix (lumping or no-lumping), there are twelve optional finite element numerical schemes reported in the present model as shown in Table 1.

Table 1. Optional finite element schemes

	Time Marching Methods			Weighting Function		Mass Matrix Lumping	
	Crank-Nicolson	Backward	Mid-difference	Galerkin	Upstream	No	Yes
1	x			x		x	
2	x				x	x	
3	x			x			x
4	x				x		x
5		x		x		x	
6		x			x	x	
7		x		x			x
8		x			x		x
9			x	x		x	
10			x		x	x	
11			x	x			x
12			x		x		x

III. COMPUTER IMPLEMENTATION

The computer program consists of the thirteen (13) different subprograms shown in Fig. 3. As is implied by its name, the routine MAIN performs the control function for the program. In it, input-output operations are coordinated with primary and support computations as the calculation is stepped sequentially over the time variable. All input data are read in through subroutine DATAIN. MAIN then calls two subroutines HYDROM and POLLUM.

The subroutine HYDROM sets up a system of algebraic equations for the stream function. In doing so, it has to call subroutine Q4H? which calculates the element matrix, $[S_{ij}]$, and the element load vector, $\{D_i\}$. After the setup of the system of equations, Dirichlet boundary conditions are applied to the nodes with prescribed stream functions. The nodes on one island are set equal to each other. Subroutine SOLVE is then called to solve the resulting system for the stream function at all nodal points. DERIF is finally called by HYDROM to compute the partial derivatives of the stream function with respect to x and y , respectively. This subroutine first call Q4DI to evaluate the element matrix and load vector which are resulted from applying the Galerkin finite element method to Eq. (2). It then assemble the element matrix and load vector to form a global matrix and load vector. No boundary conditions are required in this subroutine since no spatial derivatives are involved in the unknowns. Finally, DERIF calls SOLVE to yield the solutions of the partial derivatives of stream function at all nodal points, thus giving the flow rate components, U and V .

ORNL-DWG 73-18275

Fig. 3. Subroutine of SIMFE.

The resulting hydrodynamic variables from HYDROM are common-blocked through MAIN to the POLLUM, which is called by the MAIN to simulate the distribution of pollutants. The main function of POLLUM is to assemble the element matrices, $[M_{ij}]$ and $[S_{ij}]$, and the load vector, $\{D_i\}$ over all the elements to form the global matrix $[T_{ij}]$ and load vector X_i . $[M_{ij}]$, $[S_{ij}]$, and $\{D_i\}$ are calculated by the subroutine Q4P0. The boundary conditions are also applied in the POLLUM. In the segment that incorporates the boundary conditions, Q2SP is called to compute the element flux and the boundary element matrix, $\{Q_i\}$ and $\{E_{ij}\}$. A subroutine AFABTA is called from POLLUM to compute the weighting factors α_1 , α_2 , β_1 and β_2 . These four factors are needed in the subroutine SHAPE to evaluate the upstream weighting functions and their derivatives. SHAPE is called by Q4P0.

IV. RESULTS

In this chapter, two simulations are made. The first one is applied to an ideal system to test the code. The second one is applied to the Prairie Island, Mississippi River, which typifying a class of problems that SIMFE may be applied. Guidance for preparing the input data is given in Appendix B. The source program listing is given in Appendix E.

IV.1 Ideal System Application

The ideal system is consisting of a straight channel with 150 meters wide and 270 meters long and 3 meters deep. The region is covered by 45 elements and 60 nodal points as in Fig. 4. Assume a flow rate of $90 \text{ m}^3 \text{ s}^{-1}$ passes through the channel at its entrance. The velocity field as simulated by SIMFE is shown in Fig. 5. Uniform velocity of 0.2 ms^{-1} is obtained as expected. For one case, constant concentration is assumed at all six nodal points at the channel entrance. Computer printouts in Appendix C show that the normalized concentration is accurate to six digits. Thus, the accuracy of the model is assured and the internal consistency of the computer code is verified. For another case, constant concentration is assumed only at nodal points 3 and 4 while zero concentration is maintained at nodal points, 1, 2, 5, and 6. The iso-concentration line for this latter case is shown in Fig. 6. The results are compared with those obtained by analytical solution (Yeh and Tsai 1976) denoted by the symbol $\bullet$ in Fig. 6. The almost identical agreement partially validates the model.

ORNL-DWG 78-19274

Fig. 4. Finite element discretization of an ideal channel.

Fig. 5. Velocity vector field in an ideal system.

ORNL-DWG 78-19273R

Fig. 6. Normalized iso-concentration as predicted by SIMFE (——) and analytical solution (•).

IV.2 Prairie Island Application

The Prairie Island vicinity area is enclosed on the west by the river bank, on the east by Prairie Island. It extends to Sturgeon Lake on the north and to Barney's point on the south as shown in Fig. 7. During the month of June, 1976, a typical continuous flow rate of $13.7 \text{ m}^3 \text{ s}^{-1}$ is discharged to the region through discharge channel and $31 \text{ m}^3 \text{ s}^{-1}$ is returned to the plant through intake canal. For this month, a flow of $23.8 \text{ m}^3 \text{ s}^{-1}$ is drawn from Sturgeon Lake passing EF to the region, $4.0 \text{ m}^3 \text{ s}^{-1}$ and $18.8 \text{ m}^3 \text{ s}^{-1}$ of flows are returned to the Mississippi River through sections AB and CD, respectively. These inflows and outflows are obtained according to the flow net analysis (Stefan and Anderson 1977).

The area of interest is discretized by 91 elements and 127 nodal points as in Fig. 7. Using the above inflow and outflow information along with the geometry and bathymetry of the impoundment, the hydrodynamic model generates the flow field as shown in Fig. 8.

Assume that the discharge from the channel is maintained at a constant Dissolved Oxygen (DO) concentration of 1.00 ppm. A value of DO depletion rate of $3.2 \times 10^{-5} \text{ s}^{-1}$ and typical dispersivities of $a_L = a_T = 99 \text{ m}$ are used to represent the physical parameters in the system. The iso-concentration line as simulated by the pollutant transport model is shown in Fig. 9. These iso-lines are consistent with the flow pattern in Figure 8. The input and output data for this simulation is given in Appendix D.

It must be cautioned that the model should be verified and calibrated against all the system parameters, such as K_m , a_T , a_L , etc., before it is applied to a practical problem.

Fig. 7. Finite element directization of Prairie Island.

Fig. 8. Flow rate vectors as predicted by the model.

ORNL-DWG 78-2C088R

Fig. 9. Iso-concentration lines of Dissolved Oxygen (DO) at Prairie as predicted by the model.

V. NOTATION

A_e	= Area of the element e
B_e	= Boundary of the element e
$\{B_i\}$	= Global boundary vector
c	= Concentration
$c_1(x,y,t)$	= Value of c on the boundary B_1
$\{c_j\}$	= concentration vector
$[C_{ij}]$	= Element coefficient matrix
$\{D_i\}$	= Element column matrix
$[E_{ij}]$	= Element boundary matrix
f	= Coriolis parameter
f_s	= Value of the normal derivative of ψ on $S(x,y) = 0$
h	= Water depth
$[J]$	= Transformation Jacobian
J	= Determinant of $[J]$
κ	= Linearized friction parameter
K_m	= First order reaction rate
K_x	= Dispersion coefficient in the x-direction
K_y	= Dispersion coefficient in the y-direction
L	= Differential operator
$L(x,y)$	= A function describing the water-land interface

M	= Artificial source or sink of pollutant mass
$[M_{ij}]$	= Element mass matrix
N_i	= Base function at nodal point i
n_x	= Directional cosine in the x -direction
n_y	= Directional cosine of a curve in the y -direction
$q_1(x,y,t)$	= Total flux of the pollutant through the boundary B_3
$\{Q_i\}$	= Element boundary column matrix
R	= The region of interest
R_e	= Region of the element e
$\{R_i\}$	= Modified element column matrix
$S(x,y)$	= A function describing the open water boundaries
$[S_{ij}]$	= Element stiff matrix
t	= Time
$[T_{ij}]$	= Global coefficient matrix
Δt	= Time step
U	= x -component flow rate, or a velocity scale
$\bar{u}$	= Vertically averaged x -component velocity
V	= y -component flow rate
$\bar{v}$	= Vertically averaged y -component velocity
W_i	= Weighting function of nodal point i
x	= One of the global spatial coordinates
x_i	= Global x -coordinate of nodal point i
$\{X_i\}$	= Global load vector before applying boundary condition

y	= One of the global spatial coordinate
y_i	= Global y-coordinate of nodal point i
$\{Y_i\}$	= Global load vector after applying boundary conditions
α_1	= Weighting factor on one side of the element
α_2	= Weighting factor on one side of the element
β_1	= Weighting factor on one side of the element
β_2	= Weighting factor on one side of the element
ξ	= One of the local spatial coordinates
ξ_i	= ξ -coordinate of the nodal point i
η	= One of the local spatial coordinates
η_i	= η -coordinate of the nodal point i
ϕ	= A general function
$\hat{\phi}$	= Approximate solution of
ϕ_i	= The value of ϕ at nodal point i
ψ	= Stream function
ψ_i	= The value of ψ at nodal point i
ψ_L	= Stream function on the curve $L(x,y) = 0$
ψ_S	= Stream function on the curve $S(x,y) = 0$
λ	= Decay constant
ρ	= Water density
τ_x^w	= Wind stress component in the x-direction
τ_y^w	= Wind stress component in the y-direction

VI. REFERENCES

1. Abbott, M. B., et al. 1975. Systems Modeling of Stratified Fluids, Symposium on Modeling Techniques, Modeling 75, San Francisco, California.
2. Christodoulou, G. C., J. J. Connor, B. R. Pearce. 1976. Mathematical Modeling of Dispersion in Stratified Waters, Report No. MITSG 76-14, MIT, Cambridge, Mass.
3. Clough, R. W. 1971. Analysis of Structural Vibrations and Dynamic Response, in Recent Advances in Matrix Methods of Structural Analysis and Design, R. H. Gallagher, y. Yamado, and J. T. Oden (eds.), Univeristy of Alabama Press, Huntsville, Alabama.
4. Gureghian, A. M., D. S. Ward, and R. W. Cleary. 1978. A Finite Element Model for the Migration of Leachate from a Stationary Landfill in Long Island, New York, Submitted for Publication.
5. Hutton, S., and D. Anderson. 1971. Finite Element Method: A Galerkin Approach, J. Eng. Mech., ASCE. Vol. 96, 1503-1519.
6. Huyakorn, P. S. 1976. An Upwind Finite Element Scheme for Imporved Solution of the Convective-Diffusion Equation, Research Report No. 76-WR-2, Dept. of Civil Engineering, Princeton University, Princeton, New Jersey.
7. Lamb, Sir Horace. 1932. Hydrodynamics. Dover Publications, New York, New York. pp. 738.
8. Lee, K. K. 1972. Wind-induced and Thermally-induced Currents in Great Lakes, Water Resources Research, Vol. 8, No. 6.

9. Leendertse, J. J. 1970. A Water-quality Simulation Model for Well-mixed Estuaries and Coastal Seas: Vol. 1, Principles of Computations, RM-6230-RC, Rand Corporation, Santa Monica, California.
10. Liggett, J. A. 1975. Stratified Lake Circulation Calculations by the Finite Element Method. Proceedings of XVI I.A.H.R. Congress, Sao Paulo.
11. Schlichting, H., and J. Kestin. 1968. Boundary-layer Theory. McGraw-Hill Book Company, New York. pp. 747.
12. Simons, T. J. 1973. Development of three-dimensional numerical models of the Great Lakes. Scientific Series, No. 12, Canada Center for Inland Lakes, Burlington, Ontario.
13. Stefan, H., and K. Anderson. 1977. Analysis of Flow Through Sturgen Lake and Backwater Channel of Mississippi River Pool No. 3 near Red Wing, Minnesota. Project Report No. 165, St. Anthony Falls Hydraulic Laboratory, University of Minnesota, Minneapolis, Minnesota.
14. Wang, J. D., and J. J. Connor. 1975. Mathematical Modeling of Near Coastal Circulation, Report No. MITSG 75-13, MIT, Cambridge, Mass.
15. Yeh, G. T. 1976. Two-dimensional Hydrodynamic Model, Computer Program Development and Documentation, Report No. EN-122, Stone and Webster Engineering Corporation, Boston, Mass.
16. Yeh, G. T. 1980. Transport and Dispersion of Pollutants in Surface Impoundments: A Finite Difference Model. ORNL-5521. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

17. Yeh, G. T., A. P. Verma, and F. H. Lai. 1973. Unsteady Temperature Prediction for Cooling Ponds, Water Resources Research Vol. 9, No. 6.
18. Yeh, G. T., and Y. J. Tsai. 1976. Analytical three-dimensional transient modeling of effluent discharges, Water Resources Research Vol. 12, No. 3. 533-540.

VII. APPENDICES

APPENDIX A. APPLICABILITY OF THE MODEL

The applicability of the present model lies on the assumptions made for the hydrodynamic model in Section II.1. While assumptions (1) through (3) are obvious, assumptions (4) through (6) require some elaboration. To discuss those assumptions, one must refer to the governing equations from which Eq. (1) is derived. Under assumptions (1) through (3), the equations of motion are obtained by taking the ensemble average of the Navier-Stokes equations and written as follows:

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} = fv - \frac{1}{\rho} \frac{\partial p}{\partial x} + \frac{1}{\rho} \frac{\partial \tau_{xz}}{\partial z} \quad (A1)$$

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} = fu - \frac{1}{\rho} \frac{\partial p}{\partial y} + \frac{1}{\rho} \frac{\partial \tau_{yz}}{\partial z} \quad (A2)$$

$$\frac{\partial p}{\partial z} + \rho g = 0 \quad (A3)$$

where u , v , and w are the ensemble average velocity components in the x -, y -, and z -directions, respectively; p is the pressure; g is the gravitational acceleration; f is the Coriolis coefficient; t is the time; and τ_{xz} and τ_{yz} are the combined apparent and viscous stress components in the x - and y -directions, respectively (Schlichting and Kestin 1968). It must be noted that terms $\partial \tau_{xx}/\partial x$, $\partial \tau_{xy}/\partial y$ and $\partial \tau_{yx}/\partial x$, $\partial \tau_{xy}/\partial y$, in Eqs. (A1) and (A2), respectively, have been omitted because they are small compared to terms, $\partial \tau_{xz}/\partial z$ and $\partial \tau_{yz}/\partial z$, respectively.

The equation of continuity of an incompressible fluid mass may be written as:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad (A4)$$

The number of unknowns in Eqs. (A1) through (A4) exceeds the number of equations for the problem. The problem can be closed by relating the stress components, τ_{xz} and τ_{yz} to the velocity components, u and v through the concept of the eddy viscosity. For the present problem, this can be written as

$$\tau_{xz} = \rho v_e \frac{\partial u}{\partial z} \quad (A5)$$

and

$$\tau_{yz} = \rho v_e \frac{\partial v}{\partial z} \quad (A6)$$

where v_e is the total vertical eddy viscosity.

It has been pointed out (Lamb 1932) that the effects of wind on a water body, to which Eqs. (A1) through (A6) are applicable, would approach steady state for a time scale, t_e ,

$$t_e = 4 h^2 / (\pi^2 v_e) \quad (A7)$$

In the mean time, it has been shown (Lamb 1932) that the effect of earth rotation on the water body would approach steady for a time scale, t_f

$$t_t = \frac{h}{\sqrt{v_e f}} \quad (A8)$$

A third time scale one has to consider for steady motion is the resident time of the water particle in the water body. This resident time, t_Q , can be approximated by:

$$t_Q = \frac{v}{Q} = \frac{h L^2}{Q} \quad (A9)$$

where v is the volume of water body under consideration, Q is the total flow-through rate, and L is the representative horizontal length.

If the assumption of steady motion is to be valid, the time scales, t_f 's for the respectively applied external forces must be greater than those given in Eqs. (A7) through (A9). It can be seen that all conditions presented above can be met for most of the surface impoundments. Take for example, a typical value of $v_e = 100$ cm^2/sec ($0.1 \text{ ft}^2/\text{sec}$), $h = 500 \text{ cm}$ (15 ft), and $f = 10^{-4} \text{ s}^{-1}$ would yield $t_e = 17$ minutes and $t_f = 1.4$ minutes. The time for constant flow operation is normally longer than that given by Eq. (A9). Thus, assumption (4) is a valid one.

The ratio of the convective-inertia force to the turbulent shear stress in Eqs. (A1) and (A2) can be characterized by a modified Reynolds number, R_N^* .

$$R_N^* = \frac{U_s h}{v_e} \frac{h}{L} \quad (A10)$$

where U_s is a representative velocity scale. This characterization is made based on the analysis of relative magnitude of order of the convective-inertia and turbulent shear stress. If this R_N^* is much

less than unit, then assumption (5) is valid. indeed, R_N^* is much less than unit for most of the surface impoundments. Expressed in the C. G. S. unit. U_s is in the order of 10^0 , h is in the order of 10^2 , and v_e is in the order of 10^2 . Thus, R_N^* is in the order of h/L , which is much smaller than unit for practically all surface impoundments. Hence, assumption (5) is a valid one.

The linearization of the bottom stresses results in a mathematical simplification of analysis. It is justifiable for small values of velocity in a typical surface impoundment (Simon 1973).

APPENDIX B. DATA INPUT GUIDE

CARD GROUP I

Format(20A4)

TITLE = Any characters on column 1 - 80

CARD GROUP II

Format (16I5)

NNP = Total numbers of nodal points

NEL = Total numbers of elements

NTI = Total numbers of time steps

KVEL = velocity input control or hydrodynamic simulation control: = 0 for steady state velocity
= 1 for unsteady state velocity

KBV = Boundary value input control for pollutant model:
= 1 for transient boundary value,
= 0 for constant boundary value,

KSOS = Source/sink input control:
= 0 for constant source/sink
= 1 for transient source/sink

KSTR = Output control:
= 0 no output on disk,
= 1 with output on disk

ITRANS = Transient simulation control:
= 0 steady state solution of concentration,
= 1 transient solution for concentration

NREAD = velocity input control, every NREAD steps read velocity from field from hydrodynamic simulation

IWET = Weighting function control:
= 0 Galerkin weighting function,
= 1 Upstream weighting function

ILUMP = Mass matrix lumping control:
= 0 no lumping
= 1 lumping

IMID = Time marching control:
= 0 central or backward difference,
= 1 mid-difference

CARD GROUP III

Format(8F10.0)

OMEGA = Time weighting parameter:
= 0.5 for central difference
= 1.0 for backward difference

DELT = Time step size

TMAX = Maximum simulation time

DELTMA = Maximum time step size allowed

CHNG = Percentage of time step changed

EPS = Error allowance for iteration

CARD GROUP IV

Format(80I1)

KPRO = Line printout control for initial time:
= 0 print nothing
= 1 print stream function
= 2 print stream function and velocity
= 3 print concentration
= 4 print concentration and material flux
= 5 print everything

KPR(I) = Same as KPRO but for I-th time step

CARD GROUP V

Format(I5,F5.0,3F10.0,I5,F5.0,3F10.0)

I = I-th nodal no.

R(I) = Initial concentration of I-th node

X(I) = X-coordinate of I-th node

Y(I) = Y-coordinate of I-th node

I1 = I1-th nodal no.

R(I1) = Initial concentration of I1-th node

X(I1) = X-coordinate of I1-th node

Y(I1) = Y-coordinate of I1th node

HH(I1) = Water depth of I1-th node

HH(I) = Water depth of I-th node

CARD GROUP VI

(Format (5I5))

M = M-th element
 IE(M,1) = Global nodal no. of the first node of element M
 IE(M,2) = Global nodal no. of the second node of element M
 IE(M,3) = Global nodal no. of the third node of element M
 IE(M,4) = Global nodal no. of the fourth node of element M

CARD GROUP VII

NAMELIST/SIDE/

ISIDE(I,1) = Global nodal no. of the beginning point of I-th side
 ISIDE(I,2) = Global nodal no. of the ending point of I-th side
 ISIDE(I,3) = Element no. of the I-th side
 ISIDE(I,4) = Local nodal no. of the beginning point of the I-th side
 ISIDE(I,5) = Local nodal no. of the ending point of the I-th side
 ISIDE(I,6) = Indicator specifying the location of boundary and type of boundary conditions applied:
 = 1 open boundary with given concentration,
 = 2 open boundary with concentration dependent BC,
 = 3 open boundary with zero flux,
 = 11 closed boundary with given concentration,
 = 12 closed boundary with concentration dependent BC,
 = 13 closed boundary with zero flux
 NSIDE = Total numbers of sides

CARD GROUP VIII

Card 1

Format(15)

NILND = Total numbers of islands

Card 2

Format (16I5)

NLNDS(I) = Total numbers of sides of the I-th island

Card 3 Format (16I5)

IILND(I,J,1) = Global nodal no. of the beginning point of J-th side of I-th island

IILND(I,J,2) = Global nodal no. of the ending point of the J-th side of I-th island

IILND(I,J,3) = Element no. of the J-th side of the I-th island

IILND(I,J,4) = Local nodal no. of the beginning point of the J-th side of the I-th island

IILND(I,J,5) = Local nodal no. of the ending point of the J-th side of the I-th island

CARD GROUP IX Format(8F10.0)

AL = Longitudinal dispersivity

AT = Transverse dispersivity

DD = Molecular diffusion coefficient

RK = First order reaction rate

RLAMD = Decay constant

CARD GROUP X Format(8F10.0)

CORIL = Coriolis parameter

RHOW = Water density

CKW = Linearized bottom stress coefficient

RHOA = Air density

CKA = Wind stress coefficient

WINANG = Angle between the x-coordinate and wind velocity

WINVEL = Wind speed

AVU = Estimated average current speed

CARD GROUP XI**NAMelist/BNDVH/**

- BVH(I)** = Boundary value of stream function of I-th Dirichlet point
- IBVH(I)** = Global nodal no. of I-th Dirichlet point
- NBVH** = Total numbers of points with given streamfunction values

CARD GROUP XII**NAMelist/SOSNL/**

- SOS(I)** = Source/sink value of I-th source/sink point
- ISOS(I)** = Global nodal no. of I-th source/sink point
- NSOS** = Total numbers of source/sink points

CARD GROUP XIII**NAMelist/BANDV/**

- BV(I)** = Given value of concentration of I-th Dirichlet point
- IBV(I)** = Global nodal no. of I-th point with known concentration
- NBV** = Total numbers of the points with known concentration

INPUT

[illegible]

APPENDIX C. OUTPUT (Continued)

INPUT TABLE 2: NODAL POINT DATA

NODE	X	Y	Z
01	100.0000	120.0000	1.0000
02	100.0000	150.0000	1.0000
03	210.0000	0.0	1.0000
04	210.0000	30.0000	1.0000
05	210.0000	60.0000	1.0000
06	210.0000	90.0000	1.0000
07	210.0000	120.0000	1.0000
08	210.0000	150.0000	1.0000
09	200.0000	0.0	1.0000
10	200.0000	30.0000	1.0000
11	200.0000	60.0000	1.0000
12	200.0000	90.0000	1.0000
13	200.0000	120.0000	1.0000
14	200.0000	150.0000	1.0000
15	270.0000	0.0	1.0000
16	270.0000	30.0000	1.0000
17	270.0000	60.0000	1.0000
18	270.0000	90.0000	1.0000
19	270.0000	120.0000	1.0000
20	270.0000	150.0000	1.0000

INPUT TABLE 3: ELEMENT DATA

GLOBAL INDICES OF ELEMENT BODIES					
ELEMENT	1	2	3	4	BODY DIFF.
1	1	7	8	2	7
2	2	8	9	3	7
3	3	9	10	4	7
4	4	10	11	5	7
5	5	11	12	6	7
6	7	13	14	8	7
7	8	14	15	9	7
8	9	15	16	10	7
9	10	16	17	11	7
10	11	17	18	12	7
11	13	19	20	14	7
12	14	20	21	15	7
13	15	21	22	16	7
14	16	22	23	17	7
15	17	23	24	18	7
16	19	25	26	20	7
17	20	26	27	21	7
18	21	27	28	22	7
19	22	28	29	23	7
20	23	29	30	24	7
21	25	31	32	26	7
22	26	32	33	27	7
23	27	33	34	28	7
24	28	34	35	29	7
25	29	35	36	30	7
26	31	37	38	32	7
27	32	38	39	33	7
28	33	39	40	34	7
29	34	40	41	35	7
30	35	41	42	36	7
31	37	43	44	38	7
32	38	44	45	39	7
33	39	45	46	40	7
34	40	46	47	41	7
35	41	47	48	42	7
36	43	49	50	44	7
37	44	50	51	45	7
38	45	51	52	46	7
39	46	52	53	47	7
40	47	53	54	48	7
41	49	55	56	50	7
42	50	56	57	51	7
43	51	57	58	52	7
44	52	58	59	53	7
45	53	59	60	54	7

APPENDIX C. OUTPUT (Continued)

FIGURE 1. SECONDARY VALUE DATA

NO. OF POINTS WITH DISCRETEY NO. = 4

NO.	1	2	3	4	5	6	7	8
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

PLOTTER COMMENCING

----- DISSEPLA VERSION 7.5 -----
NO. OF PLOTS PLOT = 1

PLOT NO. 1 WITH THE TITLE
FIGURE 1 ELEMENT GUIDES
HAS BEEN COMPLETED.

