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FEMWATER: A Finite-Element Model of WATER Flow Through Saturated-Unsaturated Porous Media

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Reeves and Duguid's original work provided the basis and stimulation for this study. Numerous constructive and valuable discussions with D. D. Huff led to the improvement in computing moisture-content rate change and in evaluating nonlinear terms.

ABSTRACT

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Upon examining the "Water Movement Through Saturated-Unsaturated Porous Media: A Finite-Element Galerkin Model," it was felt that the model should be modified and expanded. The modification is made in calculating the flow field in a manner consistent with the finite element approach, in evaluating the moisture-content increasing rate within the region of interest, and in numerically computing the nonlinear terms. With these modifications, the flow field is continuous everywhere in the flow regime, including element boundaries and nodal points, and the mass loss through boundaries is much reduced. Expansion is made to include four additional numerical schemes which would be more appropriate for many situations. Also, to save computer storage, all arrays pertaining to the boundary condition information are compressed to smaller dimension, and to ease the treatment of different problems, all arrays are variably dimensioned in all subroutines. This report is intended to document these efforts. In addition, in the derivation of finite-element equations, matrix component representation is used, which is believed more readable than the matrix representation in its entirety. Two identical sample problems are simulated to show the difference between the original and revised models.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

To study the transport of dissolved constituents in a subsurface flow system, the velocity field therein must be determined first. A finite-element Galerkin model has been developed to obtain the flow field (Reeves and Duguid 1975). The continuity equation of water mass governing the distribution of pressure head is solved by the Galerkin finite-element method subject to appropriate boundary and initial conditions. The flow field is then computed with Darcy's law by taking the derivatives of the calculated pressure field. Inherent in that approach, however, is the resulting discontinuity in the velocity at element boundaries and nodal points, which unfortunately leads to a violation of the conservation of mass in a local sense. When the spatial distribution of the velocity is significant in the region, inputting this discontinuous flow field to the contaminant transport computation could conceivably produce a large error. This report describes a method to overcome this problem, this is, solving Darcy's law for the velocity field at nodal points by the finite-element method rather than by taking the derivatives of the pressure field. This approach is consistent with the spirit of finite-element methods, and yields, of course, continuous velocity over the whole region of interest, including element boundaries and nodal points. An alternative method is to evaluate the velocity at the Gaussian points of an element rather than at the nodal points from the pressure field with Darcy's law (Segol 1976, Huyakorn and Pinder 1977). Because only the velocity at Gaussian points are needed in the pollutant transport computations if the Galerkin finite element is used therein, this method circumvents the need to calculate the velocity at nodal points. However, if the upstream weighting function is used in the pollutant transport formulation, continuous velocity field at nodal points is required to compute the optimum weighting factors. Under such circumstances, the alternative approach is not applicable, and the proposed method must be used.

In the development of the moisture transport model, the time-marching is dealt with by either the Crank-Nicolson central-difference or the backward-difference methods. The mass matrix (the matrix associated with the time derivative) as derived from the finite-element discretization in space is used without any modification. However, in many situations, the mid-difference in the time-marching would yield better results than either the central or backward-difference if the consistent mass matrix is used (Gureghian et al. 1978). The mid-difference option is, therefore, incorporated into the revised computer code.

Referring to the mass matrix, it appears as a unit matrix if the spatial discretization is done with the finite-difference method. By suitable scaling, the mass matrix may be reduced to a finite-difference equivalent if it is lumped (Clough 1971). The lumping of the mass matrix in many situations results in a better-behaved global matrix than that from no lumping, in particular, if it is used along with the central or backward-difference time-marching. Thus, the lumping option of the mass matrix is included in the revised code.

II. MATHEMATICAL STATEMENTS

The original work (Reeves and Duguid 1975) is followed very closely in the following statements of the problem. However, in the derivation of finite-element approximations, matrix component representation is used rather than the matrix itself. This component representation is believed more readable.

1. Governing Equations

The governing equations to describe the pressure field in a two-dimensional subsurface system are obtained from the principle of conservation of mass and Darcy's law. This can be written in the form:

$$L(h) = F \frac{\partial h}{\partial t} - \left[\frac{\partial}{\partial x} \left(K_{xx} \frac{\partial H}{\partial x} + K_{xz} \frac{\partial H}{\partial z}\right) + \frac{\partial}{\partial z} \left(K_{zx} \frac{\partial H}{\partial x} + K_{zz} \frac{\partial H}{\partial z}\right)\right] - Q = 0, \quad (1)$$

where

$$F = \frac{\theta}{n} \alpha' + \beta' \theta + \frac{d\theta}{dh} \quad , \quad (1a)$$

and

$$H = h + z \quad , \quad (1b)$$

in which h is the pressure head; θ is the moisture content; n is the effective porosity; α' and β' are the modified coefficients of compressibility of the medium and water, respectively; K_{xx}, K_{xz}, K_{zx}, and K_{zz} are the hydraulic conductivity tensor components; x and z are the horizontal and vertical coordinates, respectively; t is the time; Q is the artificial recharge or withdrawal; and L is an operator. In general, Eq. (1) is nonlinear as both the soil properties, F, and hydraulic conductivity, K, are functions of the pressure head.

The initial condition of Eq. (1) is assumed to be known as:

$$h = h_0(x,z) \text{ in } R \quad , \tag{2}$$

where h_0 is a known function of spatial coordinates, x and z. R is a region bounded by the curve B(x,z) (Fig. 1). The function, h_0, may be obtained by simulating the steady state version of Eq. (1) with time-invariant boundary conditions. Three types of boundary conditions are considered in the problem. In the first type (Dirichlet) boundary the pressure head is prescribed:

$$h = h_1(x,z,t) \text{ on } B_1 \quad , \tag{3}$$

where B_1 is a portion of B, and h_1 is a known function of time and (x,z) on B_1. In the second type (Neumann) boundary the flux is prescribed as:

$$- \left[\left(K_{xx} \frac{\partial h}{\partial x} + K_{xz} \frac{\partial h}{\partial z} + K_{xz}\right) \bullet n_x + \left(K_{zx} \frac{\partial h}{\partial x} + K_{zz} \frac{\partial h}{\partial z} + K_{zz}\right) \bullet n_z\right] = q_2 \text{ on } B_2 \quad , \tag{4}$$

where n_x and n_z are the directional cosines of the outward unit vector normal to the B_2 portion of the curve B. The third type is the variable in the sense that either the Dirichlet or the Neumann conditions may prevail,