PLOT NO. 1
PLOT 1 22.37.79 22 JUL 1979 JOB=TCFOLD3. ORNL DISSEPLA VER 7.5

DATA FOR PLOT

NO. OF CURVES KNOWN = 2

HCSTL. AXIS LENGTH 6.5 INS.
VSTL. AXIS LENGTH 9.0 INS.

HCSTL. ORIGIN 0.0 VSTL. ORIGIN 0.0

HCSTL. AXIS LINEAR
STEP SIZE 0.1077E-01 UNITS/INCH

VSTL. AXIS LINEAR
STEP SIZE 0.1000E-01 UNITS/INCH

LOCATION OF CURRENT PHYSICAL ORIGIN
X = 1.25 Y = 0.55 INCHES
FROM LOWER LEFT CORNER OF PAGE

FLOW TABLE 1 STEADY STATE STREAM FUNCTION

1	5.0000E-01	7.2000E-01	5.0000E-01	3.6000E-01	1.0000E-01	0.0	9.0000E-01	7.2000E-01
9	5.0000E-01	3.6000E-01	1.0000E-01	0.0	9.0000E-01	7.2000E-01	5.0000E-01	3.6000E-01
17	1.0000E-01	0.0	9.0000E-01	7.2000E-01	0.0	9.0000E-01	1.0000E-01	0.0
25	9.0000E-01	7.2000E-01	5.0000E-01	3.6000E-01	1.0000E-01	0.0	9.0000E-01	7.2000E-01
33	5.0000E-01	3.6000E-01	1.0000E-01	0.0	9.0000E-01	7.2000E-01	5.0000E-01	3.6000E-01
41	1.0000E-01	0.0	9.0000E-01	7.2000E-01	5.0000E-01	3.6000E-01	1.0000E-01	0.0
49	5.0000E-01	7.2000E-01	5.0000E-01	3.6000E-01	1.0000E-01	0.0	9.0000E-01	7.2000E-01
57	5.0000E-01	1.0000E-01	1.0000E-01	0.0				

FLOW TABLE 2 STEADY STATE VELOCITY FIELD

VTL-X AT NODES

VTL-Y AT NODES

1	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	1.7000E-06	2.5806E-06	1.0759E-06	3.0092E-06
5	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	8.5461E-07	7.9540E-06	1.3645E-07	1.9332E-06
9	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	8.8001E-07	1.0648E-06	1.1767E-06	-1.9047E-06
13	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	-1.1361E-07	5.7587E-07	-7.5850E-07	6.1980E-07
17	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	8.8240E-07	-1.0160E-06	2.1631E-06	-1.3780E-07
21	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	3.2047E-07	-8.1290E-07	-1.5487E-07	2.7985E-06
25	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	2.6918E-07	-8.5707E-06	1.2643E-06	-1.0103E-07
29	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	-7.6540E-09	-2.5444E-06	-2.7900E-07	1.1189E-07
33	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	-1.7328E-06	5.5012E-07	2.6221E-07	3.5427E-06
37	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	2.9031E-06	6.1738E-09	2.0331E-07	2.5992E-07
41	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	3.4092E-07	1.2528E-06	2.4246E-07	-2.9535E-07
45	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	2.7459E-06	3.5321E-07	-1.2492E-07	-1.6160E-06
49	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	-9.6309E-06	6.3933E-07	-3.5668E-07	1.0543E-06
53	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	1.9567E-07	3.3652E-06	-4.9587E-06	1.6289E-06
57	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	-1.8521E-06	1.9579E-06	5.5913E-07	3.6276E-06

APPENDIX C. OUTPUT (Continued)

OUTPUT TABLE 1 STEADY STATE CONCENTRATION

AT NODE 1 CONCENTRATION AT NODES 1,1+1, . . . 1+7

1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
49	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
57	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

PLOTING COMMENCING

----- DISPLA VERSION 7.5 -----
 NC. OF FIRST PLOT 2

PLOT NO. 2 WITH THE TITLE
 FIGURE 8 PLOT PAGE PATTERNS
 HAS BEEN COMPLETED.

PLOT TO BE PLOTTED
 PLOT 2 23.37.00 MON 22 JAN, 1979 JOB=TCYFOL03. ORNL DISPLA VER 7.5

DATA FOR PLOT

NC. OF CURVES DRAWN 0

HCPIX. AXIS LENGTH 6.5 INS.
 VERT. AXIS LENGTH 9.0 INS.

HCPIX. ORIGIN 0.0 VERT. ORIGIN 0.0

HCPIX. AXIS LINEAR
 STEP SIZE 0.6233E 00 UNITS/INCH

VERT. AXIS LINEAR
 STEP SIZE 0.5556E 00 UNITS/INCH

 . LOCATION OF CURRENT PHYSICAL ORIGIN .
 . X= 1.25 Y= 0.55 INCHES .
 . PLOT LOCUS LEFT CORNER OF PAGE .

THE VALUE OF IPEN IS NOT PERMITTED IN THE CALL OF PLOT X=0.0
 THE VALUE OF 2 IS USED FOR IPEN

Y=0.0

IPEN=

999

END DISPLA -- 2006 VECTORS GENERATED IN 2 PLOT FRAMES.

APPENDIX C. OUTPUT (Continued)STEADY STATE SOLUTION IS SOUGHT AND ARE GIVEN BELOW WITH $\epsilon = 1$

FLOW TABLE 3 STEADY STATE STREAM FUNCTION

1	9.7000E-01	7.2000E-01	5.4000E-01	3.6000E-01	1.8000E-01	0.0	9.0000E-01	7.2000E-01
9	5.4000E-01	3.6000E-01	1.8000E-01	0.0	9.0000E-01	7.2000E-01	5.4000E-01	3.6000E-01
17	1.8000E-01	0.0	9.0000E-01	7.2000E-01	5.4000E-01	3.6000E-01	1.8000E-01	0.0
25	9.0000E-01	7.2000E-01	5.4000E-01	3.6000E-01	1.8000E-01	0.0	9.0000E-01	7.2000E-01
33	5.4000E-01	3.6000E-01	1.8000E-01	0.0	9.0000E-01	7.2000E-01	5.4000E-01	3.6000E-01
41	1.8000E-01	0.0	9.0000E-01	7.2000E-01	5.4000E-01	3.6000E-01	1.8000E-01	0.0
49	9.0000E-01	7.2000E-01	5.4000E-01	3.6000E-01	1.8000E-01	0.0	9.0000E-01	7.2000E-01
57	5.4000E-01	3.6000E-01	1.8000E-01	0.0				

FLOW TABLE 4 STEADY STATE VELOCITY FIELD

VEL-X AT NODES					VEL-Y AT NODES			
1	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	1.7000E-08	2.5806E-06	1.0759E-06	3.0092E-06
5	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	8.5461E-07	7.9548E-08	1.3645E-07	1.9332E-06
9	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	4.8041E-07	1.8668E-06	1.1767E-06	-1.9047E-08
13	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	-1.1361E-07	5.7587E-07	-7.5850E-07	6.1980E-07
17	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	8.8248E-07	-1.4164E-08	2.1631E-08	-1.3780E-07
21	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	3.2897E-07	-8.1294E-07	-1.5887E-07	2.7985E-08
25	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	2.6914E-07	-8.4707E-08	1.2633E-06	-1.0143E-07
29	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	-7.6540E-09	-2.5444E-08	-2.7900E-07	1.1449E-07
33	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	-1.7328E-06	5.5012E-07	2.6221E-07	3.5427E-08
37	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	2.9031E-08	6.1734E-09	2.0331E-07	2.5992E-07
41	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	3.4092E-07	1.2524E-08	2.4246E-07	-2.9535E-07
45	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	2.7459E-06	3.5321E-07	-1.2492E-07	-1.6160E-08
49	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	-9.6309E-08	6.3933E-07	-3.5668E-07	1.0533E-06
53	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	1.9567E-07	3.3652E-07	-4.9587E-08	1.6289E-06
57	6.0000E-01	6.0000E-01	6.0000E-01	6.0000E-01	-1.8521E-06	1.9555E-06	5.5913E-07	3.6276E-08

OUTPUT TABLE 2 STEADY STATE CONCENTRATION

AT NODE I CONCENTRATION AT NODES I, I+1, . . . I+7

1	0.0	0.0	1.0000E-00	1.0000E-00	0.0	0.0	-1.4186E-02	1.4864E-01
9	8.5245E-01	8.5846E-01	1.4864E-01	-1.4186E-02	2.4147E-02	2.2878E-01	7.5914E-01	7.5914E-01
17	2.2879E-01	2.4147E-02	7.7456E-02	2.7575E-01	6.8553E-01	6.8553E-01	2.7575E-01	7.7457E-02
25	1.3059E-01	3.0578E-01	6.2893E-01	6.2893E-01	3.0578E-01	1.3059E-01	1.7808E-01	3.2653E-01
33	5.8444E-01	5.8444E-01	3.2653E-01	1.7808E-01	2.1854E-01	3.4174E-01	5.4900E-01	5.4900E-01
41	3.4175E-01	2.1854E-01	2.5213E-01	3.5333E-01	5.2061E-01	5.2061E-01	3.5333E-01	2.5213E-01
49	2.7881E-01	3.6212E-01	4.9849E-01	4.9849E-01	3.6212E-01	2.7881E-01	2.9033E-01	3.6585E-01
57	4.8900E-01	4.8900E-01	3.6585E-01	2.9033E-01				

APPENDIX D. INPUT AND OUTPUT AT PRAIRIE ISLAND

INPUT

PRAIRIE ISLAND APPLICATION OF SINCE WITH ISLANDS - TYPICAL JUNE 1976									
117	91	100	0	0	0	0	0	101	0
1.0	5.0	100000.0	20.0	0.5	0.01	0	0	0	0
55	3	3	3	3	3	3	3	3	3
1	1120.0	160.0	10.0	2	1200.0	176.0	10.0		
3	1272.0	216.0	10.0	4	1328.0	240.0	10.0		
5	1508.0	280.0	10.0	6	1580.0	300.0	10.0		
7	1188.0	516.0	8.0	8	1272.0	560.0	8.0		
9	56.0	1108.0	8.0	10	196.0	1080.0	8.0		
11	800.0	960.0	8.0	12	560.0	900.0	8.0		
13	720.0	864.0	8.0	14	936.0	720.0	8.0		
15	1000.0	720.0	10.0	16	1120.0	720.0	10.0		
17	1201.0	720.0	10.0	18	80.0	1176.0	8.0		
19	228.0	1120.0	8.0	20	400.0	1056.0	8.0		
21	560.0	1008.0	8.0	22	744.0	976.0	8.0		
23	880.0	960.0	15.0	24	596.0	944.0	15.0		
25	1108.0	928.0	15.0	26	1200.0	916.0	15.0		
27	96.0	1248.0	8.0	28	240.0	1200.0	8.0		
29	400.0	1180.0	8.0	30	560.0	1184.0	8.0		
31	784.0	1116.0	8.0	32	880.0	1108.0	15.0		
33	996.0	1100.0	15.0	34	1100.0	1084.0	15.0		
35	1176.0	1076.0	15.0	36	120.0	1320.0	10.0		
37	240.0	1100.0	10.0	38	400.0	1288.0	5.0		
39	560.0	1280.0	5.0	40	800.0	1264.0	5.0		
41	920.0	1260.0	5.0	42	1000.0	1248.0	10.0		
43	1088.0	1216.0	15.0	44	1176.0	1200.0	5.0		
45	256.0	1440.0	3.0	46	400.0	1440.0	3.0		
47	560.0	1440.0	3.0	48	720.0	1440.0	3.0		
49	880.0	1424.0	5.0	50	976.0	1404.0	10.0		
51	1080.0	1376.0	15.0	52	1144.0	1360.0	5.0		
53	320.0	1600.0	3.0	54	440.0	1600.0	3.0		
55	592.0	1600.0	3.0	56	728.0	1568.0	3.0		
57	880.0	1520.0	5.0	58	976.0	1520.0	10.0		
59	1080.0	1520.0	15.0	60	1144.0	1520.0	5.0		
61	336.0	1760.0	3.0	62	480.0	1744.0	3.0		
63	640.0	1724.0	3.0	64	800.0	1696.0	3.0		
65	880.0	1680.0	5.0	66	976.0	1680.0	10.0		
67	1080.0	1680.0	15.0	68	1144.0	1680.0	5.0		
69	400.0	1920.0	5.0	70	496.0	1920.0	5.0		
71	616.0	1920.0	5.0	72	760.0	1920.0	5.0		
73	880.0	1920.0	8.0	74	984.0	1952.0	10.0		
75	1096.0	1976.0	15.0	76	1200.0	2000.0	10.0		
77	400.0	2080.0	10.0	78	492.0	2084.0	10.0		
79	608.0	2092.0	10.0	80	720.0	2108.0	10.0		
81	880.0	2108.0	12.0	82	984.0	2116.0	12.0		
83	1096.0	2120.0	12.0	84	1200.0	2124.0	12.0		
85	240.0	2192.0	10.0	86	360.0	2164.0	10.0		
87	400.0	2240.0	12.0	88	560.0	2240.0	12.0		
89	720.0	2240.0	12.0	90	880.0	2240.0	12.0		
91	984.0	2240.0	15.0	92	1096.0	2240.0	15.0		
93	1200.0	2240.0	15.0	94	240.0	2240.0	15.0		
95	240.0	2320.0	15.0	96	400.0	2324.0	12.0		
97	560.0	2312.0	12.0	98	720.0	2340.0	12.0		
99	880.0	2348.0	12.0	100	984.0	2356.0	12.0		
101	1096.0	2364.0	12.0	102	1200.0	2372.0	12.0		
103	240.0	2376.0	8.0	104	320.0	2400.0	8.0		
105	560.0	2480.0	8.0	106	720.0	2480.0	10.0		
107	880.0	2480.0	10.0	108	984.0	2480.0	10.0		
109	1096.0	2480.0	10.0	110	1200.0	2480.0	10.0		
111	412.0	2548.0	5.0	112	640.0	2640.0	8.0		
113	720.0	2640.0	10.0	114	880.0	2640.0	10.0		
115	984.0	2640.0	10.0	116	1096.0	2640.0	10.0		
117	1200.0	2640.0	5.0						
1	1	2	6	5					
2	2	3	7	6					
3	3	4	8	7					
4	4	5	9	8					
5	5	6	10	9					
6	6	7	11	10					
7	7	8	12	11					
8	8	9	13	12					
9	9	10	14	13					
10	10	11	15	14					
11	11	12	16	15					
12	12	13	17	16					
13	13	14	18	17					
14	14	15	19	18					
15	15	16	20	19					
16	16	17	21	20					
17	17	18	22	21					
18	18	19	23	22					
19	19	20	24	23					
20	20	21	25	24					
21	21	22	26	25					
22	22	23	27	26					
23	23	24	28	27					
24	24	25	29	28					
25	25	26	30	29					
26	26	27	31	30					

APPENDIX D. OUTPUT

PRAIRIE ISLAND APPLICATIONS OF SILVER HORN ISLANDS - CIRCUIT JUNE 1976

IDENT: TABLE 1 BASIC PARAMETERS

WHEELS OF DOGS	117
WHEELS OF THERMIS	49
NO. OF TIME INCREMENTS	100
VELOCITY INPUT CONTROL	0
BOUNDARY VALUE INPUT CONTROL	0
SOURCE INPUT CONTROL	0
RELIABLE STORAGE CONTROL	0
TRANSIENT SIMULATION CONTROL	0
FEAR CONTROL	101
TIME INTEGRATION PARAMETERS	1.00
TIME INCREMENT	5.00
MAXIMUM VALUE OF TIME	1.00E-02
MAXIMUM VALUE OF DELT	0.20E-02
MULTIPLIER FOR TIME INCREMENT	0.500
SPRINKLE TOLERANCE	1.00E-01
LIGHTNING PROTECTION CONTROL	0
LUMPING CONTROL	0
TIME DIFFERENCE CONTROL	0

[illegible]

TABLE 2. LOCAL ECOSYSTEM

PCP	I	E	R
1	1120.3200	160.0000	10.0000
2	1200.0000	176.0000	10.3000
3	1272.3000	216.0000	10.3000
4	1320.3000	240.3000	10.3000
5	1030.3000	480.3000	10.3000
6	1080.3000	520.0000	10.3000
7	1180.0000	516.0000	8.3000
8	1272.3000	560.0000	9.3000
9	56.0000	100.0000	9.3000
10	104.3000	100.0000	9.3000
11	800.3000	960.0000	8.3000
12	460.0000	920.0000	8.0000
13	720.3000	640.3000	8.3000
14	436.0000	720.0000	8.3000
15	1000.3000	720.0000	10.3000
16	1120.3000	720.0000	10.0000
17	1200.3000	720.0000	10.3000
18	80.0000	1176.3000	8.3000
19	270.3000	1120.3000	8.3000
20	800.3000	1056.0000	8.3000
21	540.0000	1070.0000	8.3000
22	740.0000	976.0000	8.3000
23	880.3000	960.0000	10.3000
24	696.0000	940.0000	10.3000
25	1100.3000	920.3000	10.3000
26	1200.0000	916.0000	10.3000
27	96.0000	1240.0000	8.3000
28	200.3000	1200.3000	8.3000
29	400.3000	1180.0000	8.3000
30	560.0000	1180.3000	8.3000
31	780.3000	1116.0000	8.0000
32	980.0000	1100.0000	10.3000
33	906.0000	1100.3000	10.3000
34	1100.3000	1080.0000	10.3000
35	1176.3000	1076.3000	10.3000
36	120.3000	1320.3000	10.3000
37	240.3000	1300.3000	10.3000
38	400.3000	1280.0000	5.3000
39	560.0000	1280.0000	5.3000
40	800.3000	1260.3000	5.3000

APPENDIX D. OUTPUT (Continued)

INPUT TABLE 2: SCALAR POINT DATA

POINT	X	Y	R
41	920.0000	1260.0000	5.0000
42	1070.0000	1200.0000	10.0000
43	1000.0000	1216.0000	15.0000
44	1176.0000	1200.0000	5.0000
45	256.0000	1440.0000	3.0000
46	400.0000	1440.0000	3.0000
47	560.0000	1440.0000	3.0000
48	720.0000	1440.0000	3.0000
49	880.0000	1424.0000	5.0000
50	976.0000	1424.0000	10.0000
51	1080.0000	1376.0000	15.0000
52	1144.0000	1360.0000	5.0000
53	320.0000	1600.0000	3.0000
54	440.0000	1600.0000	3.0000
55	592.0000	1600.0000	3.0000
56	720.0000	1560.0000	3.0000
57	880.0000	1520.0000	5.0000
58	976.0000	1520.0000	10.0000
59	1080.0000	1520.0000	15.0000
60	1144.0000	1520.0000	5.0000
61	136.0000	1760.0000	3.0000
62	400.0000	1744.0000	3.0000
63	640.0000	1728.0000	3.0000
64	900.0000	1696.0000	3.0000
65	1080.0000	1680.0000	5.0000
66	976.0000	1680.0000	10.0000
67	1080.0000	1680.0000	15.0000
68	1144.0000	1680.0000	5.0000
69	400.0000	1920.0000	5.0000
70	496.0000	1920.0000	5.0000
71	616.0000	1920.0000	5.0000
72	760.0000	1920.0000	5.0000
73	880.0000	1920.0000	8.0000
74	984.0000	1952.0000	10.0000
75	1056.0000	1976.0000	15.0000
76	1200.0000	2000.0000	10.0000
77	400.0000	2080.0000	10.0000
78	452.0000	2080.0000	10.0000
79	608.0000	2092.0000	10.0000
80	720.0000	2108.0000	10.0000
81	880.0000	2108.0000	12.0000
82	984.0000	2116.0000	12.0000
83	1096.0000	2120.0000	12.0000
84	1200.0000	2124.0000	12.0000
85	240.0000	2192.0000	10.0000
86	360.0000	2160.0000	10.0000
87	400.0000	2240.0000	12.0000
88	560.0000	2240.0000	12.0000
89	720.0000	2240.0000	12.0000
90	880.0000	2240.0000	12.0000
91	984.0000	2240.0000	15.0000
92	1096.0000	2240.0000	15.0000
93	1200.0000	2240.0000	15.0000
94	240.0000	2240.0000	15.0000
95	240.0000	2320.0000	15.0000
96	400.0000	2320.0000	12.0000
97	560.0000	2332.0000	12.0000
98	720.0000	2340.0000	12.0000
99	880.0000	2340.0000	12.0000
100	984.0000	2356.0000	12.0000
101	1096.0000	2364.0000	12.0000
102	1200.0000	2372.0000	12.0000
103	240.0000	2376.0000	8.0000
104	320.0000	2400.0000	8.0000
105	460.0000	2400.0000	8.0000

APPENDIX D. OUTPUT (Continued)

INFO: TABLE 2 MODAL POINT DATA

MODE	X	Y	Z
106	720.0000	2480.0000	10.0000
107	880.0000	2480.0000	10.0000
108	980.0000	2480.0000	10.0000
109	1096.0000	2480.0000	10.0000
110	1200.0000	2480.0000	10.0000
111	812.0000	2580.0000	5.0000
112	640.0000	2680.0000	8.0000
113	720.0000	2680.0000	10.0000
114	880.0000	2680.0000	10.0000
115	980.0000	2680.0000	10.0000
116	1096.0000	2680.0000	10.0000
117	1200.0000	2680.0000	5.0000

INFO: TABLE 3 ELEMENT DATA

GLOBAL SUBTYPES OF ELEMENT TYPES

ELEMENT	1	2	3	4	MODE DIFF.
1	1	2	6	5	5
2	2	3	7	6	5
3	3	4	8	7	5
4	5	6	15	14	10
5	6	7	16	15	10
6	7	8	17	16	10
7	8	10	19	18	10
8	10	11	20	19	10
9	11	12	21	20	10
10	12	13	22	21	10
11	13	14	23	22	10
12	14	15	24	23	10
13	15	16	25	24	10
14	16	17	26	25	10
15	16	18	28	27	10
16	19	20	29	28	10
17	20	21	30	29	10
18	21	22	31	30	10
19	22	23	32	31	10
20	23	24	33	32	10
21	24	25	34	33	10
22	25	26	35	34	10
23	27	28	37	36	10
24	28	29	38	37	10
25	28	30	39	38	10
26	30	31	40	39	10
27	31	32	41	40	10
28	32	33	42	41	10
29	33	34	43	42	10
30	34	35	44	43	10
31	37	38	46	45	9
32	38	39	47	46	9
33	39	40	48	47	9
34	41	42	50	49	9
35	42	43	51	50	9
36	43	44	52	51	9
37	45	46	54	53	9
38	46	47	55	54	9
39	47	48	56	55	9
40	48	49	57	56	9

APPENDIX D. OUTPUT (Continued)

INPUT TABLE 1 ELEMENT DATA

GLOBAL INDICES OF ELEMENT CODES					
ELEMENT	1	2	3	4	MODE DIFF.
41	49	50	58	57	9
42	40	51	59	58	9
43	51	52	60	59	9
44	52	58	62	61	9
45	54	55	63	62	9
46	55	56	64	63	9
47	57	58	66	65	9
48	58	59	67	66	9
49	59	60	68	67	9
50	61	62	70	69	9
51	62	63	71	70	9
52	63	64	72	71	9
53	64	65	73	72	9
54	65	66	74	73	9
55	66	67	75	74	9
56	67	68	76	75	9
57	65	70	78	77	9
58	70	71	79	78	9
59	71	72	80	79	9
60	72	73	81	80	9
61	73	74	82	81	9
62	74	75	83	82	9
63	75	76	84	83	9
64	77	78	87	86	10
65	78	79	88	87	10
66	79	80	89	88	10
67	80	81	90	89	10
68	81	82	91	90	10
69	82	83	92	91	10
70	83	84	93	92	10
71	85	86	87	94	9
72	94	87	96	95	9
73	87	88	97	96	10
74	88	89	98	97	10
75	89	90	99	98	10
76	90	91	100	99	10
77	91	92	101	100	10
78	92	93	102	101	10
79	95	96	104	103	9
80	96	97	105	104	9
81	97	98	106	105	9
82	98	99	107	106	9
83	99	100	108	107	9
84	100	101	109	108	9
85	101	102	110	109	9
86	104	105	112	111	8
87	105	106	113	112	8
88	106	107	114	113	8
89	107	108	115	114	8
90	108	109	116	115	8
91	109	110	117	116	8

APPENDIX D. OUTPUT (Continued)

INPUT TABLE 4 SIDE BOUNDARY DATA: NO. OF SIDES= 54

SIDE	1	2	3	4	5	6
1	9	10	7	1	2	13
2	10	11	8	1	2	13
3	11	12	9	1	2	13
4	12	13	10	1	2	13
5	13	14	11	1	2	13
6	14	5	4	4	1	13
7	5	1	1	4	1	13
8	1	2	1	1	2	2
9	2	3	2	1	2	2
10	3	4	3	1	2	2
11	4	8	3	2	3	13
12	8	17	6	2	3	13
13	17	26	14	2	3	13
14	26	35	22	2	3	13
15	35	44	30	2	3	13
16	44	52	37	2	3	13
17	52	60	44	2	3	13
18	60	68	51	2	3	13
19	68	76	58	2	3	13
20	76	84	65	2	3	2
21	84	93	72	2	3	2
22	93	102	80	2	3	2
23	102	110	87	2	3	2
24	110	117	93	2	3	2
25	117	126	93	3	4	1
26	126	135	92	3	4	1
27	135	144	91	3	4	1
28	144	153	90	3	4	1
29	153	162	89	3	4	1
30	162	171	88	3	4	13
31	171	180	88	4	1	13
32	180	189	81	3	4	13
33	189	195	81	4	1	2
34	195	204	74	4	1	2
35	204	213	73	4	1	2
36	213	222	73	1	2	13
37	222	231	66	4	1	13
38	231	240	59	4	1	13
39	240	249	52	4	1	13
40	249	258	45	4	1	13
41	258	267	38	4	1	13
42	267	276	31	4	1	13
43	276	285	23	7	4	13
44	285	294	15	4	1	1
45	294	303	15	4	1	1
46	303	312	13	2	3	13
47	312	321	11	1	2	13
48	321	330	10	1	2	13
49	330	339	9	1	2	13
50	339	348	8	1	2	13
51	348	357	7	2	3	13
52	357	366	6	1	2	13
53	366	375	5	4	1	13
54	375	384	4	3	4	13

APPENDIX C. OUTPUT (Continued)

FIFTY TABLE 41 ISLAND DATA: NO. OF ISLANDS= 2

I	J	TABLE(I,J,1)	TABLE(I,J,2)	TABLE(I,J,3)	TABLE(I,J,4)	TABLE(I,J,5)
1	1	89	81	38	8	1
1	2	81	80	27	3	8
1	3	80	88	33	2	3
1	4	88	89	40	1	2
2	1	65	57	67	8	1
2	2	57	56	60	3	8
2	3	56	64	66	2	3
2	4	64	65	53	1	2

INPUT TABLE 6: SYSTEM PARAMETERS

LONGITUDINAL PERMEABILITY	325.00
LATERAL DIFFUSIVITY	325.00
SCALAR DIFFUSION COEFFICIENT	0.01000

```

DISCUSSION DATE . . . . . 0.327-06
ENCLY CONSTANT . . . . . 0.0

```

INFO: TABLE 4. SYSTEM PARAMETERS AND BOUNDARY DATA FOR HYDRODYNAMIC MODEL : NO. OF POINTS WITH DIRICHLET BC = 32

```

COPOLLS PARABOLIC . . . . . 0.0
DENSITY OF WATER . . . . . 1.00000
LYNBAR BOTTOM STRESS COEFFICIENT . . . . . 0.00001
AIR DENSITY . . . . . 0.00123
WIND STRESS COEFFICIENT . . . . . 0.00001
WIND SPEED . . . . . 0.0
WIND ANGLE WITH X-AXIS . . . . . 0.0
AVERAGE CURRENT VELOCITY . . . . . 0.20000

```

I	1998	BVN	I	1998	BVN	I	1998	BVN
1	9	1290.000	2	10	1290.000	3	11	1290.000
4	12	1290.000	5	1	1290.000	6	10	1290.000
7	5	1290.000	8	1	1290.000	9	0	626.000
10	0	626.000	11	0	626.000	12	26	626.000
13	35	626.000	14	00	626.000	15	52	626.000
16	60	626.000	17	60	626.000	18	76	626.000
19	117	009.000	20	112	1327.000	21	111	1327.000
22	104	1327.000	23	103	1327.000	24	05	009.000
25	06	009.000	26	77	009.000	27	69	009.000
28	01	009.000	29	53	009.000	30	05	009.000
31	37	009.000	32	36	009.000	33	0	0.0

INPUT TABLE 7 SOURCE DATA

[illegible]

APPENDIX D. OUTPUT (Continued)

INPUT TABLE 0 BOUNDARY VALUE DATA

NO. OF POINTS WITH DIRICHLET BC = 4

NO.	1	2	3	4	5	6	7	8
1	1.00	1.00	1.00	1.00				

PLOTING COMMANDS

..... KISSPLA VERSION 7.5

NO. OF FIRST PLOT 1

PLOT NO. 1 WITH THE TITLE
FIGURE 7 ELEMENT GRID
HAS BEEN COMPLETED.

PLOT ID. BEARS
PLOT 1 00.06.58 TUES 23 JAN, 1979 JOB=TCYPOLOM. ORNL KISSPLA VER 7.5

DATA FOR PLOT

NO. OF CURVES DRAWN 0

HORIZ. AXIS LENGTH 6.5 INS.
VERT. AXIS LENGTH 9.0 INS.

HORIZ. ORIGIN C.C. VERT. ORIGIN 0.0

HORIZ. AXIS LINEAR
STEP SIZE 0.3077E 01 UNITS/INCH

VERT. AXIS LINEAR
STEP SIZE 0.3089E 01 UNITS/INCH

..... LOCATION OF CURRENT PHYSICAL ORIGIN

X= 1.25 Y= 0.55 INCHES .

..... FROM LOWER LEFT CORNER OF PAGE

FLOW TABLE 1 STEADY STATE STREAM FUNCTION

1	1.2900E 03	1.0593E 03	8.2906E 02	6.2600E 02	1.2900E 03	1.0785E 03	8.1033E 02	6.2600E 02
9	1.2900E 03	1.2900E 03	1.2900E 03	1.2900E 03	1.2900E 03	1.2900E 03	1.1613E 03	8.6207E 02
17	6.2600E 02	1.1836E 03	1.1634E 03	1.1663E 03	1.1978E 03	1.2002E 03	1.1272E 03	9.8873E 02
25	8.0150E 02	6.2600E 02	1.0827E 03	1.0374E 03	1.0293E 03	1.0602E 03	1.0773E 03	1.0361E 03
33	9.1598E 02	7.5680E 02	6.2600E 02	8.0900E 02	8.0900E 02	9.3089E 02	9.5670E 02	1.0222E 03
41	1.0222E 03	9.3681E 02	7.457E 02	6.2600E 02	8.0900E 02	8.3819E 02	8.7311E 02	1.0222E 03
49	1.0222E 03	9.1438E 02	7.1652E 02	6.2600E 02	8.0900E 02	8.2020E 02	8.2278E 02	7.2327E 02
57	7.2327E 02	7.7587E 02	6.7616E 02	6.2600E 02	8.0900E 02	8.0885E 02	7.7441E 02	7.2327E 02
65	7.2327E 02	7.0633E 02	6.5155E 02	6.2600E 02	8.0900E 02	7.9655E 02	7.8192E 02	7.6596E 02
73	7.4916E 02	7.3873E 02	6.8459E 02	6.2600E 02	8.0900E 02	8.2625E 02	8.3829E 02	8.3233E 02
81	8.0021E 02	7.6925E 02	7.3880E 02	7.2139E 02	8.0900E 02	8.0900E 02	9.7085E 02	9.7889E 02
89	9.2163E 02	8.5532E 02	8.0868E 02	7.6701E 02	7.5367E 02	9.3628E 02	1.1951E 03	1.1517E 03
97	1.0925E 03	1.0016E 03	8.9741E 02	8.3008E 02	7.7157E 02	7.4876E 02	1.3270E 03	1.3270E 03
105	1.2332E 03	1.1040E 03	9.3024E 02	8.2847E 02	7.3085E 02	7.0006E 02	1.3270E 03	1.3270E 03
113	1.1652E 03	9.4163E 02	8.2100E 02	6.6332E 02	8.8500E 02			

APPENDIX D. OUTPUT (Continued)

FLOW TABLE 2 STEADY STATE VELOCITY FIELD

VEL-X AT NODES				VEL-Y AT NODES			
1	1.0205E-01	1.0267E-01	9.4953E-01	4.3099E-01	-2.6706E-01	-2.6666E-01	-2.8123E-01
5	9.6115E-01	7.3047E-01	5.7923E-01	5.6090E-01	-2.9750E-01	-2.6455E-01	-2.1524E-01
9	1.0275E-01	1.0740E-01	1.0590E-01	8.5661E-01	-0.6461E-01	-6.005E-01	-4.1762E-01
13	7.3889E-01	0.6059E-01	6.2051E-01	4.7204E-01	-1.2132E-01	-1.2000E-01	-2.4541E-01
17	6.1267E-01	1.0197E-01	1.2906E-01	1.2309E-01	-2.0426E-01	-5.4070E-01	-3.7567E-01
21	9.9162E-01	7.7537E-01	0.6571E-01	0.3930E-01	-1.2040E-01	-2.9027E-01	-0.9615E-01
25	3.9026E-01	1.9501E-02	1.9932E-01	2.1966E-01	-1.0047E-01	-1.9747E-01	-4.0947E-01
29	1.1304E-01	9.2939E-01	7.6090E-01	2.5306E-01	-0.6302E-02	2.7635E-02	-1.0199E-01
33	3.0692E-02	2.9057E-01	2.0512E-01	3.3034E-01	-1.3039E-01	-1.7092E-01	-1.7550E-01
37	1.2580E-01	6.9605E-01	6.2650E-01	-2.0566E-01	5.0601E-01	0.4963E-01	1.0023E-01
41	-3.4797E-01	-1.2071E-01	2.7120E-01	1.0505E-01	-0.2077E-01	-1.0000E-01	-1.9992E-01
45	-2.9052E-01	0.1292E-01	2.9035E-01	1.0362E-01	3.6565E-01	7.6920E-02	6.2003E-01
49	2.7067E-01	7.2705E-01	3.6775E-01	1.7271E-01	-1.1975E-01	-1.0206E-01	-1.9203E-01
53	1.0170E-01	1.3241E-01	1.3122E-01	1.0203E-01	3.6561E-02	1.0236E-01	-2.9000E-01
57	2.3037E-01	7.0112E-01	3.1211E-01	-9.9644E-02	2.9510E-01	-1.7532E-01	-1.1666E-01
61	-0.0510E-02	0.2010E-02	1.1035E-01	-0.0950E-01	2.2530E-02	-1.0265E-01	-3.2031E-01
65	-3.1727E-01	7.0570E-03	-1.0174E-02	5.0006E-02	0.0077E-02	-0.0020E-01	-5.2120E-01
69	-3.9009E-03	-0.7022E-03	-1.1069E-01	-1.2622E-01	-1.6006E-01	-1.2761E-01	-1.0277E-01
73	-1.0551E-01	-1.7312E-01	-2.5079E-01	-3.5923E-01	-1.5061E-01	-3.2391E-01	-5.0091E-01
77	-0.5797E-02	-0.0017E-01	-5.9367E-01	-5.0656E-01	3.5540E-01	1.2735E-01	-5.1036E-02
81	-3.7507E-01	-2.7407E-01	-3.5474E-01	-6.0972E-01	-2.5670E-01	-3.5092E-01	-2.4379E-01
85	-2.3315E-01	-1.5043E-01	-1.7159E-01	-1.1353E-01	1.6025E-01	1.2020E-01	3.0520E-01
89	-7.6996E-01	-0.2715E-01	-2.9272E-01	-1.0050E-01	-4.3330E-01	-4.7017E-01	-4.0925E-01
93	-3.5510E-02	-3.2010E-01	-2.9172E-01	-2.2093E-01	-6.0304E-02	1.5037E-01	-2.6117E-01
97	-1.0490E-01	-0.3079E-01	-1.2933E-01	-6.6301E-02	-5.3004E-01	-6.6760E-01	-6.0112E-01
101	1.6090E-01	1.1925E-01	-2.3600E-01	-0.5119E-01	-3.5003E-01	-1.2093E-01	-5.1610E-01
105	-0.0979E-01	-5.6402E-01	-1.0037E-01	6.6094E-02	-7.1675E-01	-9.4928E-01	-1.0902E-01
109	0.2597E-01	9.9621E-01	3.9960E-01	-1.0702E-01	-6.0710E-01	-1.3225E-01	3.9133E-01
113	-3.7669E-01	-0.1062E-03	1.9652E-02	4.1292E-01	-1.7900E-01	-1.1674E-01	-1.2360E-01
117	1.5170E-01	-1.7999E-01					

OUTPUT TABLE 3 STEADY STATE CONCENTRATION

A= NODE I CONCENTRATION AT NODES I, I+1, . . . , I+7

1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	0.0	0.0	0.0	0.0	0.0	0.0	0.0
49	0.0	0.0	0.0	0.0	0.0	0.0	0.0
57	0.0	0.0	0.0	0.0	0.0	0.0	0.0
65	0.0	0.0	0.0	0.0	0.0	0.0	0.0
73	0.0	0.0	0.0	0.0	0.0	0.0	0.0
81	0.0	0.0	0.0	0.0	0.0	0.0	0.0
89	0.0	0.0	0.0	0.0	0.0	0.0	0.0
97	0.0	0.0	0.0	0.0	0.0	0.0	0.0
105	0.0	0.0	0.0	0.0	0.0	0.0	0.0
113	0.0	0.0	0.0	0.0	0.0	0.0	0.0

APPENDIX D. OUTPUT (Continued)

PLOTTING COMMENCING

..... DISSELA VERSION 7.5
 NO. OF PLOTS: 2

PLOT NO. 2 WITH THE TITLE
 FIGURE 8 FLOW RATE PATTERNS
 HAS BEEN COMPLETED.

PLOT IC. DATA:
 PLOT 2 AC. 05.55 TUES 23 JAN, 1979 JOB=TCYPOLOM. ORNL DISSELA VER 7.5

DATA FOR PLOT

NO. OF CURVES DRAWN 0

HORIZ. AXIS LENGTH 6.5 INS.
 VERT. AXIS LENGTH 9.0 INS.

HORIZ. ORIGIN 0.0 VERT. ORIGIN 0.0

HORIZ. AXIS LINEAR
 STEP SIZE 0.55555 CO UNITS/INCH

VERT. AXIS LINEAR
 STEP SIZE 0.55555 CO UNITS/INCH

..... LOCATION OF CURRENT PHYSICAL ORIGIN
 X= 1.25 Y= 0.55 INCHES
 PLOT LOCUS LEFT CORNER OF PAGE

THE VALUE OF IPEN IS NOT PERMITTED IN THE CALL OF PLOT X=0.0
 THE VALUE OF Y=0.0 IS USED FOR IPEN

Y=0.0

IPEN=

999

END DISSELA -- 3076 VECTORS GENERATED IN 2 PLOT FRAMES.

STEADY STATE SOLUTION IS SOUGHT AND ARE GIVEN BELOW ITH = 1

FLOW FIELD 3 STEADY STATE STEADY FUNCTION

1	1.2940E 03	1.0943E 03	8.2900E 02	6.2600E 02	1.2940E 03	1.0785E 03	8.1033E 02	6.2600E 02
9	1.2940E 03	1.2940E 03	1.2940E 03	1.2940E 03	1.2940E 03	1.2940E 03	1.1613E 03	8.6207E 02
17	6.2600E 02	1.1836E 03	1.1756E 03	1.1863E 03	1.1978E 03	1.2062E 03	1.1272E 03	9.8873E 02
25	8.0150E 02	6.2600E 02	1.0027E 03	1.0374E 03	1.0293E 03	1.0662E 03	1.0773E 03	1.0361E 03
33	5.1590E 02	7.5680E 02	6.2600E 02	8.0900E 02	8.0900E 02	9.1089E 02	9.5670E 02	1.0222E 03
41	1.0222E 03	9.1661E 02	7.8752E 02	8.2600E 02	8.0900E 02	8.3819E 02	8.7311E 02	1.0222E 03
49	1.0222E 03	9.1661E 02	7.1652E 02	8.2600E 02	8.0900E 02	8.2020E 02	8.2274E 02	7.2327E 02
57	7.2327E 02	7.7587E 02	6.7616E 02	8.2600E 02	8.0900E 02	8.0485E 02	7.7441E 02	7.2327E 02
65	7.2327E 02	7.0633E 02	6.5155E 02	8.2600E 02	8.0900E 02	7.9655E 02	7.8192E 02	7.6596E 02
73	7.4910E 02	7.3873E 02	6.8454E 02	8.2600E 02	8.0900E 02	8.2625E 02	8.3829E 02	8.3233E 02
81	8.0021E 02	7.6925E 02	7.3880E 02	7.2139E 02	8.0900E 02	8.0900E 02	9.7045E 02	9.7889E 02
89	9.2163E 02	8.5532E 02	8.0868E 02	7.6701E 02	7.5367E 02	9.3628E 02	1.1951E 03	1.1517E 03
97	1.0925E 03	1.0016E 03	8.9741E 02	8.3008E 02	7.7157E 02	7.8876E 02	1.3270E 03	1.3270E 03
105	1.2335E 03	1.1044E 03	9.3028E 02	8.2847E 02	7.3085E 02	7.0006E 02	1.3270E 03	1.3270E 03
113	1.1652E 03	9.4163E 02	8.2100E 02	6.6432E 02	6.8500E 02			

APPENDIX D. OUTPUT (Continued)

FLOW TABLE 4 STEADY STATE VELOCITY FIELD

VEL-X AT NODES					VEL-Y AT NODES				
1	1.0245E-00	1.0267E-00	9.0953E-01	0.3099E-01	-2.6706E-00	-2.6666E-00	-2.0123E-00	-3.3760E-00	
5	0.4115E-01	7.3047E-01	5.7923E-01	5.6090E-01	-2.9750E-00	-2.6055E-00	-2.1524E-00	-1.5957E-00	
9	1.0275E-00	1.0740E-00	1.0594E-00	0.5661E-01	-0.6461E-01	-6.0005E-01	-0.1762E-01	-2.6449E-01	
13	7.3059E-01	0.6059E-01	6.2451E-01	0.7204E-01	-1.2132E-01	-1.2400E-00	-2.4541E-00	-2.6333E-00	
17	6.1267E-01	1.0191E-00	1.2906E-00	1.2309E-00	-2.0426E-00	-5.4070E-01	-3.7541E-01	-3.0264E-01	
21	9.9102E-01	7.7537E-01	0.6571E-01	0.3030E-01	-1.2040E-01	-2.9027E-01	-0.9615E-01	-1.5720E-00	
25	7.9026E-01	1.9501E-02	1.9932E-00	2.1966E-00	-1.0047E-00	-1.9747E-00	-4.4947E-01	-4.4096E-01	
29	1.1344E-00	9.2939E-01	7.6094E-01	2.5306E-01	-0.6302E-02	2.7635E-02	-1.4199E-01	-7.0100E-01	
33	3.0698E-02	2.9057E-01	2.0512E-01	3.3042E-00	-1.3039E-00	-1.7092E-00	-1.7550E-00	-1.0446E-00	
37	1.3501E-00	6.9605E-01	6.2650E-01	-2.0566E-01	5.0681E-01	0.4963E-01	1.0023E-01	3.0325E-01	
41	-1.4797E-01	-1.2971E-01	2.7120E-01	1.0505E-01	-0.2077E-01	-1.0000E-00	-1.9992E-00	-1.1097E-00	
45	-2.9005E-01	0.1292E-01	2.9035E-01	1.4036E-00	3.6565E-01	7.6924E-02	6.2043E-01	7.0902E-01	
49	2.7067E-00	7.2705E-01	3.6775E-01	1.7271E-01	-1.1975E-00	-1.0206E-00	-1.9203E-00	-1.2445E-00	
53	1.0170E-01	1.3241E-01	1.3122E-01	1.0243E-00	3.6561E-02	1.4236E-01	-2.9004E-01	-1.2356E-00	
57	2.3037E-00	7.0112E-01	3.1211E-01	-9.9640E-02	2.9510E-01	-1.7153E-01	-1.1666E-00	-5.0029E-01	
61	-0.0510E-02	0.2014E-02	1.7035E-01	-4.4910E-01	2.2530E-02	-1.0265E-01	-3.2031E-01	-1.7127E-01	
65	-3.1727E-01	7.0570E-03	-1.4174E-02	5.0006E-02	0.0077E-02	-0.0020E-01	-5.2120E-01	-3.3637E-01	
69	-3.3009E-03	-0.7022E-03	-1.1069E-01	-1.2622E-01	-1.6006E-01	-1.2761E-01	-1.0277E-01	-1.2625E-01	
73	-1.0551E-01	-1.7312E-01	-2.5079E-01	-3.5923E-01	-1.5461E-01	-3.2391E-01	-5.0891E-01	-6.6379E-01	
77	-0.5757E-02	-0.0017E-01	-5.9367E-01	-5.0656E-01	3.5540E-01	1.2735E-01	-5.1036E-02	-1.5126E-01	
81	-3.7507E-01	-2.7401E-01	-3.5474E-01	-6.0972E-01	-2.5670E-01	-3.5092E-01	-2.4379E-01	-1.2391E-01	
85	-2.3315E-00	-1.5043E-00	-1.7159E-00	-1.1353E-00	1.6025E-01	1.2029E-00	1.0520E-01	-2.1009E-01	
89	-7.6996E-01	-0.2715E-01	-2.9272E-01	-1.0054E-01	-0.3330E-01	-0.2017E-01	-0.4025E-01	-2.0953E-01	
93	-3.5510E-02	-3.2010E-00	-2.9172E-00	-2.2097E-00	-6.4100E-02	1.5037E-01	-2.6117E-01	-0.5257E-01	
97	-1.0490E-00	-0.3079E-01	-3.2933E-01	-6.6301E-02	-5.3000E-01	-6.6760E-01	-6.0172E-01	-6.2505E-01	
101	1.6090E-01	1.1925E-01	-2.7500E-00	-0.5119E-01	-3.5003E-01	-1.2093E-01	-5.1614E-01	-6.6504E-01	
105	-0.0979E-01	-5.6402E-01	-1.4037E-01	0.6094E-02	-7.1675E-01	-9.4920E-01	-1.0902E-00	-9.6071E-01	
109	0.2597E-01	9.9621E-01	3.9960E-01	-1.0702E-00	-6.0710E-01	-1.3225E-01	3.9133E-01	-9.3303E-01	
113	-3.7669E-01	-0.1062E-03	3.9652E-02	0.1292E-01	-1.7900E-00	-1.1674E-00	-1.2360E-00	-1.5012E-00	
117	1.5170E-00	-1.7999E-00							