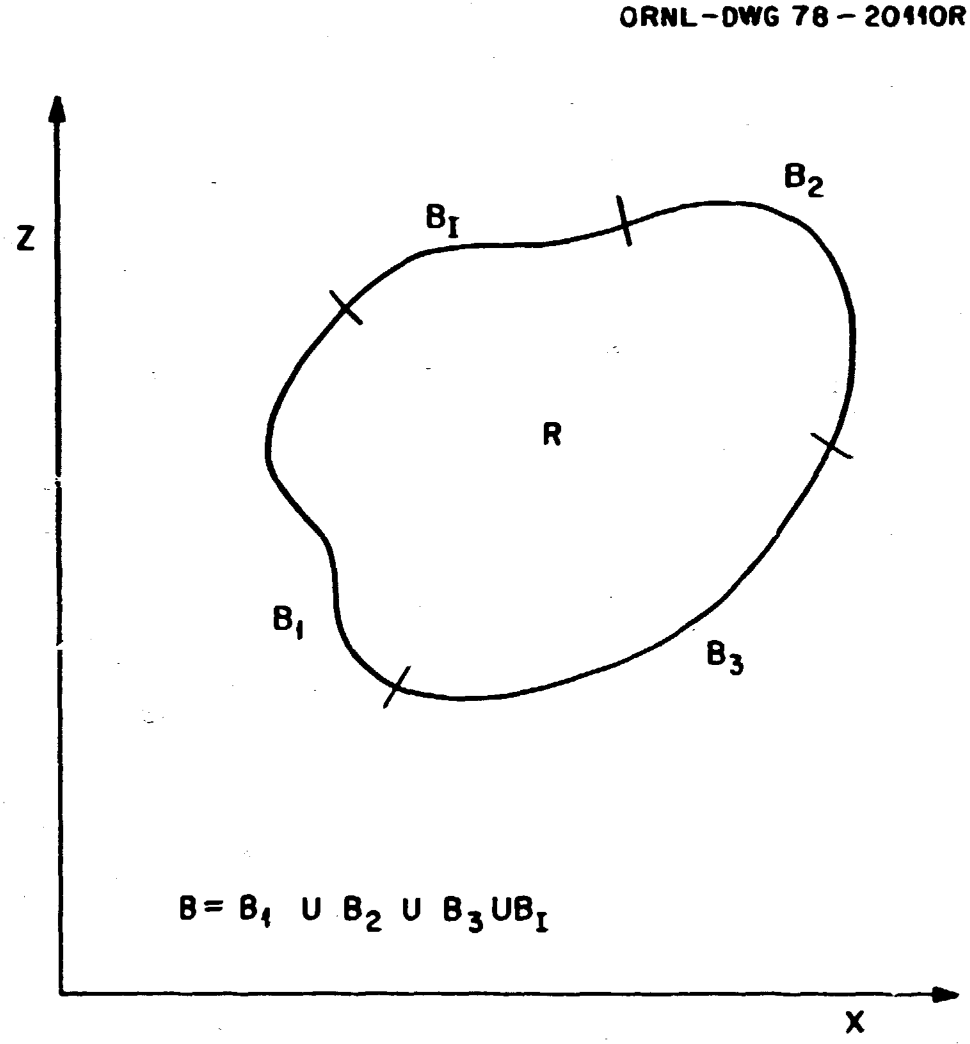

Fig. 1. Spatial boundaries of flow region, R.

$$h = h_3(x,z,t) \text{ on } B_3 \quad , \tag{5}$$

or

$$-\left[\left(K_{xx}\frac{\partial h}{\partial x} + K_{xz}\frac{\partial h}{\partial z} + K_{xz}\right) \bullet n_x + \left(K_{zx}\frac{\partial h}{\partial x} + K_{zz}\frac{\partial h}{\partial z} + K_{zz}\right) \bullet n_z\right] = q_3, \tag{6}$$

where h_3 and q_3 are two known functions of time and (x,z) on the B_3 portion of B. The boundaries, B_1, B_2, B_3, and the impervious boundary, B_I, constitute the entire boundary, B(x,z) = 0. Initially Eq. (5) is applied to the boundary B_3 when the exact boundary conditions cannot in general be predicted a priori. Such a case would arise at the ground surface where either ponding (Dirichlet) or infiltration (Neumann) conditions could prevail (Segol 1976). This can only be determined in the cyclic process of solving Eq. (1).

After Eq. (1) is solved for the pressure head, h [subject to initial and boundary conditions, Eqs. (2) through (6)], the velocity components are then obtained by,

$$V_x = -\left(K_{xx}\frac{\partial h}{\partial x} + K_{xz}\frac{\partial h}{\partial z} + K_{xz}\right) \quad ,$$

and

$$V_z = -\left(K_{zx}\frac{\partial h}{\partial x} + K_{zz}\frac{\partial h}{\partial z} + K_{zz}\right) \quad . \tag{7}$$

The important modification to the original work lies in the numerical treatment of Eq. (7). Expansion is made to provide optional numerical methods for solving Eqs. (1) through (6).