OUTPUT TABLE 2 STEADY STATE CONCENTRATION

AT NODE 1 CONCENTRATION AT NODES 1, 5, 9, 13, 17

1	5.2802E-01	5.2694E-01	5.2089E-01	5.3002E-01	5.2603E-01	5.2010E-01	5.2040E-01	5.2733E-01	
9	1.0050E-00	9.5195E-01	0.6906E-01	7.4277E-01	6.6065E-01	5.5100E-01	5.4714E-01	5.3604E-01	
17	5.3064E-01	1.0000E-00	9.4905E-01	0.8119E-01	0.0576E-01	6.7716E-01	5.0950E-01	5.0540E-01	
25	5.2500E-01	5.2634E-01	1.0000E-00	9.4656E-01	0.8075E-01	0.1492E-01	6.6530E-01	5.0613E-01	
33	5.2042E-01	5.0724E-01	5.0639E-01	1.3000E-00	9.3926E-01	0.0593E-01	7.6542E-01	7.3400E-01	
41	0.6661E-01	0.8034E-01	0.4160E-01	0.0464E-01	0.4303E-01	0.2019E-01	0.0671E-01	6.2931E-01	
49	0.6013E-01	0.4595E-01	0.5175E-01	0.5506E-01	7.3660E-01	6.7200E-01	5.7099E-01	5.7377E-01	
57	0.7756E-01	0.4740E-01	0.0103E-01	3.9005E-01	3.0605E-01	3.0161E-01	3.9110E-01	0.0450E-01	
65	3.0397E-01	3.0927E-01	2.7699E-01	2.6761E-01	1.4746E-01	1.3715E-01	1.4599E-01	1.3993E-01	
73	1.3965E-01	9.0051E-02	0.7641E-02	6.7057E-02	5.4740E-02	5.6505E-02	5.7052E-02	5.5690E-02	
81	5.3309E-02	5.4352E-02	5.4516E-02	5.6970E-02	3.6115E-02	0.1210E-02	3.7440E-02	3.7927E-02	
89	3.0679E-02	3.2211E-02	3.1947E-02	3.4992E-02	3.0092E-02	3.6305E-02	3.5426E-02	3.4170E-02	
97	3.0190E-02	2.5463E-02	2.0940E-02	1.8033E-02	1.6627E-02	1.4173E-02	3.4510E-02	3.3667E-02	
105	2.1549E-02	1.6099E-02	1.2904E-02	1.1330E-02	9.7753E-03	9.2543E-03	2.5150E-02	1.1640E-02	
113	5.7302E-03	7.6900E-03	6.5007E-03	5.0392E-03	5.7629E-03				

APPENDIX E. LISTING OF FORTRAN PROGRAM

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5      C      MAIN PROGRAM                                MAIN 005
10     C                                              MAIN 010
15     C      TRANSPORT AND DISPERSION OF POLLUTANTS IN SURFACE IMPOUNDMENT MAIN 015
20     C      A FINITE ELEMENT MODEL                                MAIN 020
25     C      DEVELOPED BY G. T. YEH OF OAK NATIONAL LABORATORY    MAIN 025
30     C      FOR ANY QUESTION ON THE MODEL CALL G. T. YEH OF    MAIN 030
35     C      (615) 483-4611-X30227 OR WRITE P.O. BOX 1          MAIN 035
40     C      OAK RIDGE NATIONAL LABORATORY, OAK RIDGE, TN. 37830 MAIN 040
45     C      ATT. DR. G. T. YEH, RM 203, BLDG. 1505              MAIN 045
50     C                                              MAIN 050
55     C                                              MAIN 055
60     C      DIMENSION TITLE(20)                                MAIN 060
65     C      DIMENSION C(290,33),PHI(290),DPHIX(290),DPHIY(290),R(290),RP(290) MAIN 065
70     C      DIMENSION X(290),Y(290),HH(290),VX(290),VYP(290),VXW(290),VY(290),MAIN 070
75     C      1 VYP(290),VYW(290),SOURCE(290),SOURCEP(290),SOURCEW(290), IE(245,4) MAIN 075
80     C      DIMENSION TAUXX(290),TAUYH(290)                    MAIN 080
85     C                                              MAIN 085
90     C      COMMON /CONTRL/ NWP,WEL,IBAND,HXDIP,IALFB,IBBP      MAIN 090
95     C      COMMON /YEH/ BVH(99),IBVH(99),NBVPH,IILND(5,20,5),WILNDS(5),WILWD MAIN 095
100    C      COMMON /GT/ BV(99),IBV(99),ISIDE(99,6),WBVP,WSIDE   MAIN 100
105    C      COMMON /PRTHW/ WTI,KVEL,KBV,KSOS,KSTP              MAIN 105
110    C      COMMON /WED/ WREAD,IREAD,KPRO,KPR(800)             MAIN 110
115    C      COMMON /HYDR/ CKW,RHOW,COTIL,AVD                   MAIN 115
120    C      COMMON /PARH/ OMEGA,DELT,THAX,DELTHX,CHNG,EFS      MAIN 120
125    C      COMMON /TRANSP/ AL,AT,DD,BK,RKH,RLAND,ITRAWS      MAIN 125
130    C      COMMON /WELUHH/ IWPT,ILOHF,INID                    MAIN 130
135    C      COMMON /BUG/ IDOGE,IBUGT,IBUGQH,IBUGQT            MAIN 135
140    C                                              MAIN 140
145    C      DATA MAXWP,MAXEL,MAXLW,MAXBVH,MAXILD,MAXILDS,MAXBVP,MAXSID,MAXWTI/ MAIN 145
150    C      1 290,245,33,99,5,20,99,99,999/                  MAIN 150
155    C                                              MAIN 155
160    C                                              MAIN 160
165    C      CALL ECNC2                                          MAIN 165
170    C                                              MAIN 170
175    C      READ(5,10) TITLE                                    MAIN 175
180    C      WRITE(6,1000) TITLE                                  MAIN 180
185    C                                              MAIN 185
190    C      KOUT=0                                              MAIN 190
195    C      KDIAG=0                                             MAIN 195
200    C      CALL DATAIN(C,PHI,R,X,Y,HH,VX,VY,SOURCE,TAUXX,TAUYH,IE,1, MAIN 200
205    C      1 MAXWP,MAXEL,MAXBW,MAXBVH,MAXILC,MAXILDS,MAXBVP,MAXSID,MAXWTI) MAIN 205
210    C                                              MAIN 210
215    C      IHALFB=MAXDIP                                        MAIN 215
220    C      IBAND=2*IALFB+1                                     MAIN 220
225    C      IDBP=IALFB+1                                        MAIN 225
230    C                                              MAIN 230
235    C      CALL ELNGRD(X,Y,IE,MAXWP,MAXEL)                    MAIN 235
240    C      CALL HYDRON(C,PHI,DPHIX,DPHIY,X,Y,HH,VX,VY,TAUXX,TAUYH,IE, MAIN 240
245    C      1 MAXWP,MAXEL,MAXBW)                                MAIN 245
250    C                                              MAIN 250
255    C      CALL PRINTT(KPRO,KOUT,KDIAG,TIME,PHI,VX,VY,R,MAXWP) MAIN 255
260    C                                              MAIN 260
265    C      CALL VELPLT(X,Y,VX,VY,IE,MAXWF,MAXEL)              MAIN 265
270    C                                              MAIN 270
275    C      TIME=0.0                                             MAIN 275
280    C      W1=OMEGA                                             MAIN 280
285    C      W2=1.0-OMEGA                                         MAIN 285
290    C      TIME=0.0                                             MAIN 290
295    C                                              MAIN 295
300    C      DO 100 I=1,NWP                                       MAIN 300
305    C      100  PP(I)=R(I)                                       MAIN 305
310    C                                              MAIN 310
315    C      DO 850 ITH=1,WTI                                       MAIN 315
320    C      IREAL=ITH/WREAD*WREAD - ITH                          MAIN 320
325    C      TIME=TIME+DELT                                         MAIN 325
330    C                                              MAIN 330
335    C                                              MAIN 335
340    C      DO 210 I=1,NWP                                       MAIN 340
345    C      VXF(I)=VX(I)                                         MAIN 345

```


APPENDIX E. (Continued)

350	VYF(I)=VY(I)	MAIN 350
355	210 SOURCEP(I)=SOURCE(I)	MAIN 355
360	C	MAIN 360
365	C	MAIN 365
370	CALL DATAIN(C,PHI,R,X,Y,HH,VX,VY,SOURCE,TAUXH,TAUYH,IE,0,	MAIN 370
375	1 HAXHF,HAXEL,HAXBW)	MAIN 375
380	IF(KVEL.NE.0 .AND. IREAD.EQ.0) CALL HYDRON(C,PHI,DPHIX,DPHIY,X,Y,	MAIN 380
385	1 HH,VX,VY,TAUXH,TAUYH,IE,HAXHP,HAXEL,HAXBW)	MAIN 385
390	C	MAIN 390
395	ICHAH=0.0	MAIN 395
400	C	MAIN 400
405	C	MAIN 405
410	CO 220 I=1,NWP	MAIN 410
415	VXW(I)=W1*VX(I) + W2*VXF(I)	MAIN 415
420	VYW(I)=W1*VY(I) + W2*VYF(I)	MAIN 420
425	220 SOURCEW(I)=W1*SOURCE(I)+W2*SOURCEP(I)	MAIN 425
430	C	MAIN 430
435	CALL PCELLN(C,R,RP,X,Y,HH,VXW,VYW,SOURCEW,IE,HAXHP,HAXEL,HAXBW)	MAIN 435
440	C	MAIN 440
445	IF(ITRANS.EQ.0) GO TO 860	MAIN 445
450	CO 230 I=1,NWP	MAIN 450
455	IF(RF(I).EQ. 0.0) GO TO 230	MAIN 455
460	DCMA=ABS((R(I)-RP(I))/RP(I))	MAIN 460
465	IF(DCHAX.GT.DCMA) GO TO 230	MAIN 465
470	DCHAX=DCMA	MAIN 470
475	230 CONTINUE	MAIN 475
480	C	MAIN 480
485	C	MAIN 485
490	250 CO 330 I=1,NWP	MAIN 490
495	FP(I)=R(I)	MAIN 495
500	330 CONTINUE	MAIN 500
505	C	MAIN 505
510	C	MAIN 510
515	CALL PRINTT(KPR(ITM),KOUT,KDIAG,TIME,PHI,VX,VY,R,HAXHP)	MAIN 515
520	C	MAIN 520
525	IF(DCHAX.LE.EPS .AND. ITM .GT.1) GO TO 870	MAIN 525
530	IF(TIME.GT.TMAX) GO TO 880	MAIN 530
535	C	MAIN 535
540	DELT=DELT*(1.0+CHNC)	MAIN 540
545	DELT=MIN1(DELT,DELTMX)	MAIN 545
550	850 CONTINUE	MAIN 550
555	C	MAIN 555
560	WRITE(6,2000) NPI	MAIN 560
565	GO TO 900	MAIN 565
570	660 WRITE(6,3000) ITM	MAIN 570
575	GO TO 900	MAIN 575
580	670 WRITE(6,4000) ITM	MAIN 580
585	GO TO 900	MAIN 585
590	880 WRITE(6,5000) TIME, TMAX	MAIN 590
595	900 CONTINUE	MAIN 595
600	CALL PRINTT(10,KOUT,KDIAG,TIME,PHI,VX,VY,R,HAXLP)	MAIN 600
605	C	MAIN 605
610	10 FORMAT(20A4)	MAIN 610
615	1000 FORMAT(1H1,20X,20A4//)	MAIN 615
620	2000 FORMAT(1H1,'TRANSIENT SOLUTION IS SOUGHT: NO STEADY SOLUTION HAS	MAIN 620
625	11EN REACHED AFTER ',I3,' TIME STEPS')	MAIN 625
630	3000 FORMAT(1H1,'STEADY STATE SOLUTION IS SOUGHT AND ARE GIVEN BELOW',	MAIN 630
635	1' ITM = ',I3)	MAIN 635
640	4000 FORMAT(1H1,'TRANSIENT SOLUTION IS SOUGHT BUT AFTER ',I3,' TIME STE	MAIN 640
645	1PS STEADY SOLUTION HAS BEEN REACHED')	MAIN 645
650	5000 FORMAT(1H1,'TRANSIENT SOLUTION IS SOUGHT NO STEADY SOLUTION HAS BE	MAIN 650
655	1EN REACHED YET AFTER TIME = ',E15.5/1X,	MAIN 655
660	2' GREATER THAN TMAX = ',E15.5)	MAIN 660
665	C	MAIN 665
670	STOP	MAIN 670
675	END	MAIN 675

APPENDIX E. (Continued)

```

      SUBROUTINE ECHO2
      REAL*8  CH,CMT
      DIMENSION A(20)
      DATA   CMT / 'COMMENT ' /
      IPG = 0
      LINE = 0
      ICK = 0
      ICH = 0
10  READ (55,100,END=99) (A(I),I=1,20),CH
      ICK = ICK+1
      IF (ICK.LT.56 .AND. ICK.NE.1) GO TO 20
      ICK = 11
      IPG = IPG+1
      WRITE (6,200) IPG,(I,I=1,8)
20  IF (CH.EQ.CMT) GO TO 40
      LINE = LINE+1
      IF (ICH.NE.1) GO TO 30
      WRITE (6,300)
      ICK = ICK+1
30  ICH = 0
      WRITE (6,400) LINE,(A(I),I=1,20)
      WRITE (5,500) (A(I),I=1,20)
      GO TO 10
40  IF (ICH.EQ.1) GO TO 50
      WRITE (6,300)
      ICK = ICK+1
50  WRITE (6,600) (A(I),I=3,20)
      ICH = 1
      GO TO 10
99  REWIND 5
      RETURN
100 FORMAT (20A4,T1,A8)
160
165 200 FORMAT (1H1///3X,'I N ? U T  D A T A',75X,'PAGE',I4///3X,
170      2 'COLUMN NUMBER -----> ',8I10,3X/17X,'-----> 123456789012345',
175      3 '678901234567890123456789012345678901234567890123456789012345',
180      4 '67890'/3X,'LINE',3X,'NUMBER',9X,'|',8X,8('|',9X)/15X,'|',9X,
185      5 '|',8X,8('|',9X)/15X,'V',9X,'V',8X,8('V',9X)/)
190
195 300 FORMAT (1H )
200
205 400 FORMAT (3X,I13,' -----> ',20A4)
210
500 FORMAT (20A4)
600 FORMAT (25X,'***** ',18A4)
      END

```

ECHO 005
ECHO 010
ECHO 015
ECHO 020
ECHO 025
ECHO 030
ECHO 035
ECHO 040
ECHO 045
ECHO 050
ECHO 055
ECHO 060
ECHO 065
ECHO 070
ECHO 075
ECHO 080
ECHO 085
ECHO 090
ECHO 095
ECHO 100
ECHO 105
ECHO 110
ECHO 115
ECHO 120
ECHO 125
ECHO 130
ECHO 135
ECHO 140
ECHO 145
ECHO 150
ECHO 155
ECHO 160
ECHO 165
ECHO 170
ECHO 175
ECHO 180
ECHO 185
ECHO 190
ECHO 195
ECHO 200
ECHO 205
ECHO 210

APPENDIX E. (Continued)

```

5      SUBROUTINE DATAIN(C, PHI, B, I, Y, HH, VX, VY, SOURCE, TAOXH, TAOYH, IE, KGECH, DATA 005
10      1 HAXNP, HAXEL, HAXBW, HAXBVH, HAXILD, HXILDS, HAXBVP, HAXSID, HAXNTI) DATA 010
15      C DATA 015
20      DIMENSION C(HAXPL, HAXBW), PHI(HAXNP), B(HAXNP), X(HAXNP), Y(HAXNP), DATA 020
25      1 HH(HAXNP), VX(HAXNP), VY(HAXNP), SOURCE(HAXNP), TAOXH(HAXNP), DATA 025
30      2 TAOYH(HAXNP), IE(HAXEL, 4) DATA 030
35      C DATA 035
40      COMMON /CONTRL/ HNP, NEL, IBAND, HAXDIP, IHALPB, IHBP DATA 040
45      COMMON /YEH/ BVH(99), IBVH(99), HBVPH, IILND(5, 20, 5), WILNDS(5), WILND DATA 045
50      COMMON /GT/ BV(99), IBV(99), ISIDE(99, 6), HBVP, NSIDE DATA 050
55      COMMON /PRTHAN/ HTI, KVEL, KBV, KSOS, KSTR DATA 055
60      COMMON /RED/ HRPAD, IREAD, KPRO, KPR(800) DATA 060
65      COMMON /HYDR/ CKW, BHOW, CORIL, AVU DATA 065
70      COMMON /TRANSP/ AL, AT, DD, BK, RKH, ELAND, ITRANS DATA 070
75      COMMON /PARH/ OMEGA, DELT, THAX, DELTHX, CHWG, EFS DATA 075
80      COMMON /WELUMH/ INET, ILUMP, INID DATA 080
85      COMMON /BUG/ IBUGH, IBUGT, IBUGQH, IBUGQT DATA 085
90      C DATA 090
95      DIMENSION SOS(9), ISOS(9) DATA 095
100      C DATA 100
105      C DATA 105
110      NAMELIST /BNDVH/ BVH, IBVH, HBVPH DATA 110
115      NAMELIST /SIDE/ ISIDE, NSIDE DATA 115
120      NAMELIST /SOSNL/ SOS, ISOS, NSOS DATA 120
125      NAMELIST /BNDV/ BV, IBV, HBVP DATA 125
130      C DATA 130
135      C DATA 135
140      IF(KGECH.EQ.0) GO TO 350 DATA 140
145      C DATA 145
150      C DATA 150
155      DO 101 M=1, HAXEL DATA 155
160      DO 101 IQ=1, 4 DATA 160
165      IE(M, IQ)=0 DATA 165
170      101 CONTINUE DATA 170
175      C DATA 175
180      DO 104 I=1, HAXNP DATA 180
185      X(I)=0.0 DATA 185
190      Y(I)=0.0 DATA 190
195      VX(I)=0.0 DATA 195
200      VY(I)=0.0 DATA 200
205      BH(I)=0.0 DATA 205
210      TAOXH(I)=0.0 DATA 210
215      TAOYH(I)=0.0 DATA 215
220      SOURCE(I)=0.0 DATA 220
225      102 R(I)=0.0 DATA 225
230      DO 103 J=1, HAXBW DATA 230
235      C(I, J)=0.0 DATA 235
240      103 CONTINUE DATA 240
245      C DATA 245
250      DO 107 I=1, HAXBVH DATA 250
255      BVH(I)=0.0 DATA 255
260      107 HBVH(I)=0 DATA 260
265      DO 108 I=1, HAXILD DATA 265
270      WILNDS(I)=0.0 DATA 270
275      DO 108 J=1, HXILDS DATA 275
280      DO 108 K=1, 2 DATA 280
285      IILND(I, J, K)=0 DATA 285
290      108 CONTINUE DATA 290
295      C DATA 295
300      C DATA 300
305      DO 106 I=1, HAXBVP DATA 305
310      IBV(I)=0 DATA 310
315      106 BV(I)=0.0 DATA 315
320      C DATA 320
325      C DATA 325
330      C DATA 330
335      C DATA 335
340      DO 105 I=1, HAXSID DATA 340
345      DO 105 J=1, 6 DATA 345
350      105 ISIDE(I, J)=0 DATA 350
355      C DATA 355
360      C DATA 360

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APPENDIX E. (Continued)

```

365      READ(5,11) WNP,WEL,WTI,KVEL,KBV,KSOS,KSTR,ITRANS,WREAD,      DATA 365
370      1      IWET,ILUHP,INID, IBOGH,IBUGH,IBUGT,IBUGQI      DATA 370
375      C      DATA 375
380      READ(5,12) OMEGA,D,LT,THAI,DELTHX,CHNG,EPS      DATA 380
385      READ(5,13) KPRO, (KPP(I),I=1,WTI)      DATA 385
390      C      DATA 390
395      C      DATA 395
400      WRITE(6,1000) WNP,WEL,WTI,KVEL,KBV,KSOS,KSTR,ITRANS,WREAD,      DATA 400
405      1      OMEGA,D,LT,THAI,DELTHX,CHNG,EPS      DATA 405
410      WRITE(6,1001) IWET,ILUHP,INID      DATA 410
415      WRITE(6,1100) KPRO, (KPP(I),I=1,WTI)      DATA 415
420      C      DATA 420
425      C      READ AND WRITE NODAL POINT DATA      DATA 425
430      DO 110 I=1,WNP,2      DATA 430
435      I1=I+1      DATA 435
440      READ(5,14) H1,R(I),X(I),Y(I),HH(I), H2,R(I1),X(I1),Y(I1),HH(I1)      DATA 440
445      110      CCNTINUE      DATA 445
450      WRITE(6,2000)      DATA 450
455      ILINE=C      DATA 455
460      DO 115 I=1,WNP      DATA 460
465      WRITE(6,2100) I,X(I),Y(I),HH(I)      DATA 465
470      ILINE=ILINE+1      DATA 470
475      IF(MOD(ILINE,5).EQ.0) WRITE(6,9000)      DATA 475
480      IF(MOD(ILINE,40).EQ.0) WRITE(6,2000)      DATA 480
485      115      CONTINUE      DATA 485
490      C      DATA 490
495      C      DATA 495
500      C      DATA 500
505      C      READ AND WRITE ELEMENT DATA      DATA 505
510      WRITE(6,3000)      DATA 510
515      ILINE=0      DATA 515
520      MAXDIF=0      DATA 520
525      DO 129 I=1,WEL      DATA 525
530      ILINE=ILINE+1      DATA 530
535      READ(5,21) H, (IE(H,J),J=1,4)      DATA 535
540      FND=C      DATA 540
545      DO 125 IQ=1,3      DATA 545
550      IQ1=IQ+1      DATA 550
555      DO 125 JQ=IQ1,      DATA 555
560      ND=YABS(IE(H,IQ)-IE(H,JQ))      DATA 560
565      FND=MAX0(FND,ND)      DATA 565
570      125      MAXDIF=MAX0(MAXDIF,FND)      DATA 570
575      WRITE(6,3100) H, (IE(H,J),J=1,4), FND      DATA 575
580      IF(MOD(ILINE,5).EQ.0) WRITE(6,9000)      DATA 580
585      IF(MOD(ILINE,40).EQ.0) WRITE(6,3000)      DATA 585
590      129      CONTINUE      DATA 590
595      C      DATA 595
600      C      DATA 600
605      C      READ AND WRITE SIDE DATA      DATA 605
610      READ(5,SIDE)      DATA 610
615      WRITE(6,4000) NSIDE      DATA 615
620      ILINE=0      DATA 620
625      DO 130 I=1,NSIDE      DATA 625
630      ILINE=ILINE+1      DATA 630
635      WRITE(6,4100) I, (ISIDE(I,J),J=1,6)      DATA 635
640      IF(MOD(ILINE,5).EQ.0) WRITE(6,9000)      DATA 640
645      IF(MOD(ILINE,40).EQ.0) WRITE(6,4000) NSIDE      DATA 645
650      130      CONTINUE      DATA 650
655      C      DATA 655
660      CC      READ AND WRITE ISLAND DATA      DATA 660
665      C      DATA 665
670      READ(5,11) WILND      DATA 670
675      IF(WILND.EQ.0) GO TO 170      DATA 675
680      READ(5,11) (WILNDS(I),I=1,WILND)      DATA 680
685      DO 150 I=1,WILND      DATA 685
690      NUNBR=WILNDS(I)      DATA 690
695      READ(5,15) ((ILND(I,C,K),K=1,5),J=1,NUNBR)      DATA 695
700      150      CONTINUE      DATA 700
705      WRITE(6,4500) WILND      DATA 705
710      ILINE=0      DATA 710
715      DO 160 I=1,WILND      DATA 715
720      WRITE(6,9000)      DATA 720

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APPENDIX E. (Continued)

725		NUNBP=NILNDS(I)	DATA 725
730		DO 160 J=1,NUNBP	DATA 730
735		WRITE(6,4600) I,J, (IILND(I,J,K),K=1,5)	DATA 735
740		ILINE=ILINE+1	DATA 740
745		IF(MOD(IILINE,50).EQ.0) WRITE(6,4500) NILND	DATA 745
750	160	CONTINUE	DATA 750
755	170	CONTINUE	DATA 755
760	C		DATA 760
765	C	READ AND WRITE SYSTEM PARAMETERS	DATA 765
770		READ(5,30) AL,AT,DD,BK,BKH,RLAND	DATA 770
775		WRITE(6,5000) AL,AT,DD,BK,RLAND	DATA 775
780	C		DATA 780
785	C	READ AND WRITE BOUNDARY VALUE OF HYDRODYNAMIC MODEL	DATA 785
790	205	READ(5,30) CORIL,RHOW,CKW,RHOA,CKA,WINVEL,WIANG,AVU	DATA 790
795		READ(5,BNDV)	DATA 795
800		SINANG=SIN(WIANG)	DATA 800
805		COSANG=COS(WIANG)	DATA 805
810		STRESS=RHOA*CKQ*WINVEL*WINVEL	DATA 810
815		DO 210 NP=1,NBP	DATA 815
820		TAUXH(NP)=STRESS*COSANG/HH(NP)	DATA 820
825	210	TAUYH(NP)=STRESS*SINANG/HH(NP)	DATA 825
830	C		DATA 830
835		WRITE(6,6000) NBVPH,CORIL,RHOW,CKW,RHOA,CKA,WINVEL,WIANG,AVU	DATA 835
840		ILINE=0	DATA 840
845		DO 214 I=1,NBVPH,3	DATA 845
850		I1=I+1	DATA 850
855		I2=I+2	DATA 855
860		WRITE(6,6100) I, IBVH(I), BVH(I), I1,IBVH(I1),BVH(I1), I2,IBVH(I2),	DATA 860
865	1	BVH(I2)	DATA 865
870		ILINE=ILINE+1	DATA 870
875		IF(MOD(IILINE,5).EQ.0) WRITE(6,9000)	DATA 875
880		IF(MOD(IILINE,40).EQ.0) WRITE(6,6000) NBVPH,CORIL,RHOW,CKW,RHOA,	DATA 880
885	1	CKA,WINVEL,WIANG,AVU	DATA 885
890	214	CONTINUE	DATA 890
895	C		DATA 895
900	C		DATA 900
905	C		DATA 905
910		IF(KGECH.EQ.0) GO TO 410	DATA 910
915	C		DATA 915
920	C	READ AND WRITE SOURCE DATA	DATA 920
925	215	READ(5,SCSNL)	DATA 925
930		DO 218 I=1,NSOS	DATA 930
935		IMP=ISOS(I)	DATA 935
940	218	SOURCE(IMP)=SCS(I)	DATA 940
945		WRITE(6,7000)	DATA 945
950		ILINE=0	DATA 950
955		DO 220 I=1,NBP,8	DATA 955
960		NJHN=I	DATA 960
965		NJHX=I*7,NBP	DATA 965
970		WRITE(6,7100) I, (SOURCE(J),J=NJHN,NJHX)	DATA 970
975		ILINE=ILINE+1	DATA 975
980		IF(MOD(IILINE,5).EQ.0) WRITE(6,9000)	DATA 980
985		IF(MOD(IILINE,40).EQ.0) WRITE(6,7000)	DATA 985
990	220	CONTINUE	DATA 990
995	C		DATA 995
1000		IF(KGECH.EQ.0) GO TO 420	DATA 1000
1005	C		DATA 1005
1010	C	READ AND WRITE BOUNDARY VALUES DATA	DATA 1010
1015	225	READ(5,BNDV)	DATA 1015
1020		WRITE(6,8000) NBVP	DATA 1020
1025		ILINE=0	DATA 1025
1030		DO 230 I=1,NBVP,8	DATA 1030
1035		NJHN=I	DATA 1035
1040		NJHX=I*7,NBVP	DATA 1040
1045		WRITE(6,8100) I, (BV(J),J=NJHN,NJHX)	DATA 1045
1050		ILINE=ILINE+1	DATA 1050
1055		IF(MOD(IILINE,5).EQ.0) WRITE(6,9000)	DATA 1055
1060		IF(MOD(IILINE,40).EQ.0) WRITE(6,8000) NBVP	DATA 1060
1065	230	CONTINUE	DATA 1065
1070	C		DATA 1070
1075		RETURN	DATA 1075
1080	C		DATA 1080

APPENDIX E. (Continued)

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1085      350 IF(KVEL.NE.0 .AND. IREAD.EQ.0) GO TO 205          DATA1085
1090      410 IF(KSOS.NE.0 .AND. IREAD.EQ.0) GO TO 215          DATA1090
1095      420 IF(KEV.NE.0 .AND. IREAD.EQ.0) GO TO 225          DATA1095
1100      RETURN                                                  DATA1100
1105      C                                                        DATA1105
1110      C                                                        DATA1110
1115      11 FORMAT(16I5)                                          DATA1115
1120      12 FORMAT(8F10.0)                                       DATA1120
1125      13 FORMAT(80I1)                                         DATA1125
1130      14 FORMAT(I5,P5.0,3P10.0,I5,P5.0,3P10.0)              DATA1130
1135      15 FORMAT(20I4)                                          DATA1135
1140      21 FORMAT(16I5)                                          DATA1140
1145      30 FORMAT(8F10.0)                                       DATA1145
1150      1000 FORMAT(1H,'INPUT TABLE 1 BASIC PARAMETERS',//5X,   DATA1150
1155      1'NUMBER OF NODES . . . . .',I10/5X,                 DATA1155
1160      2'NUMBER OF ELEMENTS . . . . .',I10/5X,              DATA1160
1165      5'% OF TIME INCREMENTS . . . . .',I10/5X,           DATA1165
1170      6'VELOCITY INPUT CONTROL . . . . .',I10/5X,         DATA1170
1175      7'BOUNDARY VALUE INPUT CONTROL . . . . .',I10/5X,   DATA1175
1180      8'SOURCE INPUT CONTROL . . . . .',I10/5X,          DATA1180
1185      9'AUXILIARY STORAGE CONTROL . . . . .',I10/5X,      DATA1185
1190      A'TRANSIENT SIMULATION CONTROL . . . . .',I10/5X,   DATA1190
1195      B'READ CONTROL . . . . .',I10/5X,                  DATA1195
1200      E'TIME INTEGRATION PARAMETER . . . . .',F10.2/5X,   DATA1200
1205      F'TIME INCREMENT . . . . .',F10.2/5X,               DATA1205
1210      G'MAXIMUM VALUE OF TIME . . . . .',E10.3/5X,       DATA1210
1215      H'MAXIMUM VALUE OF DELT . . . . .',E10.3/5X,       DATA1215
1220      I'MULTIPLIER FOR TIME INCREMENT . . . . .',F10.3/5X, DATA1220
1225      J'ERROR TOLERANCE . . . . .',E10.3)                 DATA1225
1230      1001 FORMAT(1H,5X,                                     DATA1230
1235      1'WEIGHTING FUNCTION CONTROL . . . . .',I10/5X,     DATA1235
1240      2'LUMPING CONTROL . . . . .',I10/5X,                 DATA1240
1245      3'TIME DIFFERENCE CONTROL . . . . .',I10/)          DATA1245
1250      1100 FORMAT(1H0,'PRINT OUT CONTROL',/1X,120I1)        DATA1250
1255      2000 FORMAT(1H1,'INPUT TABLE 2 NODAL POINT DATA',//7X,'NODE',12X,'X', DATA1255
1260      114X,'Y',14X,'H'/)                                     DATA1260
1265      2100 FORMAT(1H,10,3P15.4)                               DATA1265
1270      3000 FORMAT(1H1,'INPUT TABLE 3 ELEMENT DATA',//11X,'GLOBAL INDICES OF DATA1270
1275      1'ELEMENT NODES',//7X,'ELEMENT',3X,'1',7X,'2',7X,'3',7X,'4',6X, DATA1275
1280      2'NODE DIFF. '/')                                       DATA1280
1285      3100 FORMAT(10,4I8,1I0)                                  DATA1285
1290      4000 FORMAT(1H1,'INPUT TABLE 4 SIDE BOUNDARY DATA: NO. OF SIDES=',I3//DATA1290
1295      16X,'SIDE',9X,'1',9X,'2',9X,'3',9X,'4',9X,'5',9X,'6') DATA1295
1300      4100 FORMAT(1H,5X,14,6I10)                               DATA1300
1305      4500 FORMAT(1H1,'INPUT TABLE 4A ISLAND DATA: NO. OF ISLANDS=',I3//1X, DATA1305
1310      1 9X,'1',9X,'J',5X,'IILND(I,J,1)',5X,'IILND(I,J,2)',5X,'IILND(I,J,3) DATA1310
1315      2',5X,'IILND(I,J,4)',5X,'IILND(I,J,5)')              DATA1315
1320      4600 FORMAT(1H,2I10,5X,I12,5X,I12,5X,I12,5X,I12)     DATA1320
1325      5000 FORMAT(1H1,'INPUT TABLE 5 SYSTEM PARAMETERS',//1X, DATA1325
1330      1'LONGITUDINAL DISPERSIVITY . . . . .',F10.2/1X,   DATA1330
1335      2'LATERAL DISPERSIVITY . . . . .',F10.2/1X,        DATA1335
1340      3'MOLECULAR DIFFUSION COEFFICIENT . . . . .',F10.5///1X, DATA1340
1345      5'DISORPTION RATE . . . . .',E10.2/1X,             DATA1345
1350      6'DECAY CONSTANT . . . . .',E10.2/)                 DATA1350
1355      5100 FORMAT(1H,6X,16,4E12.4)                           DATA1355
1360      6000 FORMAT(1H1,'INPUT TABLE 6 SYSTEM PARAMETERS AND BOUNDARY DATA FOR DATA1360
1365      1 HYDRODYNAMIC MODEL : NO. OF POINTS WITH DIRICHLET BC = ',I3//1X, DATA1365
1370      2'CCRCLIS PARAMETER . . . . .',F12.5/1X,          DATA1370
1375      3'DENSITY OF WATER . . . . .',F12.5/1X,            DATA1375
1380      4'LINEAR BOTTOM STRESS COEFFICIENT . . . . .',F12.5/1X, DATA1380
1385      5'AIR DENSITY . . . . .',F12.5/1X,                 DATA1385
1390      6'WIND STRESS COEFFICIENT . . . . .',F12.5/1X,     DATA1390
1395      7'WIND SPEED . . . . .',F12.5/1X,                  DATA1395
1400      8'WIND ANGLE WITH X-AXIS . . . . .',F12.5/1X,     DATA1400
1405      9'AVERAGE CURRENT VELOCITY . . . . .',F12.5///5X, DATA1405
1410      A'I IBVH BVH I IBVH BVH I IBVH BVH')              DATA1410
1415      6100 FORMAT(1H,I5,I7,P10.3,I5,I7,P10.3,I5,I7,P10.3)   DATA1415
1420      7000 FORMAT(1H1,'INPUT TABLE 7 SOURCE DATA',//1X,   DATA1420
1425      1' WNP 1 2 3 4 5                                     DATA1425
1430      2 7 8/)                                               DATA1430
1435      7100 FORMAT(1H,I5,8P10.2)                             DATA1435

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APPENDIX E. (Continued)