2. Finite Element Approximations

Equations (1) through (6) are solved by the Galerkin finite-element method. Numerical procedures for this method have been fully addressed (Reeves and Duguid 1975), thus the theoretical basis of the method will not be repeated, only the numerical procedures are summaried. The region of interest is subdivided into an assemblage of smaller subdomains called elements. The quadrilateral bilinear element is used. Following the standard procedure of the Galerkin finite-element method, approximate formulation of the pressure head h will be obtained. Thus, let the variable h be approximated in an element e by:

$$h \approx \hat{h} = \sum_{j=1}^{4} h_j(t)\, N_j \quad , \tag{8}$$

where N_j and h_j are the base function of element e and the amplitude of h, respectively, at nodal point j. Upon the substitution of Eq. (8) into Eq. (1) and application of the orthogonality theorem,

$$\int_{R_e} N_i\, L(h)\, dR = 0, \quad i = 1,2,3,4 \quad , \tag{9}$$

one obtains the following element matrix equation for element e:

$$\left[M_{ij}\right]\left\{\dot{h}_j\right\} + \left[S_{ij}\right]\left\{h_j\right\} + \left\{D_i\right\} + \left\{Q_i\right\} = 0 \quad , \tag{10}$$

where R_e is the region of the element e, dR is the differential area, and the temporal derivative of the head, $\dot{h}_i$ is given below:

$$\dot{h}_i = \frac{dh_i}{dt} \quad . \tag{11}$$

The matrix equation coefficients are defined as:

$$M_{ij} = \int_{R_e} N_i F N_j \, dR \quad , \qquad (12)$$

$$S_{ij} = \int_{R_e} \left\{ \frac{\partial N_i}{\partial x} \bullet \left(K_{xx} \frac{\partial N_j}{\partial x} + K_{xz} \frac{\partial N_j}{\partial z}\right) + \frac{\partial N_i}{\partial z} \bullet \left(K_{zx} \frac{\partial N_j}{\partial x} + K_{zz} \frac{\partial N_j}{\partial z}\right) \right\} dR \quad , \qquad (13)$$

$$D_i = \int_{R_e} \left\{ K_{xz} \frac{\partial N_i}{\partial x} + K_{zz} \frac{\partial N_i}{\partial z} - Q \right\} dR \quad , \text{ and} \qquad (14)$$

$$Q_i = \int_{B_{e2}} N_i q_2 \, dB + \int_{B_{e3}} N_i \bullet q_3 \, dB \quad , \qquad (15)$$

in which B_{e2} and B_{e3} are the boundaries of the element e, coinciding with the global boundaries B_2 and B_3, respectively. The first term in Eq. (15) appears only for those elements having one or more sides on B_2 and the integration is carried only over B_2. Similarly, the second term in that equation appears only for those elements having one or more sides on B_3, and boundary condition Eq. (6) rather than (5) is prevailing.

In the original work (Reeves and Duguid 1975), the velocity components in Eq. (7) were approximated as

$$V_x = -\left(K_{xx} \frac{\partial N_j}{\partial x} + K_{xz} \frac{\partial N_j}{\partial z}\right) h_j - K_{xz} \quad ,$$

and (16)

$$V_z = -\left(K_{zx} \frac{\partial N_j}{\partial x} + K_{zz} \frac{\partial N_j}{\partial z}\right) h_j - K_{zz} \quad .$$

This formulation results in a velocity field which is not continuous at element boundaries and nodal points if the variation of the pressure head is other than linear or constant. The alternative approach would be to apply the Galerkin technique to Eq. (7), thus one obtains

$$\left[S'_{ij}\right]\left\{V_{xj}\right\} = \left\{D_{xi}\right\} \quad ,$$

and (17)

$$\left[S'_{ij}\right]\left\{V_{zj}\right\} = \left\{D_{zi}\right\} \quad ,$$

where

$$S'_{ij} = \int_{R_e} N_i N_j dR \quad , \tag{18}$$

$$D_{xi} = -\int_{R_e} N_i \left\{K_{xx}\frac{\partial N_j}{\partial x} h_j + K_{xz}\frac{\partial N_j}{\partial z} h_j + K_{xz}\right\} dR \quad , \tag{19}$$

and

$$D_{zi} = -\int_{R_e} N_i \left\{K_{zx}\frac{\partial N_j}{\partial x} h_j + K_{zz}\frac{\partial N_j}{\partial z} h_j + K_{zz}\right\} dR \quad . \tag{20}$$

Referring to the element mass matrix (the matrix associated with the time-derivative term) in Eq. (10), one may recall that this is a unit matrix if the finite-difference formulation is adopted in spatial discretization. Hence, by proper scaling, the mass matrix can be reduced to the finite-difference equivalent by lumping (Clough 1971). In many occasions, the lumped mass matrix would result in better solution, in particular, if it is used in conjunction with the central or backward-difference time marching (Gureghian et al. 1978). Under such circumstances, it is preferred to the consistent mass matrix (mass matrix without lumping). Therefore, an option is provided for the lumping of matrix M_{ij}. More explicitly, M_{ij} will be lumped according to

$$M_{ii} = \sum_{j=1}^{4} \int_{R_e} F N_i N_j \, dR \text{ (no summation over } i\text{)} \quad , \qquad (21)$$

and

$$M_{ij} = 0 \text{ if } i \neq j \quad . \qquad (22)$$

3. Time-Marching Methods

An important advantage in finite-element approximation over the finite-difference approximation is the inherent ability to handle complex boundaries and obtain the normal derivatives therein. In the time dimension, such advantages are not evident. Thus, the finite-difference methods are typically used in the approximation of the time derivative. Three time-marching methods are adopted in the present water flow model. In the first one, the central or Crank-Nicolson formulation may be written as:

$$\left[M_{ij}\right] \left(\left\{h_j\right\}_{t+\Delta t} - \left\{h_j\right\}_t\right)/\Delta t + \tfrac{1}{2}\left[S_{ij}\right]\left(\left\{h_j\right\}_{t+\Delta t} + \left\{h_j\right\}_t\right) + \left\{D_i\right\} + \left\{Q_i\right\} = 0 \quad , \qquad (23)$$

where $\{M_{ij}\}$, $\{S_{ij}\}$, $\{D_i\}$, and $\{Q_i\}$ are evaluated at $(t + \Delta t/2)$. In the second method the backward difference formulation may be written as:

$$\left[M_{ij}\right]\left(\left\{h_j\right\}_{t+\Delta t} - \left\{h_j\right\}_t\right)/\Delta t + \left[S_{ij}\right]\left\{h_j\right\}_{t+\Delta t} + \left\{D_i\right\} + \left\{Q_i\right\} = 0 \quad , \tag{24}$$