```
1440      C'OC FORNAT(1H1,'INPUT TABLE 8 BOUNDARY VALUE DATA'//1X,  
1445      A 'NO. CP POINTS WITH DIRICHLET BC = ',I3//1X,  
1450      1' WBP      1      2      3      4      5  
1455      2      7      8'/)  
1460      8100 FORNAT(1H ,I5,8F10.2)  
1465      9000 FORNAT(1H0)  
1470      END
```

DATA1440
DATA1445
6DATA1450
DATA1455
DATA1460
DATA1465
DATA1470

APPENDIX E. (Continued)

5	SUBROUTINE ELNG2D(X,Y,IE,HAXHP,HAXEL)	ELNG 005
10	DEFINITION X(HAXHP),Y(HAXHP),IE(HAXEL,4)	ELNG 010
15	COMMON /CONTROL/ HWP,WEL,IBAND,IXDIP,HALPB,INBP	ELNG 015
20	C	ELNG 020
25	CALL CALCHP(0)	ELNG 025
30	CALL BGNFL(1)	ELNG 030
35	XAXIS=6.5	ELNG 035
40	YAXIS=9.0	ELNG 040
45	XORGB=0.0	ELNG 045
50	YORGB=0.0	ELNG 050
55	CALL TITLE('FIGURE 7 ELEMENT GRIDS',100,' ',0,' ',0,XAXIS,YAXIS)	ELNG 055
60	XSTP=1	ELNG 060
65	YSTP=1	ELNG 065
70	XXHAX=20.	ELNG 070
75	YYHAX=35.0	ELNG 075
80	CALL GRAP(XORGB,XSTP,XXHAX,YORGB,YSTP,YYHAX)	ELNG 080
85	XHAX=0.0	ELNG 085
90	YHAX=0.0	ELNG 090
95	DO 100 N=1,WEL	ELNG 095
100	DO 100 IQ=1,4	ELNG 100
105	HP=IE(N,IQ)	ELNG 105
110	IX=X(HP)	ELNG 110
115	XHAX=AX*Y1(XHAX,IX)	ELNG 115
120	IY=Y(HP)	ELNG 120
125	YHAX=AH*Y1(YHAX,IY)	ELNG 125
130	100 CONTINUE	ELNG 130
135	SCALX=6.5/XHAX	ELNG 135
140	SCALY=9.0/YHAX	ELNG 140
145	SCALZ=AMIN1(SCALX,SCALY)	ELNG 145
150	DO 200 N=1,WEL	ELNG 150
155	DO 200 IQ=1,4	ELNG 155
160	HBP=IE(N,IQ)	ELNG 160
165	JQ=Y1(+1	ELNG 165
170	IF(IQ.EQ.4) JQ=1	ELNG 170
175	HFP=IE(N,JQ)	ELNG 175
180	XFROM=X(HBP)*SCALE	ELNG 180
185	YFROM=Y(HBP)*SCALE	ELNG 185
190	XTC=X(HFP)*SCALE	ELNG 190
195	YTC=Y(HFP)*SCALE	ELNG 195
200	CALL VECTOR(XFROM,YFROM,XTC,YTC,0)	ELNG 200
205	200 CONTINUE	ELNG 205
210	CALL ENDFL(1)	ELNG 210
215	RETURN	ELNG 215
220	END	ELNG 220

APPENDIX E. (Continued)

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5      SUBROUTINE HYDRON(C, PHI, DPHIX, DPHIE, X, Y, RH, VX, VY, TANH, TAYTH, IE,
10      1 HAXWP, HAXEL, HAKBW)
15      C
20      DIMENSION C(HAXWP, HAXWP), PHI(HAXWP), DPHIX(HAXWP), DPHIE(HAXWP),
25      1 X(HAXWP), Y(HAXWP), RH(HAXWP), VX(HAXWP), VY(HAXWP), TAUHX(HAXWP),
30      2 TAYTH(HAXWP), IE(HAXEL, 4)
35      C
40      COMMON /CTRL/ HWP, NEL, IBAND, HAXDIF, IHALFB, INBP
45      COMMON /TCH/ BVH(99), IBVH(99), HBVPH, IILKD(5, 20, 5), WILKDS(5), WILND
50      COMMON /HYDR/ CKW, RHOW, CONIL, AVU
55      COMMON /BUG/ IBUGH, IBUGT, IBUGQH, IBUGQT
60      C
65      DIMENSION QQ(4, 4), RQ(4), XQ(4), YQ(4), TAUHQ(4), TAUHQ(4), HHQ(4)
70      DIMENSION DISLX(4, 4), KQ(2)
75      C
80      IF(IBUGH.EQ.0) WRITE(6, 1000) HAXDIF, IHALFB, INBP, IBAND, HWP, NEL
85      C
90      DO 110 I=1, HWP
95      PHI(I)=0.0
100     DO 110 IB=1, IBAND
105     110 C(I, IB)=0.0
110      C
115     DO 300 N=1, NEL
120      C
125     DO 200 IQ=1, 4
130     WP=IE(N, IQ)
135     XQ(IQ)=X(WP)
140     YQ(IQ)=Y(WP)
145     TAUHQ(IQ)=TAUHX(WP)
150     TAYHQ(IQ)=TAYTH(WP)
155     200 HHQ(IQ)=RH(WP)
160     IF(IEUGH.EQ.0) GO TO 201
165     WRITE(6, 2000) N, (XQ(I), I=1, 4), (YQ(I), I=1, 4), (TAUHQ(I), I=1, 4),
170     1 (TAYHQ(I), I=1, 4), (HHQ(I), I=1, 4)
175     201 CONTINUE
180      C
185     CALL QARY(QQ, RQ, XQ, YQ, TAUHQ, TAYHQ, HHQ)
190      C
195      C
200      C
205     DO 250 IQ=1, 4
210     NI=IE(N, IQ)
215     DO 210 JQ=1, 4
220     NJ=IE(N, JQ)
225     IB=NJ-NI+INBP
230     210 C(NI, IB)=C(NI, IB)+QQ(IQ, JQ)
235     PHI(NI)=PHI(NI)-RQ(IQ)
240     250 CONTINUE
245     300 CONTINUE
250      C
255     IF(IBUGH.EQ.0) GO TO 351
260     WRITE(6, 3000)
265     DO 350 I=1, HWP
270     350 WRITE(6, 3100) I, (C(I, J), J=1, IBAND), PHI(I)
275     351 CONTINUE
280      C
285      C
290      C
295     DO 500 I=1, HBVPH
300     NI=INBP(I)
305     DO 400 IB=1, IBAND
310     400 C(NI, IB)=0.0
315     C(NI, INBP)=1.0
320     PHI(NI)=BVH(I)
325     IF(BVH(I).EQ.0.0) GO TO 450
330     DO 420 IB=1, IHALFB
335     NJ=NI-IB
340     IF(NJ.LT.1) GO TO 430
345     JB=INBP+IB
350     420 PHI(NJ)=PHI(NJ)-B*PHI(I)*C(NJ, JB)

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HYDR 005
HYDR 010
HYDR 015
HYDR 020
HYDR 025
HYDR 030
HYDR 035
HYDR 040
HYDR 045
HYDR 050
HYDR 055
HYDR 060
HYDR 065
HYDR 070
HYDR 075
HYDR 080
HYDR 085
HYDR 090
HYDR 095
HYDR 100
HYDR 105
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HYDR 330
HYDR 335
HYDR 340
HYDR 345
HYDR 350

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APPENDIX E. (Continued)

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355      430 IC = 40 IB=1, IHALPB                      HYDR 355
360      NJ=NI+IB                      HYDR 360
365      IF (NJ.GT.NNP) GO TO 450                      HYDR 365
370      JE=IBRF-IB                      HYDR 370
375      440 PHI(NJ)=PHI(NJ)-BVH(I)*C(NJ,JB)           HYDR 375
380      45C IC = 40 IB=1, IHALPB                      HYDR 380
385      NJ=NI-IP                      HYDR 385
390      IF (NJ.LI.1) GO TO 470                      HYDR 390
395      JE=IBRP+IB                      HYDR 395
400      460 C(NJ,JB)=0.0                      HYDR 400
405      470 IC = 40 IB=1, IHALPB                      HYDR 405
410      NJ=NI+IB                      HYDR 410
415      IF (NJ.GT.NNP) GO TO 490                      HYDR 415
420      JE=IBRP-IB                      HYDR 420
425      48C C(NJ,JB)=0.0                      HYDR 425
430      490 CONTINUE                      HYDR 430
435      500 CONTINUE                      HYDR 435
440      C                      HYDR 440
445      IF (IPUGH.EQ.0) GO TO 551                      HYDR 445
450      WRITE(6,4000)                      HYDR 450
455      DO 550 I=1,NNP                      HYDR 455
460      550 WRITE(6,3100) I, (C(I,J),J=1,IBAND), PHI(I) HYDR 460
465      551 CONTINUE                      HYDR 465
470      C                      HYDR 470
475      IF (NWLND.EQ.0) GO TO 700                      HYDR 475
480      C                      HYDR 480
485      C      FOR THE FIRST POINT OF EACH ISLAND THE CORRESPONDING ROW HYDR 485
490      C      OF C(NP,IB) HAS TO BE MODIFIED                      HYDR 490
495      C                      HYDR 495
500      DO 660 IL=1,NWLND                      HYDR 500
505      NUNBR=NWLND(IL)                      HYDR 505
510      DO 650 IS=1,NUNBR                      HYDR 510
515      NI=IILND(IL,IS,1)                      HYDR 515
520      NJ=IILND(IL,IS,2)                      HYDR 520
525      M=IILND(IL,IS,3)                      HYDR 525
530      KQ(1)=IILND(IL,IS,4)                      HYDR 530
535      KQ(2)=IILND(IL,IS,5)                      HYDR 535
540      XLNG=X(NJ)-X(NI)                      HYDR 540
545      YLNG=Y(NJ)-Y(NI)                      HYDR 545
550      ALNG=SQRT(XLNG*XLNG+YLNG*YLNG)          HYDR 550
555      ANGLE=ATAN2(YLNG,XLNG)                  HYDR 555
560      DO 640 IQ=1,4                      HYDR 560
565      NP=IE(N,IQ)                      HYDR 565
570      XQ(IQ)=X(NP)                      HYDR 570
575      YQ(IQ)=Y(NP)                      HYDR 575
580      C                      HYDR 580
585      C      CALCULATE BOUNDARY ELEMENT MATRIX FROM BOUNDARY INTEGRATION HYDR 585
590      C                      HYDR 590
595      CALL QNISL(DISLFX,KQ,YQ,KQ,ALNG,ANGLE)    HYDR 595
600      C                      HYDR 600
605      C      ASSEMBLY THE BOUNDARY MATRIX TO FORM THE GLOBAL BOUNDARY MATRIX HYDR 605
610      C                      HYDR 610
615      DO 620 IQ=1,2                      HYDR 615
620      LQ=KQ(IQ)                      HYDR 620
625      NI=IE(N,LQ)                      HYDR 625
630      DO 620 JQ=1,4                      HYDR 630
635      NJ=IE(N,JQ)                      HYDR 635
640      IB=NJ-NI+IHBP                      HYDR 640
645      620 C(NI,IB)=C(NI,IB)-DISLFX(IQ,JQ)        HYDR 645
650      65C CONTINUE                      HYDR 650
655      660 CONTINUE                      HYDR 655
660      C                      HYDR 660
665      C      FOR ALL OTHER ISLAND POINTS OF EACH ISLAND SET THE VALUE OF HYDR 665
670      C      EACH POINT EQUAL TO THE FIRST POINT                      HYDR 670
675      C                      HYDR 675
680      C                      HYDR 680
685      C      APPLYING ISLAND BOUNDARY CONDITIONS                      HYDR 685
690      C                      HYDR 690
695      C                      HYDR 695
700      DO 650 I=1,NWLND                      HYDR 700
705      NUNBR=NWLND(I)-1                      HYDR 705
710      DO 660 J=1,NUNBR                      HYDR 710

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APPENDIX E. (Continued)

715	SI=IILND(I,J,1)	HYDR 715
720	SJ=IILND(I,J,2)	HYDR 720
725	PHI(SJ)=0.0	HYDR 725
730	DO 67C JP=1,IBAND	HYDR 730
735	C(SJ,JB)=0.0	HYDR 735
740	67C CONTINUE	HYDR 740
745	C(SJ,IBEF)=1.0	HYDR 745
750	IB=S1-SJ+IBBP	HYDR 750
755	C(SJ,IB)=-1.0	HYDR 755
760	68C CONTINUE	HYDR 760
765	690 CONTINUE	HYDR 765
770	C	HYDR 770
775	IF(IBUGH.EQ.0) GO TO 696	HYDR 775
780	WRITE(6,5000)	HYDR 780
785	DO 695 I=1,NWP	HYDR 785
790	695 WRITE(6,3100) I, (C(I,J),J=1,IBAND), PHI(I)	HYDR 790
795	696 CONTINUE	HYDR 795
800	C	HYDR 800
805	7CC CONTINUE	HYDR 805
810	C	HYDR 810
815	CALL SOLVE(1,C,PHI,NWP,IHALPB,MAXNP,MAXBW)	HYDR 815
820	CALL SOLVE(2,C,PHI,NWP,IHALPB,MAXNP,MAXBW)	HYDR 820
825	C	HYDR 825
830	CALL DERIP(C,DPHIX,DPHIY,PHI,X,Y,IE,MAXNP,MAXEL,MAXBW)	HYDR 830
835	C	HYDR 835
840	DO 900 I=1,NWP	HYDR 840
845	VX(I)=-DPHIY(I)	HYDR 845
850	VY(I)=DPHIX(I)	HYDR 850
855	900 CONTINUE	HYDR 855
860	RETURN	HYDR 860
865	1C00 FORMAT(1H1,10X,'DEBUG FOR HYDRODYNAMIC MODEL IS ACTIVATED'/1X,	HYDR 865
870	1 'MAXDIF=',I3,' IHALPB=',I3,' IBBP=',I3,' IBAND=',I3,	HYDR 870
875	2 ' NWP=',I3,' NEL=',I3)	HYDR 875
880	2C00 FORMAT(1H0,I3,' TH ELEMENT', ' IQ=',4F8.1,' YQ=',4F8.1/20X,	HYDR 880
885	1 'TAUXHQ=',4F8.1,' TAUHQ=',4F8.1/20X,' HHQ=',4F8.1/)	HYDR 885
890	3000 FORMAT(1H1,'GLOBAL MATRIX AND LOAD VECTOR BEFORE APPLY BC'/)	HYDR 890
895	310C FORMAT(1H0,I3,{11E11.3})	HYDR 895
900	4000 FORMAT(1H1,'GLOBAL MATRIX AND LOAD VECTOR AFTER APPLY DIRI. BC'/)	HYDR 900
905	5000 FORMAT(1H1,'GLOBAL MATRIX AND LOAD VECTOR AFTER APPLY ISLAND BC'/)	HYDR 905
910	END	HYDR 910

APPENDIX E. (Continued)

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5      SUBROUTINE Q4HY (Q0,PQ,XQ,YQ,TAUXHQ,TAUYHQ,HQ,
10      PIAL*4,B(4)
15      CCHCK /HYDP/ CFW,RHCV,COSIL,AVO
20      COMMON /BUG/ IBUGH,IBUGT,IBUGQH,IBUGQT
25      DIMENSION Q0(4,4),HQ(4),IQ(4),YQ(4),TAUXHQ(4),TAUYHQ(4),HQ(4)
30      DIMENSION S(4),T(4),DNX(4),DNY(4)
35      C
40      DATA P/C,577350/
45      DATA S/-1.0,1.0,1.0,-1.0/, T/-1.0,-1.0,1.0,1.0/
50      C
55      C
60      DO 100 IQ=1,4
65      HQ(IQ)=0.0
70      DO 100 JQ=1,4
75      CQ(IQ,JQ)=0.0
80      C
85      X12=XQ(1)-XQ(2)
90      X13=XQ(1)-XQ(3)
95      X14=XQ(1)-XQ(4)
100     X23=XQ(2)-XQ(3)
105     X24=XQ(2)-XQ(4)
110     X34=XQ(3)-XQ(4)
115     Y12=YQ(1)-YQ(2)
120     Y13=YQ(1)-YQ(3)
125     Y14=YQ(1)-YQ(4)
130     Y23=YQ(2)-YQ(3)
135     Y24=YQ(2)-YQ(4)
140     Y34=YQ(3)-YQ(4)
145     ARIA=0.0
150     AREA=X13*Y24-X24*Y13
155     C
160     DO 400 FT=1,4
165     SS=P*S(KG)
170     TT=P*T(KG)
175     DJ=AREA+SS*(X34*Y12-X12*Y34)+TT*(X23*Y14-X14*Y23)
180     DJAC=DJ/R.0
185     ARIA=ARIA+DJAC
190     DJI=1.0/DJ
195     SH=1.0-SS
200     SP=1.0+SE
205     TH=1.0-TT
210     TP=1.0+TT
215     DNY(1)=(-X24+X34*SS+X23*TT)*DJI
220     DNY(2)=(X13-X34*SS-X14*TT)*DJI
225     DNY(3)=(X24-X12*SS+X14*TT)*DJI
230     DNY(4)=(-X13+X12*SS-X23*TT)*DJI
235     DNX(1)=(Y24-Y34*SS-Y23*TT)*DJI
240     DNX(2)=(-Y13+Y34*SS+Y14*TT)*DJI
245     DNX(3)=(-Y24+Y12*SS-Y14*TT)*DJI
250     DNX(4)=(Y13-Y12*SS+Y23*TT)*DJI
255     N(1)=0.25*SH*TH
260     N(2)=0.25*SP*TH
265     N(3)=0.25*SP*TP
270     N(4)=0.25*SH*TP
275     C
280     C
285     DNK=0.0
290     DNYK=0.0
295     RKK=C.0
300     DO 200 IQ=1,4
305     RKK=RKK+HQ(IQ)*HQ(IQ)
310     DNK=DNK+HQ(IQ)*DNX(IQ)
315     DNYK=DNYK+HQ(IQ)*DNY(IQ)
320     IF (IBUGQH.NE.0) WRITE(6,1000) KG,RKK,DNKK,DNYK,(N(I),I=1,4),
325     1 (DNX(I),I=1,4),(DNY(I),I=1,4)
330     C
335     DO 300 IQ=1,4
340     DO 300 JQ=1,4
345     DNKDNK=DNK(IQ)*DNK(JQ)*DJAC
350     DNYDNY=DNY(IQ)*DNY(JQ)*DJAC
355     DNDN=DNK(IQ)*DNY(JQ)*DJAC

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APPENDIX E. (Continued)

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360      WDMY=N(IQ)*DMY(JQ)*DJAC                      Q4HY 360
365      QQ(IQ,JQ)=DMXDMX+DMYDMY + WDMY*(2.C*DHXK/HKK+CORIL*DMYK/(CKW*AVU)) Q4HY 365
370      1+WDMY*(2.0*DHXK/HKK-CORIL*DHXK/(CKW*AVU)) + QQ(IQ,JQ) Q4HY 370
375      BQ(IC)=BQ(IQ) + HKK*HKK*WDMY*TAUXHQ(JQ)/(RHOW*CKW*AVU) - Q4HY 375
380      1      HKK*HKK*WDMY*TAUXHQ(JQ)/(RHOW*CKW*AVU) Q4HY 380
385      200 CONTINUE Q4HY 385
390      C Q4HY 390
395      IF (IBNGQH.EQ.0) GO TO 351 Q4HY 395
400      WRITE(6,2000) KG,ARIA Q4HY 400
405      DO 350 I=1,4 Q4HY 405
410      350 WRITE(6,2100) I,(QQ(I,J),J=1,4),BQ(I) Q4HY 410
415      351 CONTINUE Q4HY 415
420      C Q4HY 420
425      400 CONTINUE Q4HY 425
430      RETURN Q4HY 430
435      1000 FORMAT(1H0,I3,' TH GAUSS POINT', ' HKK=',E10.3, ' DH/DY=',E10.3, Q4HY 435
440      1' DH/DY=',E10.3, ' W=',E11.3/1X,'DMX=',E11.3,10X,'DMY=',E11.3) Q4HY 440
445      2000 FORMAT(1H0,'ELEMENT MATRIX AND LOAD VECTOR SUMMED OVER ',I3, Q4HY 445
450      1' GAUSS POINTS', ' AREA=',E11.3) Q4HY 450
455      2100 FORMAT(1H,'I=',I5,2X,'QQ=',E12.3,5X,'BQ=',E12.3) Q4HY 455
460      END Q4HY 460

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APPENDIX E. (Continued)

5	SUBROUTINE SOLVE(KKK,C,R,WNP,IHALPB,MAXWP,MAXBW)	SOLV 005
10	DIMENSION C(MAXWF,MAXBW),R(MAXWP)	SOLV 010
15	C	SOLV 015
20	IHBP=IHALPB+1	SOLV 020
25	IF (KKK.EQ.2) GO TO 50	SOLV 025
30	WU=WNP-IHALPB	SOLV 030
35	DO 20 NI=1,WU	SOLV 035
40	PIVOTI=1./C(NI,IHBP)	SOLV 040
45	WJ=NI+1	SOLV 045
50	IE=IHBP	SOLV 050
55	WK=NI+IHALPB	SOLV 055
60	DO 10 WL=WJ,WK	SOLV 060
65	IE=IE-1	SOLV 065
70	A=-C(WL,IE)*PIVOTI	SOLV 070
75	C(WL,IE)=A	SOLV 075
80	JB=IE+1	SOLV 080
85	KB=IE+IHALPB	SOLV 085
90	LB=IHBP-IE	SOLV 090
95	DO 10 MB=JB,KB	SOLV 095
100	MB=LB+MB	SOLV 100
105	10 C(WL,MB)=C(WL,MB)+A*C(NI,MB)	SOLV 105
110	20 CCNTINUE	SOLV 110
115	WR=WU+1	SOLV 115
120	WU=WNP-1	SOLV 120
125	WK=WFF	SOLV 125
130	DO 40 NI=WR,WU	SOLV 130
135	PIVOTI=1./C(NI,IHBP)	SOLV 135
140	WJ=NI+1	SOLV 140
145	IE=IHBP	SOLV 145
150	DO 30 WL=WJ,WK	SOLV 150
155	IE=IE-1	SOLV 155
160	A=-C(WL,IE)*PIVOTI	SOLV 160
165	C(WL,IE)=A	SOLV 165
170	JB=IE+1	SOLV 170
175	KB=IE+IHALPB	SOLV 175
180	LB=IHBP-IE	SOLV 180
185	DO 30 MB=JB,KB	SOLV 185
190	MB=LB+MB	SOLV 190
195	30 C(WL,MB)=C(WL,MB)+A*C(NI,MB)	SOLV 195
200	40 CCNTINUE	SOLV 200
205	RETURN	SOLV 205
210	50 WU=WNP+1	SOLV 210
215	IBAND=2*IHALPB+1	SOLV 215
220	DO 70 NI=2,IHBP	SOLV 220
225	IB=IHBP-NI+1	SOLV 225
230	WJ=1	SOLV 230
235	SUM=0.0	SOLV 235
240	DO 60 JB=IB,IHALPB	SOLV 240
245	SUM=SUM+C(NI,JB)*R(WJ)	SOLV 245
250	60 WJ=WJ+1	SOLV 250
255	70 R(NI)=R(NI)+SUM	SOLV 255
260	IB=1	SOLV 260
265	IL=IHBP+1	SOLV 265
270	DO 90 NI=IL,WNP	SOLV 270
275	WJ=NI-IHBP+1	SOLV 275
280	SUM=0.0	SOLV 280
285	DO 80 JB=IB,IHALPB	SOLV 285
290	SUM=SUM+C(NI,JB)*R(WJ)	SOLV 290
295	80 WJ=WJ+1	SOLV 295
300	90 R(NI)=R(NI)+SUM	SOLV 300
305	R(WNF)=R(WNP)/C(WNP,IHBP)	SOLV 305
310	DO 110 IB=2,IHBP	SOLV 310
315	NI=WU-IB	SOLV 315
320	WJ=NI	SOLV 320
325	MB=IHALPB+IB	SOLV 325
330	SUM=0.0	SOLV 330
335	DO 100 JB=NL,MB	SOLV 335
340	WJ=WJ+1	SOLV 340
345	SUM=SUM+C(NI,JB)*R(WJ)	SOLV 345
350	110 R(NI)=(R(NI)-SUM)/C(NI,IHBP)	SOLV 350
355	MB=IBAND	SOLV 355

APPENDIX E. (Continued)

360	CO 130 IB=NL,NMP	SOLV 360
365	NI=NO-IB	SOLV 365
370	NI=NI	SOLV 370
375	SUM=0.0	SOLV 375
380	DC 120 JB=NL,NB	SOLV 380
385	NJ=NJ+1	SOLV 385
390	120 SUM=SUM+C(NI,JB)*R(NJ)	SOLV 390
395	130 R(NI)=(R(NI)-SUM)/C(NI,IBBP)	SOLV 395
400	RETURN	SOLV 400
405	END	SOLV 405

APPENDIX E. (Continued)

5		SUBROUTINE DERIF(C,PDPX,PDPY,FCTF,X,Y,IE,MAXNP,MAXEL,MAXBW)	DERI 005
10	C		DERI 010
15		DIMENSION C(MAXNP,MAXBW),PDPX(MAXNP),PDPY(MAXNP),FCTF(MAXNP),	DERI 015
20		1 X(MAXNE),Y(MAXNE),IE(MAXEL,4)	DERI 020
25		DIMENSION QQ(4,4),RQ(4),XQ(4),YQ(4),FCTPQ(4)	DERI 025
30	C		DERI 030
35		COMMON /CONTRL/ NNP,NEL,IBAND,MAXDIP,IALPFB,INBP	DERI 035
40	C		DERI 040
45	C	TO CALCULATE THE DERIVATIVES OF A FUNCTION AT NODAL POINTS	DERI 045
50	C	GIVEN THE VALUE OF FUNCTION AT ALL NODAL POINTS	DERI 050
55	C		DERI 055
60		IALPFB=MAXDIP	DERI 060
65		IBAND=2*IALPFB+1	DERI 065
70		INBP=IALPFB+1	DERI 070
75	C		DERI 075
80		DO 100 I=1,NNP	DERI 080
85		PDPX(I)=0.0	DERI 085
90	100	PDPY(I)=0.0	DERI 090
95	C		DERI 095
100	C		DERI 100
105		DO 300 IXY=1,2	DERI 105
110	C		DERI 110
115		DO 110 I=1,NNP	DERI 115
120		DO 110 IB=1,IBAND	DERI 120
125	110	C(I,IB)=C.0	DERI 125
130	C		DERI 130
135		DO 160 M=1,NEL	DERI 135
140	C		DERI 140
145		DO 120 IQ=1,4	DERI 145
150		NP=IE(M,IQ)	DERI 150
155		XQ(IQ)=X(NP)	DERI 155
160		YQ(IQ)=Y(NP)	DERI 160
165	120	FCTPQ(IQ)=FCTF(NP)	DERI 165
170		CALL GADI(QQ,RQ,XQ,YQ,FCTPQ,IXY)	DERI 170
175		DO 140 JQ=1,4	DERI 175
180		NI=IE(M,IQ)	DERI 180
185		DO 120 JQ=1,4	DERI 185
190		NJ=IE(M,JQ)	DERI 190
195		IB=NJ-NI+IALPFB	DERI 195
200	120	C(NI,IB)=C(NI,IB)+QQ(IQ,JQ)	DERI 200
205		IF (IXY.EQ.2) GO TO 135	DERI 205
210		PDPX(NI)=PDPX(NI)+RQ(IQ)	DERI 210
215		GO TO 140	DERI 215
220	135	PDPY(NI)=PDPY(NI)+RQ(IQ)	DERI 220
225	140	CONTINUE	DERI 225
230	C		DERI 230
235		180 CONTINUE	DERI 235
240	C		DERI 240
245	C		DERI 245
250		IF (IXY.EQ.2) GO TO 200	DERI 250
255		CALL SOLVE(1,C,PDPX,NNP,IALPFB,MAXNP,MAXBW)	DERI 255
260		CALL SOLVE(2,C,PDPY,NNP,IALPFB,MAXNP,MAXBW)	DERI 260
265		GO TO 300	DERI 265
270	200	CALL SOLVE(1,C,PDPY,NNP,IALPFB,MAXNP,MAXBW)	DERI 270
275		CALL SOLVE(2,C,PDPX,NNP,IALPFB,MAXNP,MAXBW)	DERI 275
280	300	CONTINUE	DERI 280
285	C		DERI 285
290		RETURN	DERI 290
295		END	DERI 295

APPENDIX E. (Continued)

```

5      SUBROUTINE Q4DI (QQ,RQ,IQ,YQ,PCTPQ,IND)
10      C
15      REAL*4 H(4)
20      C
25      DIMENSION QQ(4,4),RQ(4),IQ(4),YQ(4),PCTPQ(4)
30      DIMENSION S(4),T(4),DNI(4),DNY(4)
35      C
40      DATA P/0.577350/
45      DATA S/-1.0,1.0,1.0,-1.0/, T/-1.0,-1.0,1.0,1.0/
50      C
55      DO 100 IQ=1,4
60      RQ(IQ)=0.0
65      DO 100 JQ=1,4
70      100 QQ(IQ,JQ)=0.0
75      C
80      X12=XQ(1)-XQ(2)
85      X13=XQ(1)-XQ(3)
90      X14=XQ(1)-XQ(4)
95      X23=XQ(2)-XQ(3)
100     X24=XQ(2)-XQ(4)
105     X34=XQ(3)-XQ(4)
110     Y12=YQ(1)-YQ(2)
115     Y13=YQ(1)-YQ(3)
120     Y14=YQ(1)-YQ(4)
125     Y23=YQ(2)-YQ(3)
130     Y24=YQ(2)-YQ(4)
135     Y34=YQ(3)-YQ(4)
140     AREA=X13*Y24-X24*Y13
145     C
150     DO 400 KG=1,4
155     SS=P*S(KG)
160     TT=P*T(KG)
165     DJ=AREA+SS*(X34*Y12-X12*Y34)+TT*(X23*Y14-X14*Y23)
170     DJAC=DJ/8.0
175     DJI=1.0/DJ
180     SH=1.0-SS
185     SP=1.0+SS
190     TH=1.0-TT
195     TP=1.0+TT
200     DNY(1)=(-X24*X34*SS+X23*TT)*DJI
205     DNY(2)=(X13-X34*SS-X14*TT)*DJI
210     DNY(3)=(X24-X12*SS+X14*TT)*DJI
215     DNY(4)=(-X13+X12*SS-X23*TT)*DJI
220     DNI(1)=(Y24-Y34*SS-Y23*TT)*DJI
225     DNI(2)=(-Y13+Y34*SS+Y14*TT)*DJI
230     DNI(3)=(-Y24+Y12*SS-Y14*TT)*DJI
235     DNI(4)=(Y13-Y12*SS+Y23*TT)*DJI
240     H(1)=0.25*SH*TH
245     H(2)=0.25*SP*TH
250     H(3)=0.25*SP*TP
255     H(4)=0.25*SH*TP
260     C
265     CFXK=0.0
270     CFYK=0.0
275     DO 200 IQ=1,4
280     DFXK=DFXK+PCTPQ(IQ)*DNI(IQ)
285     DFXK=DFXK+PCTPQ(IQ)*DNY(IQ)
290     C
295     C
300     IF (IND.EQ.?) GO TO 320
305     C
310     DO 300 IQ=1,4
315     RQ(IQ)=RQ(IQ)+H(IQ)*DFXK+DJAC
320     DO 300 JQ=1,4
325     QQ(IQ,JQ)=QQ(IQ,JQ)+H(IQ)*H(JQ)*DJAC
330     300 CONTINUE
335     C
340     GO TO 340
345     C
350     DO 330 IQ=1,4
355     RQ(IQ)=RQ(IQ)+H(IQ)*DFXK+DJAC

```

Q4DI 635
Q4DI 010
Q4DI 015
Q4DI 020
Q4DI 025
Q4DI 030
Q4DI 035
Q4DI 040
Q4DI 045
Q4DI 050
Q4DI 055
Q4DI 060
Q4DI 065
Q4DI 070
Q4DI 075
Q4DI 080
Q4DI 085
Q4DI 090
Q4DI 095
Q4DI 100
Q4DI 105
Q4DI 110
Q4DI 115
Q4DI 120
Q4DI 125
Q4DI 130
Q4DI 135
Q4DI 140
Q4DI 145
Q4DI 150
Q4DI 155
Q4DI 160
Q4DI 165
Q4DI 170
Q4DI 175
Q4DI 180
Q4DI 185
Q4DI 190
Q4DI 195
Q4DI 200
Q4DI 205
Q4DI 210
Q4DI 215
Q4DI 220
Q4DI 225
Q4DI 230
Q4DI 235
Q4DI 240
Q4DI 245
Q4DI 250
Q4DI 255
Q4DI 260
Q4DI 265
Q4DI 270
Q4DI 275
Q4DI 280
Q4DI 285
Q4DI 290
Q4DI 295
Q4DI 300
Q4DI 305
Q4DI 310
Q4DI 315
Q4DI 320
Q4DI 325
Q4DI 330
Q4DI 335
Q4DI 340
Q4DI 345
Q4DI 350
Q4DI 355

APPENDIX E. (Continued)

```

360      DO 330 JQ=1,4
365      QQ(IQ,JQ)=QQ(IQ,JQ)+7(IQ)*W(JQ)*DJAC
370      330 CONTINUE
375      C
380      340 CONTINUE
385      400 CONTINUE
390      RETURN
395      END

```

```

Q4DI 360
Q4DI 365
Q4DI 370
Q4DI 375
Q4DI 380
Q4DI 385
Q4DI 390
Q4DI 395

```

APPENDIX E. (Continued)

```

5      SUBROUTINE Q4ISL(DISLFX,XQ,YQ,KQ,ALWC,ANGLE)
10     C
15     BEAL=8 b(4)
20     DIMENSION DISLFX(4,4),XQ(4),YQ(4),KQ(2)
25     DIMENSION S(4,4),T(4,4),DNX(4),DNY(4),SSA(2),TTA(2)
30     C
35     DATA S/0.0, 0.57735,0.0,-1.0, -0.57735,0.0,1.0,0.0,
40     1      C.0,1.0,0.0,-0.57735, -1.0,0.0,0.57735,0.0/
45     DATA T/0.0,-1.0,0.0,0.57735, -1.0,0.0,0.57735,0.0,
50     1      0.0,-0.57735,0.0,1.0, -0.57735,0.0,1.0,0.0/
55     C
60     DO 100 IQ=1,4
65     DO 100 JQ=1,4
70     100 DISLFX(IQ,JQ)=0.0
75     C
80     X12=XQ(1)-XQ(2)
85     X13=XQ(1)-XQ(3)
90     X14=XQ(1)-XQ(4)
95     X23=XQ(2)-XQ(3)
100    X24=XQ(2)-XQ(4)
105    X34=XQ(3)-XQ(4)
110    Y12=YQ(1)-YQ(2)
115    Y13=YQ(1)-YQ(3)
120    Y14=YQ(1)-YQ(4)
125    Y23=YQ(2)-YQ(3)
130    Y24=YQ(2)-YQ(4)
135    Y34=YQ(3)-YQ(4)
140    AREA=X13*Y24-X24*Y13
145    C
150    IQ=KQ(1)
155    JQ=KQ(2)
160    SSA(1)=S(LQ,HQ)
165    TTA(1)=T(LQ,HQ)
170    SSA(2)=S(HQ,LQ)
175    TTA(2)=T(HQ,LQ)
180    C
185    C
190    C
195    DO 400 KQ=1,2
200    SS=SSA(KQ)
205    TT=TTA(KQ)
210    C1J=AREA+SS*(X34*Y12-X12*Y34)+TT*(X23*Y14-X14*Y23)
215    C1JAC=C1J/8.0
220    C1J1=1.0/C1J
225    SH=1.0-SS
230    SP=1.0+SS
235    TH=1.0-TT
240    TP=1.0+TT
245    DNY(1)=(-X24+X34*SS+X23*TT)*C1J1
250    DNY(2)=(X13-X34*SS-X14*TT)*C1J1
255    DNY(3)=(X24-X12*SS+X14*TT)*C1J1
260    DNY(4)=(-X13+X12*SS-X23*TT)*C1J1
265    DNX(1)=(Y24-Y34*SS-Y23*TT)*C1J1
270    DNX(2)=(-Y13+Y34*SS+Y14*TT)*C1J1
275    DNX(3)=(-Y24+Y12*SS+Y14*TT)*C1J1
280    DNX(4)=(Y13-Y12*SS+Y23*TT)*C1J1
285    H(1)=0.25*SH*TH
290    H(2)=0.25*SP*TH
295    H(3)=0.25*SP*TP
300    H(4)=0.25*SH*TP
305    C
310    C
315    DO 300 IQ=1,2
320    IQ=KQ(IQ)
325    DO 300 JQ=1,4
330    300 DISLFX(IQ,JQ)=DISLFX(IQ,JQ)+H(LQ)*(DNX(JQ)*SIN(ANGLE)-DNY(JQ)*
335    1COS(ANGLE))
340    C
345    400 CONTINUE
350    C
355    DO 500 IQ=1,2

```