where $[M_{ij}]$, $[S_{ij}]$, $\{D_i\}$, and $\{Q_i\}$ are evaluated at $t + \Delta t$. In the third optional method, the values of the unknown variables assumed to vary linearly with time during the time interval, Δt. In this mid-difference method, the recurrence formula is written as:

$$\left(2\left[M_{ij}\right]/\Delta t + \left[S_{ij}\right]\right)\left\{h_j\right\}_{t+\Delta t/2} - \frac{2}{\Delta t}\left[M_{ij}\right]\left\{h_j\right\}_t + \left\{D_i\right\} + \left\{Q_i\right\} = 0 \tag{25}$$

and

$$\left\{h_j\right\}_{t+\Delta t} = 2\left\{h_j\right\}_{t+\Delta t/2} - \left\{h_j\right\}_t \quad , \tag{25a}$$

where $[M_{ij}]$, $[S_{ij}]$, $\{D_i\}$, and $\{Q_i\}$ are all evaluated at $t + \Delta t/2$. This option has been shown superior to the central or backward-difference formulation, if the mass matrix is not lumped (Gureghian et al. 1978).

In summary, all element matrix equations presented in this section can be written as:

$$\left[C_{ij}\right]\left\{h_j\right\} = \left\{R_i\right\} - \left\{Q_i\right\} \quad , \tag{26}$$

where $[C_{ij}]$ is the element coefficient matrix, $\{h_j\}$ is the unknown vector to be found, and $\{R_i\}$ is the element load vector. Take, for example, Eq. (24). $[C_{ij}]$, $\{h_j\}$, and $\{R_i\}$ represent the following:

$$\left[C_{ij}\right] = \left[M_{ij}\right]/\Delta t + \left[S_{ij}\right] , \qquad (24a)$$

$$\left\{h_j\right\} = \left\{h_j\right\}_{t + \Delta t} , \qquad (24b)$$

and

$$\left\{R_j\right\} = \left(\left[M_{ij}\right]/\Delta t\right) \left\{h_j\right\}_t - \left\{D_i\right\} , \qquad (24c)$$

respectively.

4. Numerical Integration

For a quadrilateral element with four corner nodes, a bilinear polynomial base function for the i-th node may be written in terms of local normalized coordinates as:

$$N_i = \tfrac{1}{4}\,(1 + \xi\xi_i)\quad(1 + \eta\eta_i) \qquad i = 1,2,3,4 \quad , \qquad (27)$$

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 counterclockwise direction as shown in Fig. 2. The element is square in the local coordinate system regardless of the shape of the quadrilateral in the global coordinates. The global coordinates at any point within the element e are given in terms of local coordinates by the relationships

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

and (28)

$$z = \sum_{j=1}^{4} z_j N_j \quad ,$$

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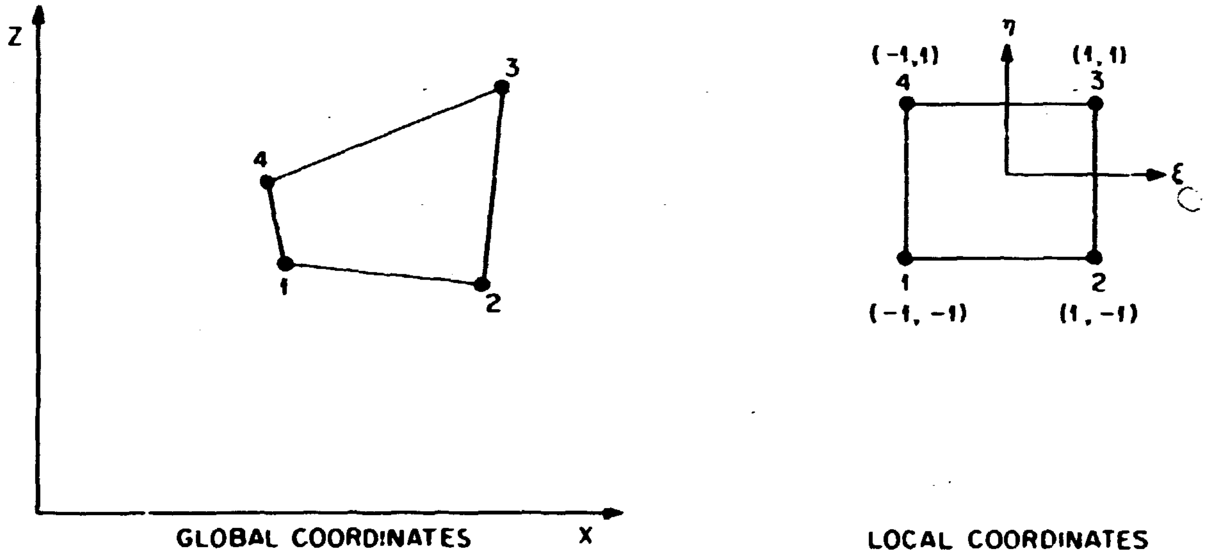


Fig. 2. A typical finite element in global and local coordinates.

where x_j and z_j are the global coordinates of the nodes and N_j is the shape function evaluated at the local coordinates, ξ and η. The shape function, N_j, of the coordinate transformation is taken the same as the basis function; hence, this element formulation is termed isoparametric. The Jacobian for the transformation from global to the local coordinates is expressed as:

$$[J] = \begin{bmatrix} \frac{\partial x}{\partial \xi} & \frac{\partial z}{\partial \xi} \\ \\ \frac{\partial x}{\partial \eta} & \frac{\partial z}{\partial \eta} \end{bmatrix} . \tag{29}$$

Substitution of Eq. (28) into the determinant of this expression yields:

$$J = \text{Det } [J] = (x_j \frac{\partial N_j}{\partial \xi}) \bullet (z_k \frac{\partial N_k}{\partial \eta}) - (z_j \frac{\partial N_j}{\partial \xi}) \bullet (x_k \frac{\partial N_k}{\partial \eta}) \quad . \tag{30}$$

The integrals of Eqs. (12-14) and (18-19) over the area of the e-th finite element may be written in local coordinates using the determinant of the Jacobian to transform the elemental area:

$$M_{ij} = \int_{-1}^{1} \int_{-1}^{1} N_i F N_j \; J d\eta d\xi \quad , \tag{31}$$

$$S_{ij} = \int_{-1}^{1} \int_{-1}^{1} \left\{ \frac{\partial N_i}{\partial x} (K_{xx} \frac{\partial N_j}{\partial x} + K_{xz} \frac{\partial N_j}{\partial z}) + \frac{\partial N_i}{\partial z} (K_{zx} \frac{\partial N_j}{\partial x} + K_{zz} \frac{\partial N_j}{\partial z}) \right\} J d\xi d\eta \quad , \tag{32}$$

and

$$D_i = \int_{-1}^{1} \int_{-1}^{1} \left\{ K_{xz} \frac{\partial N_i}{\partial x} + K_{zz} \frac{\partial N_i}{\partial z} - Q \right\} J d\xi d\eta \quad , \tag{33}$$

$$S'_{ij} = \int_{-1}^{1} \int_{-1}^{1} N_i N_j \; J d\xi d\eta \quad , \tag{34}$$

$$D_{xi} = - \int_{-1}^{1} \int_{-1}^{1} N_i \left\{ K_{xx} \frac{\partial N_j}{\partial x} h_j + K_{xz} \frac{\partial N_j}{\partial z} h_j + K_{xz} \right\} J d\xi d\eta \quad , \tag{35}$$

and

$$D_{zi} = - \int_{-1}^{1} \int_{-1}^{1} N_i \left\{ K_{zx} \frac{\partial N_j}{\partial x} h_j + K_{zz} \frac{\partial N_j}{\partial z} h_j + K_{zz} \right\} J d\xi d\eta \quad . \tag{36}$$

Integration of these equations is easily performed using 2 x 2 Gaussian integration. A linear algebraic equation, Eq. (26), results since $\left\{Q_j\right\}$ is a function of time only and the matrices, $\left[M_{ij}\right]$ and $\left[S_{ij}\right]$, and the vector $\left\{D_i\right\}$ are evaluated for the previous iteration and time step.

In order to evaluate $\left[S_{ij}\right]$, $\left\{D_i\right\}$, $\left\{R_{xi}\right\}$, and $\left\{R_{zi}\right\}$, expressions for the spatial derivative of the interpolation function and weighting function are necessary. The chain rule:

$$\left\{ \begin{matrix} \frac{\partial}{\partial \xi} \\ \\ \frac{\partial}{\partial \eta} \end{matrix} \right\} = [J] \left\{ \begin{matrix} \frac{\partial}{\partial x} \\ \\ \frac{\partial}{\partial z} \end{matrix} \right\} \quad , \tag{37}$$

may be inverted to yield

$$\begin{Bmatrix} \frac{\partial}{\partial x} \\ \\ \frac{\partial}{\partial z} \end{Bmatrix} = \frac{1}{J} \cdot \begin{bmatrix} \frac{\partial z}{\partial \eta} & -\frac{\partial z}{\partial \xi} \\ \\ -\frac{\partial x}{\partial \eta} & \frac{\partial x}{\partial \xi} \end{bmatrix} \begin{Bmatrix} \frac{\partial}{\partial \xi} \\ \\ \frac{\partial}{\partial \eta} \end{Bmatrix} , \qquad (38)$$

using the definition of $[J]$ in Eq. (29).

When the top row of Eq. (38) is applied to the base function, N_i, the following is obtained:

$$\frac{\partial N_i}{\partial x} = \frac{1}{J} \left[(z_j \frac{\partial N_j}{\partial \eta}) \bullet \frac{\partial N_i}{\partial \xi} - (z_j \frac{\partial N_j}{\partial \xi}) \bullet \frac{\partial N_i}{\partial \eta} \right] . \qquad (39)$$

Similarily,

$$\frac{\partial N_i}{\partial z} = \frac{1}{J} \; - \left[(x_j \frac{\partial N_j}{\partial \eta}) \bullet \frac{\partial N_i}{\partial \xi} + (x_j \frac{\partial N_i}{\partial \xi}) \bullet \frac{\partial N_i}{\partial \eta} \right] . \qquad (40)$$

Equations (39) and (40) are in a form suitable for numerical integration. The derivatives of N_i with respect to ξ and η can be obtained by the partial derivation of Eq. (27).

5. Assembly of the Element Matrix

Equation (26) is evaluated for each element, and the direct stiff method is adopted to assemble the terms to form a system of algebraic equations as:

$$\left[T_{ij}\right]\left\{h_j\right\} = \left\{X_i\right\} - \left\{B_i\right\} = \left\{Y_i\right\} , \qquad (41)$$

where $\left[T_{ij}\right]$ is the global coefficient matrix and $\left\{Y_i\right\}$ is the global load vector. The detailed discussion of the assembly of the element matrix into a global matrix has been presented (Desai and Abel 1972, Reeves and Duguid 1975).

6. Application of Boundary Conditions

Surfaces on which the Neumann-type boundary conditions, Eqs. (4) or (6), are imposed yield pressure-independent entries in the element column matrix $\left\{Q_i\right\}$. These entries are evaluated by direct application of substituting Eqs. (4) or (6) into Eq. (15) to yield element normal fluxes. This is followed by assembling over all boundary elements having one or more sides on the boundaries B_2 or B_3 of B to yield a global column matrix $\left\{B_i\right\}$. The results are substracted from the $\left\{X_i\right\}$ to form $\left\{Y_i\right\}$.

At nodes where Dirichlet boundary conditions are applied, an identity equation is generated for each node and included in the matrices of Eq. (41). The detailed method of applying this type of boundary conditions can be found elsewhere (Wang and Connor 1975). Computationally, this is done as shown in Fig. 3. If the k-th variable is prescribed, the k-th column in the coefficient matrix, $\left[T_{ij}\right]$, is stored. The k-th row and column in $\left[T_{ij}\right]$ are set to zero and the diagonal entry set equal to one. The stored column matrix is multiplied by the prescribed value of Y^* and substracted from the right-hand side of Eq. (41). This procedure effectively replaces the k-th equation by the prescribed constraint.