```

Q4IS 005
Q4IS 010
Q4IS 015
Q4IS 020
Q4IS 025
Q4IS 030
Q4IS 035
Q4IS 040
Q4IS 045
Q4IS 050
Q4IS 055
Q4IS 060
Q4IS 065
Q4IS 070
Q4IS 075
Q4IS 080
Q4IS 085
Q4IS 090
Q4IS 095
Q4IS 100
Q4IS 105
Q4IS 110
Q4IS 115
Q4IS 120
Q4IS 125
Q4IS 130
Q4IS 135
Q4IS 140
Q4IS 145
Q4IS 150
Q4IS 155
Q4IS 160
Q4IS 165
Q4IS 170
Q4IS 175
Q4IS 180
Q4IS 185
Q4IS 190
Q4IS 195
Q4IS 200
Q4IS 205
Q4IS 210
Q4IS 215
Q4IS 220
Q4IS 225
Q4IS 230
Q4IS 235
Q4IS 240
Q4IS 245
Q4IS 250
Q4IS 255
Q4IS 260
Q4IS 265
Q4IS 270
Q4IS 275
Q4IS 280
Q4IS 285
Q4IS 290
Q4IS 295
Q4IS 300
Q4IS 305
Q4IS 310
Q4IS 315
Q4IS 320
Q4IS 325
Q4IS 330
Q4IS 335
Q4IS 340
Q4IS 345
Q4IS 350
Q4IS 355

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APPENDIX E. (Continued)

```
360      EC 500 JQ=1.4
365      DISLFX(IQ,JQ)=DISLFX(IQ,JQ)*0.5*ALNG
370      500 CONTINUE
375      C
380      RETURN
385      END
```

```
Q4IS 360
Q4IS 365
Q4IS 370
Q4IS 375
Q4IS 380
Q4IS 385
```

APPENDIX E. (Continued)

5	SUBROUTINE VELPLT(X,Y,VI,VY,IE,HAXHP,HAYEL)	VELP 005
10	DIMENSION I(HAXHP),Y(HAXHP),VI(HAXHP),VY(HAXHP),IE(HAYEL,4)	VELP 010
15	COMMON /CTRL/ HWP,BEL,ISAND,HAXDIP,IALPBI,IBBP	VELP 015
20	COMMON /GT/ BV(99),IBV(99),ISIDE(99,6),WBVP,WBIDE	VELP 020
25	C	VELP 025
30	CALL BGVFL(2)	VELP 030
35	C	VELP 035
40	XAXIS=6.5	VELP 040
45	YAXIS=9.0	VELP 045
50	XORGN=0.0	VELP 050
55	YORGN=0.0	VELP 055
60	CALL TITLE('FIGURE 8 FLOW RATE PATTERNS',100,' ',0,' ',0,XAXIS,	VELP 060
65	YAXIS)	VELP 065
70	XSTP=1	VELP 070
75	YSTP=1	VELP 075
80	KXAX=6.0	VELP 080
85	YHAX=5.0	VELP 085
90	CALL GMAP(XORGN,XSTP,KXAX,YORGN,YSTP,YHAX)	VELP 090
95	C	VELP 095
100	C DETERMINE THE SCALE FOR FRAM PLOT	VELP 100
105	C	VELP 105
110	XHAX=0.0	VELP 110
115	YHAX=0.0	VELP 115
120	DO 100 N=1,BEL	VELP 120
125	DO 100 IQ=1,4	VELP 125
130	WP=IE(N,IQ)	VELP 130
135	XX=X(WP)	VELP 135
140	XHAX=AHAX1(XHAX,XX)	VELP 140
145	YY=Y(WP)	VELP 145
150	YHAX=AHAX1(YHAX,YY)	VELP 150
155	100 CONTINUE	VELP 155
160	SCALE=6.5/YHAX	VELP 160
165	SCALY=9.0/YHAX	VELP 165
170	SCALE=AMIN1(SCALE,SCALY)	VELP 170
175	C	VELP 175
180	C DETERMINE SCALE FOR VELOCITY PLOT	VELP 180
185	C	VELP 185
190	SCALV=0.06	VELP 190
195	C	VELP 195
200	C DRAW THE BOUNDARY	VELP 200
205	DO 200 I=1,WBIDE	VELP 205
210	IND=ISIDE(I,6)	VELP 210
215	IF (IND.LT.10) GO TO 200	VELP 215
220	N=ISIDE(I,3)	VELP 220
225	NI=ISIDE(I,1)	VELP 225
230	NJ=ISIDE(I,2)	VELP 230
235	IFRON=X(NI)*SCALE	VELP 235
240	YFRON=Y(NI)*SCALE	VELP 240
245	ITO=X(NJ)*SCALE	VELP 245
250	YTO=Y(NJ)*SCALE	VELP 250
255	CALL VECTOR(XFRON,YFRON,ITO,YTO,0)	VELP 255
260	200 CONTINUE	VELP 260
265	C DRAW FLOW RATE VECTOR	VELP 265
270	C	VELP 270
275	DO 390 N=1,BEL	VELP 275
280	VVX=0.0	VELP 280
285	VVY=0.0	VELP 285
290	IFRON=0.0	VELP 290
295	YFRON=0.0	VELP 295
300	DO 310 IQ=1,4	VELP 300
305	WP=IE(N,IQ)	VELP 305
310	XFRON=XFRON+X(WP)	VELP 310
315	YFRON=YFRON+Y(WP)	VELP 315
320	VVX=VVX+VI(WP)	VELP 320
325	VVY=VVY+VY(WP)	VELP 325
330	310 CONTINUE	VELP 330
335	IFRON=0.25*XFRON*SCALE	VELP 335
340	YFRON=0.25*YFRON*SCALE	VELP 340
345	ITC=XFRON+0.25*VVX*SCALV	VELP 345
350	YTC=YFRON+0.25*VVY*SCALV	VELP 350
355	CALL VECTOR(XFRON,YFRON,ITC,YTC,101)	VELP 355
360	390 CONTINUE	VELP 360
365	CALL ENDFL(2)	VELP 365
370	CALL DONEPL	VELP 370
375	RETURN	VELP 375
380	END	VELP 380

APPENDIX E. (Continued)

5	SUBROUTINE POLLUN(C, R, RP, K, Y, HH, VKW, VYW, SOURCEW, IE,	POLL 005
10	1 PAXWF, HAXEL, HAXBW)	POLL 010
15	C	POLL 015
20	DIMENSION C(HAXWP, HAXBW), R(HAXWP), RP(HAXWP), X(HAXWP), Y(HAXWP),	POLL 020
25	1 HH(HAXWF), VKW(HAXWP), VYW(HAXWP), SOURCEW(HAXWP), IE(HAXEL, 4)	POLL 025
30	C	POLL 030
35	COMMON /CONTR/ WWP, WEL, IBAND, HAXDIP, INALPB, INBP	POLL 035
40	COMMON /GT/ BV(99), IBV(99), ISIDE(99, 6), WBVP, WSIDE	POLL 040
45	COMMON /PARH/ OMEGA, DELT, THAX, DELTHX, CHGC, EPS	POLL 045
50	COMMON /TRANSP/ AL, AT, DB, RK, RKH, RLAND, ITRANS	POLL 050
55	COMMON /WELUM/ IWET, ILUPP, IHID	POLL 055
60	COMMON /BUG/ IBUGW, IBUGT, IBUGQH, IBUGQT	POLL 060
65	C	POLL 065
70	DIMENSION QA(4, 4), QB(4, 4), RLOADQ(4), KQ(4), YQ(4), VKQ(4), VYQ(4),	POLL 070
75	1 HHQ(4), SOURCEQ(4)	POLL 075
80	DIMENSION DPLKQ(2, 2), VKXQ(2), VYXQ(2), IXQ(2), IYQ(2), HHQ(2)	POLL 080
85	C	POLL 085
90	IF(BUGT.WE.0) WRITE(6, 1000) HAXDIP, INALPB, INBP, IBAND, WWP, WEL	POLL 090
95	ELTI=1.0/DELT	POLL 095
100	W1=OMEG	POLL 100
105	W2=1.	POLL 105
110	IF(ELT) WE.0) GO TO 100	POLL 110
115	ELTI=0.0	POLL 115
120	W1=1.0	POLL 120
125	W2=0.0	POLL 125
130	C	POLL 130
135	100 DO 110 I=1, WWP	POLL 135
140	R(I)=0.0	POLL 140
145	DO 110 IB=1, IBAND	POLL 145
150	110 C(I, IB)=0.0	POLL 150
155	C	POLL 155
160	C	POLL 160
165	DO 300 H=1, WEL	POLL 165
170	C	POLL 170
175	DO 200 IQ=1, 4	POLL 175
180	WP=IE(H, IQ)	POLL 180
185	HHQ(IQ)=HH(WP)	POLL 185
190	KQ(IQ)=X(WP)	POLL 190
195	YQ(IQ)=Y(WP)	POLL 195
200	VKQ(IQ)=VKW(WP)	POLL 200
205	VYQ(IQ)=VYW(WP)	POLL 205
210	SOURCEQ(IQ)=SOURCEW(WP)	POLL 210
215	200 CONTINUE	POLL 215
220	IF(BUGT.EQ.0) GO TO 201	POLL 220
225	WRITE(6, 2000) H, ALPHA1, ALPHA2, BETA1, BETA2, (KQ(I), I=1, 4),	POLL 225
230	1 (YQ(I), I=1, 4), (HHQ(I), I=1, 4), (SOURCEQ(I), I=1, 4), (VKQ(I), I=1, 4),	POLL 230
235	2 (VYQ(I), I=1, 4)	POLL 235
240	201 CONTINUE	POLL 240
245	C	POLL 245
250	CALL AYABTA(Alpha1, Alpha2, Beta1, Beta2, H, K, Y, VKW, VYW, IE,	POLL 250
255	1 HAXWP, HAXEL)	POLL 255
260	C	POLL 260
265	CALL QAPC(QA, QB, RLOADQ, KQ, YQ, VKQ, VYQ, HHQ, SOURCEQ, Alpha1, Alpha2,	POLL 265
270	1 BETA1, BETA2)	POLL 270
275	C	POLL 275
280	IF(IHID.WE.0) GO TO 260	POLL 280
285	C	POLL 285
290	DO 250 IQ=1, 4	POLL 290
295	WI=IE(H, IQ)	POLL 295
300	DO 210 JQ=1, 4	POLL 300
305	WJ=IE(H, JQ)	POLL 305
310	CA(IC, JQ)=QA(IQ, JQ)*DELT	POLL 310
315	R(WI)=R(WI)+(QA(IQ, JQ)-W2*QB(IQ, JQ))*RP(WJ)	POLL 315
320	IB=WJ-WI+INBP	POLL 320
325	C(WI, IB)=C(WI, IB)+QA(IQ, JQ)+W1*QB(IQ, JQ)	POLL 325
330	210 CONTINUE	POLL 330
335	R(WI)=R(WI)-RLOADQ(IQ)	POLL 335
340	250 CONTINUE	POLL 340
345	GO TO 300	POLL 345
350	C	POLL 350
355	260 CONTINUE	POLL 355
360	DO 280 IQ=1, 4	POLL 360
365	WI=II(H, IQ)	POLL 365

APPENDIX E. (Continued)

370	DO 270 JQ=1,4	POLL 370
375	HJ=IY(H,JQ)	POLL 375
380	CA(IQ,JQ)=2.0*QA(IQ,JQ)*DELTI	POLL 380
385	H(HI)=H(HI)+CA(IQ,JQ)*HP(HJ)	POLL 385
390	IB=HJ-HI+INBP	POLL 390
395	C(HI,IB)=C(HI,IB)+QA(IQ,JQ)*QB(IQ,JQ)	POLL 395
400	270 CONTINUE	POLL 400
405	R(HI)=R(HI)-RLOADQ(IQ)	POLL 405
410	2EC CONTINUE	POLL 410
415	C	POLL 415
420	300 CONTINUE	POLL 420
425	C	POLL 425
430	IF(IBGT.EQ.0) GO TO 351	POLL 430
435	WRITE(6,3000)	POLL 435
440	DO 350 I=1,NBP	POLL 440
445	350 WRITE(6,3100) I, (C(I,J),J=1,IBAND), R(I)	POLL 445
450	351 CONTINUE	POLL 450
455	C	POLL 455
460	IF(NBVP.EQ.0) GO TO 600	POLL 460
465	C	POLL 465
470	C DIRICHY BOUNDARY CONDITIONS	POLL 470
475	C	POLL 475
480	DO 500 I=1,NBVP	POLL 480
485	HI=IEV(I)	POLL 485
490	DO 400 IJ=1,IBAND	POLL 490
495	400 C(HI,IB)=0.0	POLL 495
500	C(HI,INBP)=1.0	POLL 500
505	R(HI)=BV(I)	POLL 505
510	IF(BV(I).EQ.0.0) GO TO 450	POLL 510
515	DO 420 IB=1,INALPB	POLL 515
520	HJ=HI-IB	POLL 520
525	IF(HJ.LT.1) GO TO 430	POLL 525
530	JB=INBP+IB	POLL 530
535	420 R(HJ)=R(HJ)-BV(I)*C(HJ,JB)	POLL 535
540	430 DO 440 IB=1,INALPB	POLL 540
545	HJ=HI+IB	POLL 545
550	IF(HJ.GT.NBP) GO TO 450	POLL 550
555	JB=INBP-IB	POLL 555
560	440 R(HJ)=R(HJ)-BV(I)*C(HJ,JB)	POLL 560
565	C	POLL 565
570	450 DO 460 IB=1,INALPB	POLL 570
575	HJ=HI-IB	POLL 575
580	IF(HJ.LT.1) GO TO 470	POLL 580
585	JB=INBP+IB	POLL 585
590	460 C(HJ,JB)=0.0	POLL 590
595	470 DO 480 IB=1,INALPB	POLL 595
600	HJ=HI+IB	POLL 600
605	IF(HJ.GT.NBP) GO TO 490	POLL 605
610	JB=INBP-IB	POLL 610
615	480 C(HJ,JB)=0.0	POLL 615
620	490 CONTINUE	POLL 620
625	500 CONTINUE	POLL 625
630	C	POLL 630
635	IF(IEBGT.EQ.0) GO TO 551	POLL 635
640	WRITE(6,4000)	POLL 640
645	DO 550 I=1,NBP	POLL 645
650	550 WRITE(6,3100) I, (C(I,J),J=1,IBAND), R(I)	POLL 650
655	551 CONTINUE	POLL 655
660	C	POLL 660
665	C	POLL 665
670	600 IF(NSIDE.EQ.0) GO TO 760	POLL 670
675	C	POLL 675
680	C	POLL 680
685	C IF ISIDE(NP,6)=01 OPEN BOUNDARY WITH DIRICHLET BC	POLL 685
690	C IF ISIDE(NP,6)=02 OPEN BOUNDARY WITH NEUMANN BC	POLL 690
695	C CONCENTRATION DEPENDENT BOUNDARY CONDITIONS	POLL 695
700	C IF ISIDE(NP,6)=03 OPEN BOUNDARY WITH THIRD TYPE BC	POLL 700
705	C IF ISIDE(NP,6)=11 WATER LAND INTERFACE WITH DIRICHLET BC	POLL 705
710	C IF ISIDE(NP,6)=12 WATER LAND INTERFACE WITH NEUMANN BC	POLL 710
715	C IF ISIDE(NP,6)=13 WATER LAND INTERFACE WITH THIRD TYPE BC	POLL 715
720	C	POLL 720

APPENDIX E. (Continued)

725		EO 630 NP=1,NSIDE	POLL 725
730	C		POLL 730
735		IDX=ISIDE(NP,6)	POLL 735
740		IF(ICK.NP.2) GO TO 630	POLL 740
745		NI=ISIDE(NP,1)	POLL 745
750		NJ=ISIDE(NP,2)	POLL 750
755		A=Y(NJ)-Y(NI)	POLL 755
760		B=X(NJ)-X(NI)	POLL 760
765		BATA=ATAN2(A,B)	POLL 765
770		N=ISIDE(NP,3)	POLL 770
775		NI=ISIDE(NP,4)	POLL 775
780		NJ=ISIDE(NP,5)	POLL 780
785		IF(NJ.EQ.4 .OR. NJ.EQ.1) GO TO 602	POLL 785
790		GO TO 604	POLL 790
795	602	A=-A	POLL 795
800		B=-B	POLL 800
805	604	BETA=ATAN2(A,B)	POLL 805
810		SBETA=SIN(BETA)	POLL 810
815		CBETA=COS(BETA)	POLL 815
820		VXK=0.5*(VX(NI)+VX(NJ))	POLL 820
825		VYK=0.5*(VY(NI)+VY(NJ))	POLL 825
830		VAL=VXK*CBETA + VYK*SBETA	POLL 830
835		VTK=-VXK*SBETA+VYK*CBETA	POLL 835
840		ALNG=SQRT(A*A+B*B)	POLL 840
845		VV=SQRT(VXK*VXK+VYK*VYK)	POLL 845
850		VVI=1.0/VV	POLL 850
855		DLL=(AL*VXK*VXK+AT*VYK*VYK)*VVI + DD	POLL 855
860		ELT=(AL-AT)*VXK*VYK*VVI	POLL 860
865		DTT=(AL*VYK*VYK+AT*VXK*VXK)*VVI + DD	POLL 865
870		DAL=ABS(DLL*CBETA*CBETA + 2.0*CBETA*SBETA*DLT + DTT*SBETA*SBETA)	POLL 870
875		VEL=VAL*ALNG	POLL 875
880		DISP=2.0*DAL	POLL 880
885		APHA=1.0/TANH(VEL/DISP) - DISP/VEL	POLL 885
890		IF(ABS(VAL) .LT. (0.0003*ABS(VTK))) APHA=0.0	POLL 890
895	C		POLL 895
900		IXQ(1)=X(NI)	POLL 900
905		IXQ(2)=X(NJ)	POLL 905
910		YYQ(1)=Y(NI)	POLL 910
915		YYQ(2)=Y(NJ)	POLL 915
920		NNHQ(2)=NN(NJ)	POLL 920
925		NNHQ(1)=NN(NI)	POLL 925
930		VXHQ(1)=VX(NI)	POLL 930
935		VXHQ(2)=VX(NJ)	POLL 935
940		VYHQ(1)=VY(NI)	POLL 940
945		VYHQ(2)=VY(NJ)	POLL 945
950	C		POLL 950
955	C		POLL 955
960		CALL Q*SP(DPLXQ,IXQ,YYQ,VXHQ,VYHQ,NNHQ,APHA,BATA,ALNG)	POLL 960
965	C		POLL 965
970		IB=INBP	POLL 970
975		JB=INBP+(NJ-NI)	POLL 975
980		IF(INID.NE.0) GO TO 605	POLL 980
985		C(NI,IB)=C(NI,IB)+N1*DPLXQ(1,1)	POLL 985
990		C(NI,JB)=C(NI,JB)+N1*DPLXQ(1,2)	POLL 990
995		R(NI)=R(NI)-N2*(DPLXQ(1,1)*NP(NI)+DPLXQ(1,2)*NP(NJ))	POLL 995
1000		GO TO 615	POLL 1000
1005	605	C(NI,IB)=C(NI,IB)+DPLXQ(1,1)	POLL 1005
1010		C(NI,JB)=C(NI,JB)+DPLXQ(1,2)	POLL 1010
1015	615	JB=INBP	POLL 1015
1020		IB=INBP+(NI-NJ)	POLL 1020
1025		IF(INID.NE.0) GO TO 625	POLL 1025
1030		C(NJ,JB)=C(NJ,JB)+N1*DPLXQ(2,1)	POLL 1030
1035		C(NJ,IB)=C(NJ,IB)+N1*DPLXQ(2,2)	POLL 1035
1040		R(NJ)=R(NJ)-N2*(DPLXQ(2,1)*NP(NI)+DPLXQ(2,2)*NP(NJ))	POLL 1040
1045		GO TO 630	POLL 1045
1050	625	C(NJ,JB)=C(NJ,JB)+DPLXQ(2,1)	POLL 1050
1055		C(NJ,IB)=C(NJ,IB)+DPLXQ(2,2)	POLL 1055
1060	630	CONTINUE	POLL 1060
1065		IF(IBUGT.EQ.0) GO TO 696	POLL 1065
1070		WRITE(6,5000)	POLL 1070
1075		EO 695 I=1,NBP	POLL 1075

APPENDIX E. (Continued)

1080	695	WRITE(6,3100) I, (C(I,J), J=1, IBAND), R(I)	POLL1080
1085	696	CONTINUE	POLL1085
1090	C		POLL1090
1095	760	CALL SOLVE(1,C,R,HNP,IALPB,HXNP,HXBW)	POLL1095
1100		CALL SOLVE(2,C,R,HNP,ICALPB,HXNP,HXBW)	POLL1100
1105		IF(IERD.NE.0 .AND. ITRANS.NE.0) GO TO 800	POLL1105
1110		RETURN	POLL1110
1115	C		POLL1115
1120	800	CONTINUE	POLL1120
1125		DO 820 I=1,HNP	POLL1125
1130	E2C	R(I)=2.0*R(I)-PP(I)	POLL1130
1135		DO 830 I=1,HXNP	POLL1135
1140		HI=IEV(I)	POLL1140
1145	E30	R(HI)=BV(I)	POLL1145
1150		RETURN	POLL1150
1155	1000	FORMAT(1H1,10X,'DEBUG FOR TRANSPORT MODEL IS ACTIVATED'/1X,	POLL1155
1160	1	'HARDIF=',I3,' IHALPB=',I3,' INBP=',I3,' IBAND=',I3,	POLL1160
1165	2	' SWF=',I3,' WEL=',I3)	POLL1165
1170	2000	FORMAT(1H0,I3,' TH ELEMENT', ' FOUR WEIGHTING FACTORS=',4E12.3/1X,	POLL1170
1175	1	'WQ=',4E12.3,5X,'YQ=',4E12.3/1X,'WQ=',4E12.3,5X,'SOURCEQ=',4E12.3	POLL1175
1180	3,	/1X,'VXQ=',4E12.3,5X,'YQ=',4E12.3/)	POLL1180
1185	3000	FORMAT(1H1,'GLOBAL MATRIX AND LOAD VECTOR BEFORE APPLY BC'/)	POLL1185
1190	3100	FORMAT(1H0,I3,(11E11.3))	POLL1190
1195	4000	FORMAT(1H1,'GLOBAL MATRIX AND LOAD VECTOR AFTER APPLY DIRI. BC'/)	POLL1195
1200	5000	FORMAT(1H1,'GLOBAL MATRIX AND LOAD VECTOR AFTER APPLY SIDE BC'/)	POLL1200
1205		END	POLL1205

APPENDIX E. (Continued)

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5      SUBROUTINE APABTA (ALPHA1,ALPHA2,BETA1,BETA2,H,X,Y,VXW,VYW,IE,
10      1 HAXWP,HAXEL)
15      C
20      DIMENSION I(HAXWP),Y(HAXEL),VXW(HAXWP),VYW(HAXWP),IE(HAXEL,4)
25      C
30      COMMON /CONTROL/ HWP,HXL,IEAND,HAXDIP,IHALFS,INBP
35      COMMON /TRANSP/ AL,AT,DD,BK,BKH,BLAND,ITRANS
40      C
45      DIMENSION ALPHA(4),BETA(4),NDIN(4)
50      C
55      C      THIS SUBROUTINE IS TO CALCULATE THE WEIGHTING FACTORS
60      C      FOR A GIVEN ELEMENT H
65      C
70      E1=IE(H,1)
75      E2=IE(H,2)
80      E3=IE(H,3)
85      E4=IE(H,4)
90      C
95      A=Y(E2)-Y(E1)
100     B=X(E2)-X(E1)
105     EETA(1)=ATAN2(A,B)
110     A=Y(E3)-Y(E2)
115     B=X(E3)-X(E2)
120     EETA(2)=ATAN2(A,B)
125     A=Y(E4)-Y(E3)
130     B=X(E4)-X(E3)
135     EETA(3)=ATAN2(A,B)
140     A=Y(E4)-Y(E1)
145     B=X(E4)-X(E1)
150     EETA(4)=ATAN2(A,B)
155     C
160     NDIN(1)=H1
165     NDIN(2)=H2
170     NDIN(3)=H3
175     NDIN(4)=H4
180     C
185     DO 100 J=1,4
190     100 ALPHA(J)=0.0
195     DO 400 J=1,4
200     H1=NDIN(J)
205     IF(J-3) 200,200,210
210     200 H2=NDIN(J+1)
215     GO TO 300
220     210 H2=NDIN(1)
225     300 CONTINUE
230     ALENG=SQRT((X(H2)-X(H1))**2 + (Y(H2)-Y(H1))**2)
235     CBETA=COS(BETA(J))
240     SBETA=SIN(BETA(J))
245     VXX=0.5*(VXW(H1)+VXW(H2))
250     VYY=0.5*(VYW(H1)+VYW(H2))
255     VAL=VXX*CBETA+VYY*SBETA
260     VTX=-VXX*SBETA+VYY*CBETA
265     IF(ABS(VAL).LT.(0.0001*ABS(VTX))) GO TO 400
270     VV=SQRT(VXX*VXX+VYY*VYY)
275     VVI=1.0/VV
280     DLL=(AL*VXX*VXX + AT*VYY*VYY)*VVI + DD
285     CLT=(AL-AT)*VXX*VYY*VVI
290     DTT=(AL*VYY*VYY + AT*VXX*VXX)*VVI + DD
295     DAL=ABS(DLL*CBETA*CBETA + 2.0*CBETA*SBETA*DLT + DTT*SI*PA*SBETA)
300     VEI=VAL*ALENG
305     DISP=2.0*DAL
310     ALPHA(J)=1.0/TANH(VEL/DISP) - DISP/VEL
315     400 CONTINUE
320     C
325     ALPHA1=ALPHA(1)
330     ALPHA2=ALPHA(3)
335     BETA1=BETA(2)
340     BETA2=BETA(4)
345     C
350     RETURN
355     END