7. Solution of the Assembled Equations

In solving the assembled equations expressed in Eq. (41), the matrix $\left[T_{ij}\right]$ is decomposed into the product of upper and lower

$$\begin{bmatrix} T_{11} & \cdots & T_{1,k-1} & 0 & T_{1,k+1} & \cdots & T_{1n} \\ \vdots & & \vdots & \vdots & \vdots & & \vdots \\ T_{k-1,1} & \cdots & T_{k-1,k-1} & 0 & T_{k-1,k+1} & \cdots & T_{k-1,n} \\ 0 & \cdots & 0 & 1 & 0 & \cdots & 0 \\ T_{k+1} & \cdots & T_{k+1,k-1} & 0 & T_{k+1,k+1} & \cdots & T_{k+1,n} \\ \vdots & & \vdots & \vdots & \vdots & & \vdots \\ T_{n,1} & \cdots & T_{n,k-1} & 0 & T_{n,k+1} & \cdots & T_{nn} \end{bmatrix} \cdot \left\{ \begin{matrix} h_1 \\ \vdots \\ h_{k-1} \\ h_k \\ h_{k+1} \\ \vdots \\ h_n \end{matrix} \right\} = \left\{ \begin{matrix} Y_1 \\ \vdots \\ Y_{k-1} \\ 0 \\ Y_{k+1} \\ \vdots \\ Y_n \end{matrix} \right\}$$

$$- \begin{bmatrix} 0 & \cdots & 0 & T_{1k} & 0 & \cdots & 0 \\ \vdots & & \vdots & \vdots & \vdots & & \vdots \\ 0 & \cdots & 0 & T_{k-1,k} & 0 & \cdots & 0 \\ 0 & \cdots & 0 & -1 & 0 & \cdots & 0 \\ 0 & \cdots & 0 & T_{k+1,k} & 0 & \cdots & 0 \\ \vdots & & \vdots & \vdots & \vdots & & \vdots \\ 0 & \cdots & 0 & T_{nk} & 0 & \cdots & 0 \end{bmatrix} \cdot \left\{ \begin{matrix} 0 \\ \vdots \\ 0 \\ Y^* \\ 0 \\ \vdots \\ 0 \end{matrix} \right\}$$

Fig. 3. Application of Dirichlet boundary conditions.

triangular matrices using the Crout-Dolittle method. The lower triangular matrix is used to modify the right-hand side $\left\{Y_i\right\}$ for back-substitution into the upper triangular matrix to obtain a solution. If the matrix $\left[T_{ij}\right]$ and the time step, Δt, do not significantly change with time, the decomposition needs to be performed only once, and iteration is unnecessary. Typically in the unsaturated soil-moisture zone such a time-saving device cannot be used and decomposition is necessary for each time step and each iteration.

8. Mass Balance Computation

The mass balance over the whole region of interest is obtained by integrating Eq. (1):

$$\int_R F\frac{\partial h}{\partial t}\, dR = \int_B F_n\, dB \quad , \tag{42}$$

where F_n is the normal flux through the global boundary $B(x,z) = 0$. In fact, F_n denotes:

$$F_n = \left[\left(K_{xy}\frac{\partial h}{\partial x} + K_{xz}\frac{\partial h}{\partial z} + K_{xz}\right)\bullet n_x + \left(K_{zx}\frac{\partial h}{\partial x} + K_{zz}\frac{\partial h}{\partial z} + K_{zz}\right)\bullet n_z\right] . \tag{43}$$

Having obtained the pressure-head field, h, one could integrate the right- and left-hand sides of Eq. (42) independently. If the solution for h is free of error, one would expect the equality of two integrals. In the present report, the integral of the right-hand side is broken into several components:

$$F_D = \int_{B_1} F_n dB \quad , \tag{44}$$

$$F_N = \int_{B_2} F_n dB \quad , \tag{45}$$

$$F_S = \int_{B_{3s}} F_n dB \quad , \tag{46}$$

$$F_R = \int_{B_{3R}} F_n dB \quad , \text{ and} \tag{47}$$

$$F_I = \int_{B_I} F_n dB \quad , \tag{48}$$

where F_D, F_N, F_S, F_R, and F_I represent the fluxes through the constant Dirichlet boundary, B_1; the constant Neumann boundary, B_2; the seepage boundary, B_{3S}; the rainfall-infiltration boundary, B_{3R}; and the impervious Neumann boundary, B_I; respectively. On the other hand, the integral on the left-hand side of Eq. (42),

$$F_V = \int_R F \frac{\partial h}{\partial t} dR \quad , \tag{49}$$

represents the volumetric increasing rate of the moisture content in the region. In the model developed earlier (Reeves and Duguid 1975), this term was evaluated by

$$F_V = \int_R \frac{\partial \theta}{\partial t} dR \quad , \tag{50}$$

For exact solution, the net flux across the whole boundary, $B(x,z) = 0$, defined by

$$F_{net} = F_D + F_N + F_S + F_R + F_I \quad , \tag{51}$$

should satisfy the following equation

$$F_{net} = F_V \quad . \tag{52}$$

In addition, F_I should theoretically be equal to zero. However, in any practical numerical simulation, Eq. (52) will not be satisfied and F_I will be non-zero. Nevertheless, the mass balance computation should provide a means to check the numerical scheme and the consistence in computer code.

9. Numerical Treatment of Nonlinear Terms

In computing the element matrices, nonlinear terms as function of pressure head, h, are encountered. Take for example, the following equation:

$$M_{ij} = \int_{R_e} N_i F N_j \, dR \quad , \tag{53}$$

where F is, of course, a function of h, i.e., F = F(h).

Reeves and Duguid (1975) adopted the following approximation for F as

$$F(x,y) \simeq \sum_{i=1}^{4} F_i N_i \, (\xi,\eta) \quad , \tag{54}$$

where F_i is the value of F at nodal point i and was evaluated by $F_i = F(h_i)$. This approach will yield large error when the variation of F with h is rapid unless the element size is set very small. A consistent approach should be:

$$F(x,y) \simeq F\left(\sum_{i=1}^{4} h_i N_i\ (\xi,\eta)\right) \quad . \qquad (55)$$

In our revised model we have employed the approach shown in Eq. (55) whenever nonlinear terms are encountered. It is worth noting that the nodal values of h should be used to interpolate for the field values of h. The field values of any other h-dependent variables may then be computed as a function of h. Nodal values of h-dependent variables, computed by the nodal values of h, cannot be used to interpolate for the field values of such variables without risk of significant error.

10. Alternative Numerical Schemes

To conclude this chapter, Table 1 lists six alternative numerical schemes used in this report. They are dependent on the method of time-marching and the treatment of mass matrix. For example, scheme 1 uses the central difference time-marching with no lumping on the mass matrix.

Table 1. Listing of alternative numerical schemes

	Time-marching			Mass matrix	
	Central	Backward	Mid-difference	No lumping	Lumping
1	X			X	
2		X		X	
3	X				X
4		X			X
5			X	X	
6			X		X

III. COMPUTER PROGRAM MODIFICATION AND EXPANSION

The overall program organization is shown in Fig. 4a and b. Except for the name of subroutines, the original computer code (Reeves and Duguid 1975) has been almost completely overhauled. The overhaul is necessary to accomplish: (1) the application of the finite-element method to the Darcy's law, (2) the provision of six alternative numerical schemes, (3) the modification of computing the volumetric integral of the moisture-content changing rate, (4) the computation of nonlinear terms, (5) the reduction of storage by compressing all arrays of the boundary variables, and (6) the adoption of variable array in all subroutines.

A short main program is written to dimensionalize and initialize all arrays and to specify the maximum dimension in each of the arrays. The program is then passed to the subroutine, GW2DXZ, which was the main program in the computer code developed earlier (Reeves and Duguid 1975).

Subroutine DATAIN has been substantially reduced by getting rid of the duplication of codes that serve to read the steady state and transient boundary conditions. The compression of the arrays, specifying seepage-rainfall, Dirichlet boundary, and surface source term (or Neumann boundary) conditions, has been carried out also in the subroutine DATAIN. The compression of boundary elements and nodes is performed in the subroutine SURF.

The subroutines VELT and Q4D have been rewritten. VELT in the revised model is used to sum over the element matrix $\left[S'_{ij}\right]$, and

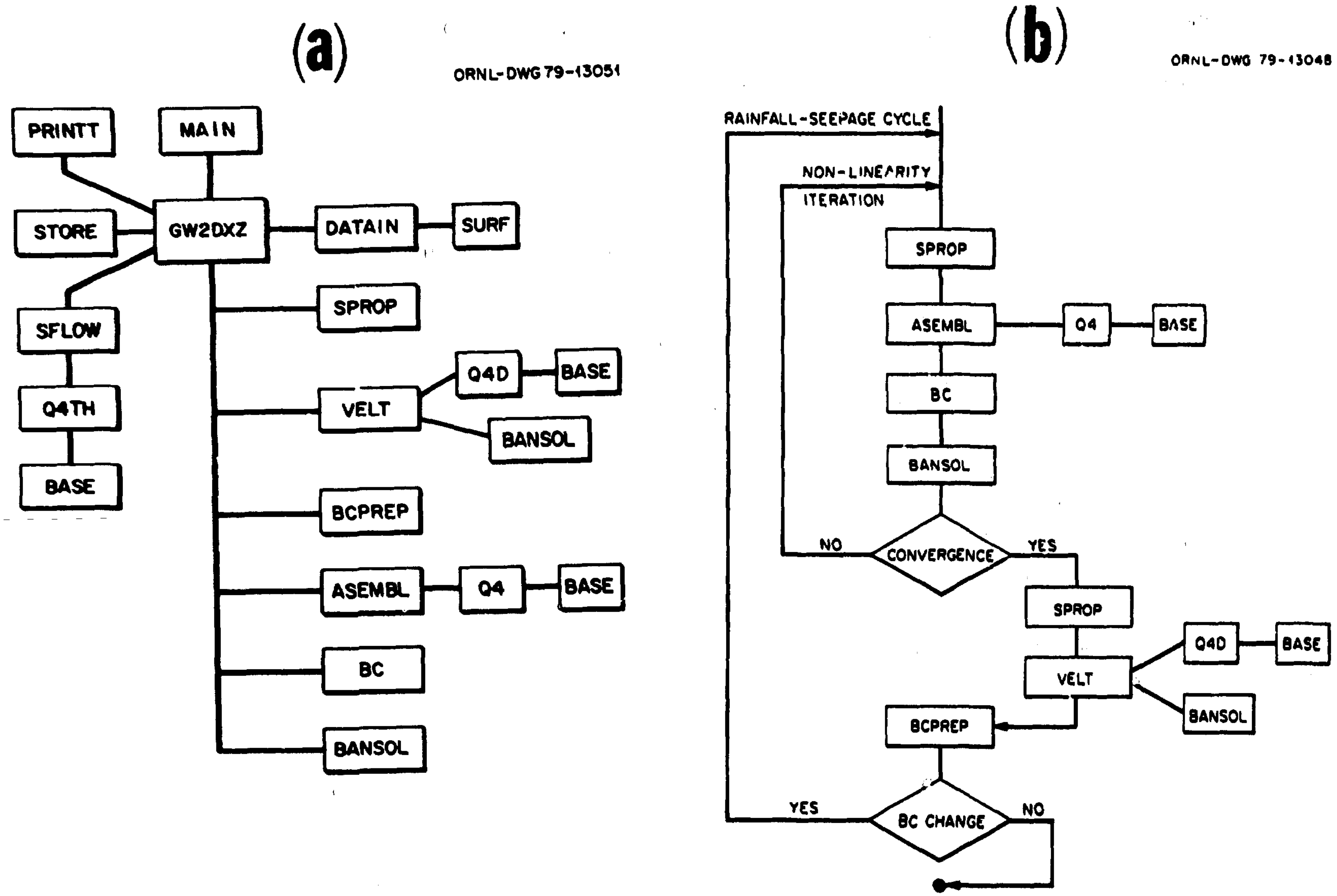


Fig. 4. (a) Subroutine chart of the computer code, (b) Nonlinearity and rainfall-seepage iteration loops in FECWATER computer code.