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APPENDIX E. (Continued)

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5      SUBROUTINE Q4PO(QA,QB,RLOADQ,IQ,YQ,VXQ,VYQ,HNQ,SOURCEQ,APHA1,APHA2,Q4PO 005
10      1      BETA1,BETA2)      Q4PO 010
15      C      Q4PO 015
20      REAL*8 S(4)      Q4PO 020
25      COMMON /TRANSP/ AL,AT,DD,RK,RKH,ELAND,ITRANS      Q4PO 025
30      COMMON /WELDRH/ IWET,ILUPF,INID      Q4PO 030
35      COMMON /BUG/ IBUGH,IBUGT,IBUGQH,IBUGQT      Q4PO 035
40      C      Q4PO 040
45      DIMENSION QA(4,4),QB(4,4),RLOADQ(4), IQ(4),YQ(4),VXQ(4),VYQ(4),      Q4PO 045
50      HNQ(4),SOURCEQ(4)      Q4PO 050
55      DIMENSION S(4),T(4),W(4),DNK(4),DNV(4),DNK(4),DNV(4)      Q4PO 055
60      DIMENSION PJAB(2,2),DWSS(4),DWTI(4),DWSS(4),DWTI(4)      Q4PO 060
65      C      Q4PO 065
70      DATA P/O.577350269189626/      Q4PO 070
75      DATA S/-1.0,1.0,1.0,-1.0/, T/-1.0,-1.0,1.0,1.0/      Q4PO 075
80      C      Q4PO 080
85      DO 100 IQ=1,4      Q4PO 085
90      RLOADQ(IQ)=0.0      Q4PO 090
95      DO 100 JQ=1,4      Q4PO 095
100     QA(IQ,JQ)=0.0      Q4PO 100
105     QB(IQ,JQ)=0.0      Q4PO 105
110     100 CONTINUE      Q4PO 110
115     C      Q4PO 115
120     AREA=0.0      Q4PO 120
125     C      Q4PO 125
130     DO 400 KG=1,4      Q4PO 130
135     SS=P*S(KG)      Q4PO 135
140     TT=P*T(KG)      Q4PO 140
145     C      Q4PO 145
150     CALL SHAPE(W,W,DWSS,DWTI,DWSS,DWTI,SS,TT,APHA1,APHA2,BETA1,BETA2)      Q4PO 150
155     C      Q4PO 155
160     DO 150 I=1,2      Q4PO 160
165     DO 150 J=1,2      Q4PO 165
170     150 PJAB(I,J)=0.0      Q4PO 170
175     C      Q4PO 175
180     DO 170 I=1,4      Q4PO 180
185     PJAB(1,1)=PJAB(1,1) + DWTI(I)*YQ(I)      Q4PO 185
190     PJAB(1,2)=PJAB(1,2) - DWSS(I)*YQ(I)      Q4PO 190
195     PJAB(2,1)=PJAB(2,1) - DWTI(I)*XQ(I)      Q4PO 195
200     170 PJAB(2,2)=PJAB(2,2) + DWSS(I)*XQ(I)      Q4PO 200
205     C      Q4PO 205
210     DJAC=PJAB(2,2)*PJAB(1,1) - PJAB(1,2)*PJAB(2,1)      Q4PO 210
215     AREA=AREA + DJAC      Q4PO 215
220     DJACI=1.0/DJAC      Q4PO 220
225     C      Q4PO 225
230     DO 175 I=1,2      Q4PO 230
235     DO 175 J=1,2      Q4PO 235
240     175 PJAB(I,J)=PJAB(I,J)*DJACI      Q4PO 240
245     DO 180 I=1,4      Q4PO 245
250     DNK(I)=DWSS(I)*PJAB(1,1) + DWTI(I)*PJAB(1,2)      Q4PO 250
255     DNV(I)=DWSS(I)*PJAB(2,1) + DWTI(I)*PJAB(2,2)      Q4PO 255
260     DNK(I)=DWSS(I)*PJAB(1,1) + DWTI(I)*PJAB(1,2)      Q4PO 260
265     DNV(I)=DWSS(I)*PJAB(2,1) + DWTI(I)*PJAB(2,2)      Q4PO 265
270     180 CONTINUE      Q4PO 270
275     C      Q4PO 275
280     C      Q4PO 280
285     C      Q4PO 285
290     C      Q4PO 290
295     HNK=0.0      Q4PO 295
300     VHK=0.0      Q4PO 300
305     VTK=0.0      Q4PO 305
310     CXHK=0.0      Q4PO 310
315     DXHK=0.0      Q4PO 315
320     CVTK=0.0      Q4PO 320
325     SOURCEK=0.0      Q4PO 325
330     C      Q4PO 330
335     C      Q4PO 335
340     DO 200 IQ=1,4      Q4PO 340
345     HNK=HNK+H(IQ)*HNQ(IQ)      Q4PO 345
350     VHK=VHK+H(IQ)*VXQ(IQ)      Q4PO 350
355     VTK=VTK+H(IQ)*VYQ(IQ)      Q4PO 355

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APPENDIX E. (Continued)

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360      SOUCIK=SOUCIK+SOUCQ(IQ)*W(IQ)
365      200 CONTINUE
370      C
375      VK=SQRT(VIK*VIK+VTK*VTK)
380      VKI=1.0/VK
385      DXIK=(AL*VIK+VTK*AT+VTK*VTK)*VKI + DD
390      DXYK=(AL-AT)*VIK+VTK*VKI
395      DYIK=(AL*VIK+VTK*AT+VTK*VTK)*VKI + DD
400      IF (IBUGQZ.NE.0) WRITE (6,1000) KG,HKK,VKK,VTK,SOUCIK,DXIK,DXYK,DYIK
405      1, (W(I),I=1,4), (DVK(I),I=1,4), (DNY(I),I=1,4)
410      C
415      DO 300 IQ=1,4
420      DO 290 JQ=1,4
425      WW=W(IQ)*W(JQ)
430      DWYDNY=DNY(IQ)*DNY(JQ)
435      DWXDIX=DXI(IQ)*DXI(JQ)
440      DWXW=DXI(IQ)*W(JQ)
445      DWYV=DNY(IQ)*W(JQ)
450      DWYDIX=DNY(IQ)*DXI(JQ)
455      DWXDNY=DXI(IQ)*DNY(JQ)
460      QA(IQ,JQ)=QA(IQ,JQ)+(WW*HKK)*DJAC
465      CB(IC,JQ)=QB(IQ,JQ)+(DXXK*DWXDXI+DXYK*(DWXDNY+DWYDIX)+DYIK*DWYDNY-
470      1 (DWXW*VKK+DWYV*VTK))*DJAC
475      C
480      CB(IC,JQ)=QB(IC,JQ)+WW*(RLAND+RKK)*HKK*DJAC+WW*RKK*DJAC
485      290 CONTINUE
490      300 CONTINUE
495      DO 350 IQ=1,4
500      RLOADQ(IQ)=RLOADQ(IQ)-W(IQ)*SOUCIK*DJAC
505      350 CONTINUE
510      IF (IBUGQZ.NE.0) GO TO 361
515      WRITE (6,2000) KG,AREA
520      DO 360 I=1,4
525      360 WRITE (6,2100) I, (QA(I,J),J=1,4), (QB(I,J),J=1,4), RLOADQ(I)
530      361 CONTINUE
535      C
540      400 CONTINUE
545      IF (ILUWF.NE.0) GO TO 410
550      RETURN
555      410 CONTINUE
560      BREA=0.0
565      DO 420 I=1,4
570      DO 420 J=1,4
575      IF (I.NE.J) GO TO 420
580      BREA=BREA+QA(I,J)
585      420 CONTINUE
590      DO 430 I=1,4
595      DO 430 J=1,4
600      QA(I,J)=QA(I,J)*AREA/BREA
605      IF (I.NE.J) QA(I,J)=0.0
610      430 CONTINUE
615      C
620      RETURN
625      1000 FORMAT (1H0,'KG=' ,I3,' HKK=' ,E10.3,' VKK=' ,E10.3,' VTK=' ,E10.3,
630      1 ' SCUCIK=' ,E10.3,' DXXK=' ,E10.3,' DXYK=' ,E10.3,' DYIK=' ,E10.3/1X,
635      2 'W=' ,E10.3,2X,'DXI=' ,E10.3,2X/1X,'DNY=' ,E10.3/1
640      2000 FORMAT (1H0,'ELEMENT MATRIX AND LOAD VECTOR SUMS OVER ',I3,
645      1 ' GAUSS POINTS', ' AREA=' ,E10.3)
650      2100 FORMAT (1H , 'QA=' ,E11.3,5X,'QB=' ,E11.3,5X,'RQ=' ,E11.3)
655      END

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APPENDIX E. (Continued)

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5      SUBROUTINE SHAPE(W,W,DWSS,DWTT,DWSS,DWTT,SS,TT,APHA1,APHA2,BETA1, SHAP 005
10      1      BETA2) SHAP 010
15      C SHAP 015
20      REAL*4 W(4) SHAP 020
25      COMMON /WELUHN/ IWET,ILUHP,INID SHAP 025
30      DIMENSION DWSS(4),DWTT(4),DWSS(4),DWTT(4),W(4) SHAP 030
35      C SHAP 035
40      SH=1.0-SS SHAP 040
45      SP=1.0+SS SHAP 045
50      TH=1.0-TT SHAP 050
55      TP=1.0+TT SHAP 055
60      W(1)=0.25*SH*TH SHAP 060
65      W(2)=0.25*SP*TH SHAP 065
70      W(3)=0.25*SP*TP SHAP 070
75      W(4)=0.25*SH*TP SHAP 075
80      DWSS(1)=-0.25*TH SHAP 080
85      DWSS(2)=0.25*TH SHAP 085
90      DWSS(3)=0.25*TP SHAP 090
95      DWSS(4)=-0.25*TP SHAP 095
100     DWTT(1)=-0.25*SH SHAP 100
105     DWTT(2)=-0.25*SP SHAP 105
110     DWTT(3)=0.25*SP SHAP 110
115     DWTT(4)=0.25*SH SHAP 115
120     C SHAP 120
125     IF(IWET.EQ.0) GO TO 100 SHAP 125
130     C SHAP 130
135     W(1)=0.0625*(TP*(3.0*BETA2*(-TH)-2.0)+4.0)*(SP*(3.0*APHA1*(-SH)- SHAP 135
140     2.0)+4.0) SHAP 140
145     W(2)=0.0625*(TP*(3.0*BETA1*(-TH)-2.0)+4.0)*(SP*(3.0*APHA1*SH+2.0)) SHAP 145
150     W(3)=0.0625*(TP*(3.0*BETA1*TH+2.0))*(SP*(3.0*APHA2*SH+2.0)) SHAP 150
155     W(4)=0.0625*(TP*(3.0*BETA2*TH+2.0))*(SP*(3.0*APHA2*(-SH)-2.0)+4.0) SHAP 155
160     DWSS(1)=0.125*(TP*(3.0*BETA2*(-TH)-2.0)+4.0)*(3.0*APHA1*SS-1.0) SHAP 160
165     DWSS(2)=-0.125*(TP*(3.0*BETA1*(-TH)-2.0)+4.0)*(3.0*APHA1*SS-1.0) SHAP 165
170     DWSS(3)=-0.125*(TP*(3.0*BETA1*TH+2.0))*(3.0*APHA2*SS-1.0) SHAP 170
175     DWSS(4)=0.125*(TP*(3.0*BETA2*TH+2.0))*(3.0*APHA2*SS-1.0) SHAP 175
180     DWTT(1)=-0.125*(SP*(3.0*APHA1*(-SH)-2.0)+4.0)*(3.0*BETA2*TT-1.0) SHAP 180
185     DWTT(2)=0.125*(SP*(3.0*APHA1*SH+2.0))*(3.0*BETA1*TT-1.0) SHAP 185
190     DWTT(3)=-0.125*(SP*(3.0*APHA2*SH+2.0))*(3.0*BETA1*TT-1.0) SHAP 190
195     DWTT(4)=-0.125*(SP*(3.0*APHA2*(-SH)-2.0)+4.0)*(3.0*BETA2*TT-1.0) SHAP 195
200     C SHAP 200
205     RETURN SHAP 205
210     C SHAP 210
215     DO 200 I=1,4 SHAP 215
220     W(I)=W(I) SHAP 220
225     DWSS(I)=DWSS(I) SHAP 225
230     DWTT(I)=DWTT(I) SHAP 230
235     C SHAP 235
240     RETURN SHAP 240
245     END SHAP 245

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APPENDIX E. (Continued)

5	SUBROUTINE QESP(DPLXQ, IQ, JQ, VIK, VYQ, HHQ, ALPHA, BETA, ALNG;	Q2SP 005
10	REAL*8 B(2)	Q2SP 010
15	COMMON /TRANSP/ AL, AT, DD, RK, RKH, RLAND, ITRANS	Q2SP 015
20	CCBCH /RELUM/ IWET, ILUP, INID	Q2SP 020
25	DIMENSION DPLXQ(2,2), VIK(2), VYQ(2), IQ(2), JQ(2), HHQ(2)	Q2SP 025
30	DIMENSION W(2)	Q2SP 030
35	C	Q2SP 035
40	C	Q2SP 040
45	C	Q2SP 045
50	DO 100 JQ=1,2	Q2SP 050
55	DO 100 IQ=1,2	Q2SP 055
60	100 DPLXQ(IQ,JQ)=0.0	Q2SP 060
65	C	Q2SP 065
70	C	Q2SP 070
75	DO 400 KG=1,2	Q2SP 075
80	XI=-0.577350269189626	Q2SP 080
85	IF(KG.EQ.2) XI=0.577350269189626	Q2SP 085
90	B(1)=0.5*(1.0-XI)	Q2SP 090
95	B(2)=0.5*(1.0+XI)	Q2SP 095
100	IF(IWET.EQ.0) GO TO 120	Q2SP 100
105	W(1)=0.25*((1.0+XI)*(3.0*ALPHA*(XI-1.0)-2.0)+4.0)	Q2SP 105
110	W(2)=0.25*((1.0+XI)*(3.0*ALPHA*(-XI+1.0)+2.0))	Q2SP 110
115	GO TO 130	Q2SP 115
120	120 W(1)=W(1)	Q2SP 120
125	W(2)=W(2)	Q2SP 125
130	C	Q2SP 130
135	130 VIK=0.0	Q2SP 135
140	VYK=0.0	Q2SP 140
145	HHK=0.0	Q2SP 145
150	DO 200 IQ=1,2	Q2SP 150
155	VIK=VIK+VYQ(IQ)*W(IQ)	Q2SP 155
160	VYK=VYK+VYQ(IQ)*W(IQ)	Q2SP 160
165	HHK=HHK+HHQ(IQ)*W(IQ)	Q2SP 165
170	200 CONTINUE	Q2SP 170
175	C	Q2SP 175
180	VKH=VIK*SIN(BETA)-VYK*COS(BETA)	Q2SP 180
185	DO 350 JQ=1,2	Q2SP 185
190	DO 300 IQ=1,2	Q2SP 190
195	DPLXQ(IQ,JQ)=DPLXQ(IQ,JQ)+ VKH*W(IQ)*W(JQ)*ALNG*0.5	Q2SP 195
200	300 CONTINUE	Q2SP 200
205	C	Q2SP 205
210	C	Q2SP 210
215	350 CONTINUE	Q2SP 215
220	C	Q2SP 220
225	400 CONTINUE	Q2SP 225
230	RETURN	Q2SP 230
235	END	Q2SP 235

APPENDIX E. (Continued)

10	C	SUBROUTINE PRINT(KPT,KOUT,KDIAG,TIME,PHI,VX,VY,R,HAKUP)	PRIN 005
15		DIMENSION PHI(HAKUP),V1(HAKUP),VY(HAKUP),R(HAKUP)	PRIN 010
20	C		PRIN 015
25		COMMON /CONTRL/ HWP,WEL,IBAND,HAKDIP,INHALPB,INBP	PRIN 020
30		COMMON /PRTMAN/ NTI,KVEL,EDV,KSOS,KSTR	PRIN 025
35		COMMON /PARAM/ OMEGA,DELT,THX,DELTHX,CHNG,SPS	PRIN 030
40		COMMON /TRANSP/ AL,AT,DD,BK,BKH,RLAND,ITRANS	PRIN 035
45	C		PRIN 040
50	C	KPT=KPR=0 PRINT NOTHING	PRIN 045
55	C	KPT=KPR=1 PRINT STREAM FUNCTION	PRIN 050
60	C	KPT=KPR=2 PRINT STREAM FUNCTION AND ELEMENT VELOCITY	PRIN 055
65	C	KPT=KPR=3 PRINT CONCENTRATION	PRIN 060
70	C	KPT=KPR=4 PRINT CONCENTRATION AND MATERIAL FLUX	PRIN 065
75	C	KPT=KPR=5 PRINT EVERYTHING	PRIN 070
80	C		PRIN 075
85		IF(KPT.EQ.0) RETURN	PRIN 080
90		IF(KPT.GE.3 .AND. KPT.LT.5) GO TO 200	PRIN 085
95	C		PRIN 090
100		KDIAG=KDIAG+1	PRIN 095
105		IF(KVEL.EQ.1) WRITE(6,6000) KDIAG,TIME,DELT	PRIN 100
110		IF(KVEL.EQ.0) WRITE(6,6005) KDIAG	PRIN 105
115		ILINE=0	PRIN 110
120		DO 620 NI=1,HWP,8	PRIN 115
125		IIINE=IIINE+1	PRIN 120
130		IJHN=NI	PRIN 125
135		IJHY=HINO(NI+7,HWP)	PRIN 130
140		WRITE(6,1100) NI, (PHI(IJ),IJ=IJHN,IJHY)	PRIN 135
145		IF(MCD(ILINE,5).EQ.0) WRITE(6,3000)	PRIN 140
150		IZERO=MOD(ILINE,40)	PRIN 145
155		IF(IZERO.EQ.0 .AND. KVEL.EQ.1) WRITE(6,6000) KDIAG,TIME,DELT	PRIN 150
160		IF(IZERO.EQ.0 .AND. KVEL.EQ.0) WRITE(6,6005) KDIAG	PRIN 155
165	620	CONTINUE	PRIN 160
170		IF(KPT.EQ.1) RETURN	PRIN 165
175	C		PRIN 170
180		KDIAG=KDIAG+1	PRIN 175
185		IF(KVEL.EQ.1) WRITE(6,1000) KDIAG,TIME,DELT	PRIN 180
190		IF(KVEL.EQ.0) WRITE(6,1005) KDIAG	PRIN 185
195	C		PRIN 190
200		ILINE=0	PRIN 195
205		DO 100 NI=1,HWP,4	PRIN 200
210		IIINE=IIINE+1	PRIN 205
215		IJHN=NI	PRIN 210
220		IJHY=HINO(NI+3,HWP)	PRIN 215
225		WRITE(6,1100) NI, (VX(IJ),IJ=IJHN,IJHY), (VY(IJ),IJ=IJHN,IJHY)	PRIN 220
230		IF(MCD(ILINE,5).EQ.0) WRITE(6,3000)	PRIN 225
235		IZERC=MOD(ILINE,40)	PRIN 230
240		IF(IZERO.EQ.0 .AND. KVEL.EQ.1) WRITE(6,1000) KDIAG,TIME,DELT	PRIN 235
245		IF(IZERC.EQ.0 .AND. KVEL.EQ.0) WRITE(6,1005) KDIAG	PRIN 240
250	100	CONTINUE	PRIN 245
255	C		PRIN 250
260		IF(KPT.EQ.2) RETURN	PRIN 255
265	C		PRIN 260
270		200 KOUT=KOUT+1	PRIN 265
275		IF(ITRANS.NE.0) WRITE(6,2000) KOUT,TIME,DELT,IBAND	PRIN 270
280		IF(ITRANS.EQ.0) WRITE(6,2005) KOUT	PRIN 275
285		ILINE=0	PRIN 280
290		DO 210 NI=1,HWP,8	PRIN 285
295		IIINE=IIINE+1	PRIN 290
300		IJHN=NI	PRIN 295
305		IJHY=HINO(NI+7,HWP)	PRIN 300
310		WRITE(6,1100) NI, (R(IJ),IJ=IJHN,IJHY)	PRIN 305
315		IF(MOD(ILINE,5).EQ.0) WRITE(6,3000)	PRIN 310
320		IZERO=MOD(ILINE,40)	PRIN 315
325		IF(IZERO.EQ.0 .AND. ITRANS.NE.0) WRITE(6,2000) KOUT,TIME,DELT,IBAND	PRIN 320
330		IF(IZERO.EQ.0 .AND. ITRANS.EQ.0) WRITE(6,2005) KOUT	PRIN 325
335	210	CONTINUE	PRIN 330
340	C		PRIN 335
345		IF(KPT.EQ.3) RETURN	PRIN 340
350	C		PRIN 345
355	C		PRIN 350
			PRIN 355

APPENDIX E. (Continued)

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360 C WRITE MATERIAL FLUX PRIN 360
365 310 CONTINUE PRIN 365
370 RETURN PRIN 370
375 C PRIN 375
380 1000 FORMAT(1H1,'FLOW TABLE',I4,' VELOCITY FIELD AT TIME = ',1PD12.4, PRIN 380
385 1 ' DELT = ',1PD12.4//32X,'VEL-X AT NODES',46X,'VEL-Y AT NODES'//) PRIN 385
390 1005 FORMAT(1H1,'FLOW TABLE',I4,' STEADY STATE VELOCITY FIELD'//32X, PRIN 390
395 1'VEL-X AT NODES',46X,'VEL-Y AT NODES'//) PRIN 395
400 1100 FORMAT(17,8(1PD15.4)) PRIN 400
405 2000 FORMAT(1H1,'OUTPUT TABLE',I4,' CONCENTRATION AT TIME = ',1PD12.4,PRIN 405
410 1 ' DELT = ',1PD12.4,' BAND WIDTH = ',I4,// PRIN 410
415 21X,' NODE I',5X,'CONCENTRATION AT NODES I,I+1, . . . I+7'//) PRIN 415
420 2005 FORMAT(1H1,'OUTPUT TABLE',I4,' STEADY STATE CONCENTRATION'//1X, PRIN 420
425 1'AT NODE I',5X,'CONCENTRATION AT NODES I,I+1, . . . I+7'//) PRIN 425
430 3000 FORMAT(1H0) PRIN 430
435 6000 FORMAT(1H1,'FLOW TABLE',I4,' STREAM FUNCTION AT TIME = ',1PD12.4,PRIN 435
440 1 ' DELT = ',1PD12.4//) PRIN 440
445 6005 FORMAT(1H1,'FLOW TABLE',I4,' STEADY STATE STREAM FUNCTION'//) PRIN 445
450 C PRIN 450
455 END PRIN 455

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