element load vectors $\left\{D_{xi}\right\}$ and $\left\{D_{zi}\right\}$, to form a global system of algebraic equations governing the velocity components, V_x and V_z, respectively. The subroutine subsequently calls BANSOL to yield the solution. Q4D is called by VELT to evaluate the element matrix $\left[S'_{ij}\right]$ and element load vectors $\left\{D_{xi}\right\}$ and $\left\{D_{zi}\right\}$. The computed continuous velocity is then returned to the calling subroutine GW2DXZ through the argument. This velocity field is then passed to the subroutine BCPREP to evaluate the Darcy's flux across the seepage-rainfall surface to ascertain the changing boundary conditions. BCPREP and SFLOW no longer call Q4S to calculate the velocity at the Gaussian point on the element boundary for obtaining the flux across the boundary surfaces. Instead, the velocity at Gaussian points is computed from the velocity field at nodal points by interpolation according to the principle of the finite-element method.

The subroutine ASSEMBL was modified to incorporate the mid-difference options and a new subroutine BASE was programmed to evaluate the basis functions at Gaussian point. The subroutine BASE was called by the subroutines, Q4, Q4D, and Q4TH. The options of lumping or no-lumping were decided in the subroutine Q4. Subroutine BC is the one with least change. It is altered only to accommodate the variable arrays. The standard subroutine, BANSOL, remains intact.

Subroutines SFLOW and Q4TH were changed to compute the new way of evaluating the volumetric integral of moisture-content changing rate. It will be seen that the new method better preserves the conservation of mass. Subroutines PRINTT and STORE are modified for better display on printout and selectively storing the dynamic variables and additional information of boundary elements and nodes on Disk Unit 2. To store the information of boundary elements and nodes eliminates the need for the subroutine SURF in the new waste transport model (Yeh and Ward 1979).

IV. RESULTS

Two sample problems are made to compare the results from the original model (Reeves and Duguid 1975) and the revised model. The first example is the seepage pond problem described in ORNL-4928 (Duguid and Reeves 1976). The second one is the Freeze's transient problem reported in ORNL-4927 (Reeves and Duguid 1975). In addition, results by all six alternative numerical schemes are compared in both examples.

1. Seepage Pond Problem

A seepage pond is assumed to situate entirely in the unsaturated zone above the water table. This pond provides a source of water which infiltrates into the subsurface aquifers. After the water reaches the water table, it flows toward a stream (Fig. 5). It is further assumed that the system is composed of a highly permeable sand with soil properties shown in Fig. 6. For the finite-element computation, the entire region is discretized by 595 nodal points and 528 elements (Fig. 5). Seven nodal points on the stream-soil interface are designated as Dirichlet nodes (Fig. 5). Seven nodal points on the bottom of the seepage pond, namely, nodal point nos. 152, 164, 172, 180, 188, 196, and 207, are considered as constant Neuman flux points and are assigned a constant infiltration rate of 4.0×10^{-4} cm/sec. The top sides of all elements on the sloping surface, except the two elements immediately to the right of the seepage pond, are considered the seepage-rainfall boundary surface. In other words, the nodal points

ORNL-DWG 79-9954

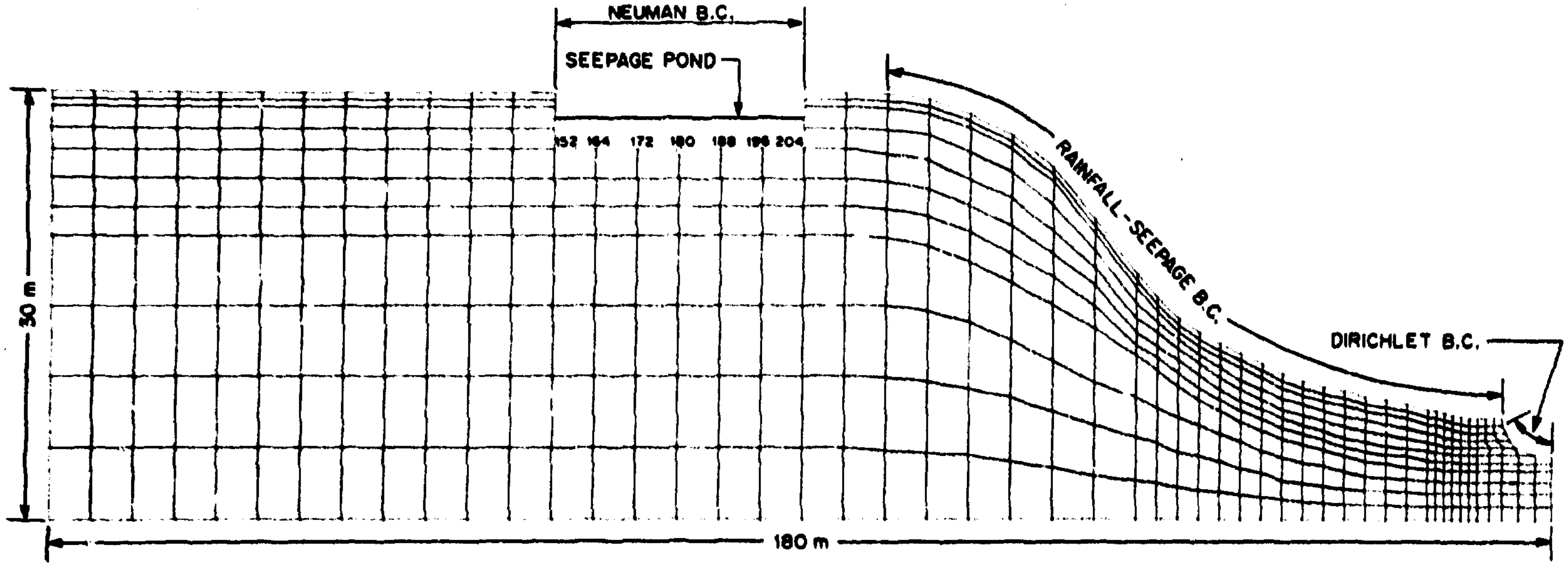


Fig. 5. Spatial discretization of the seepage pond problem.

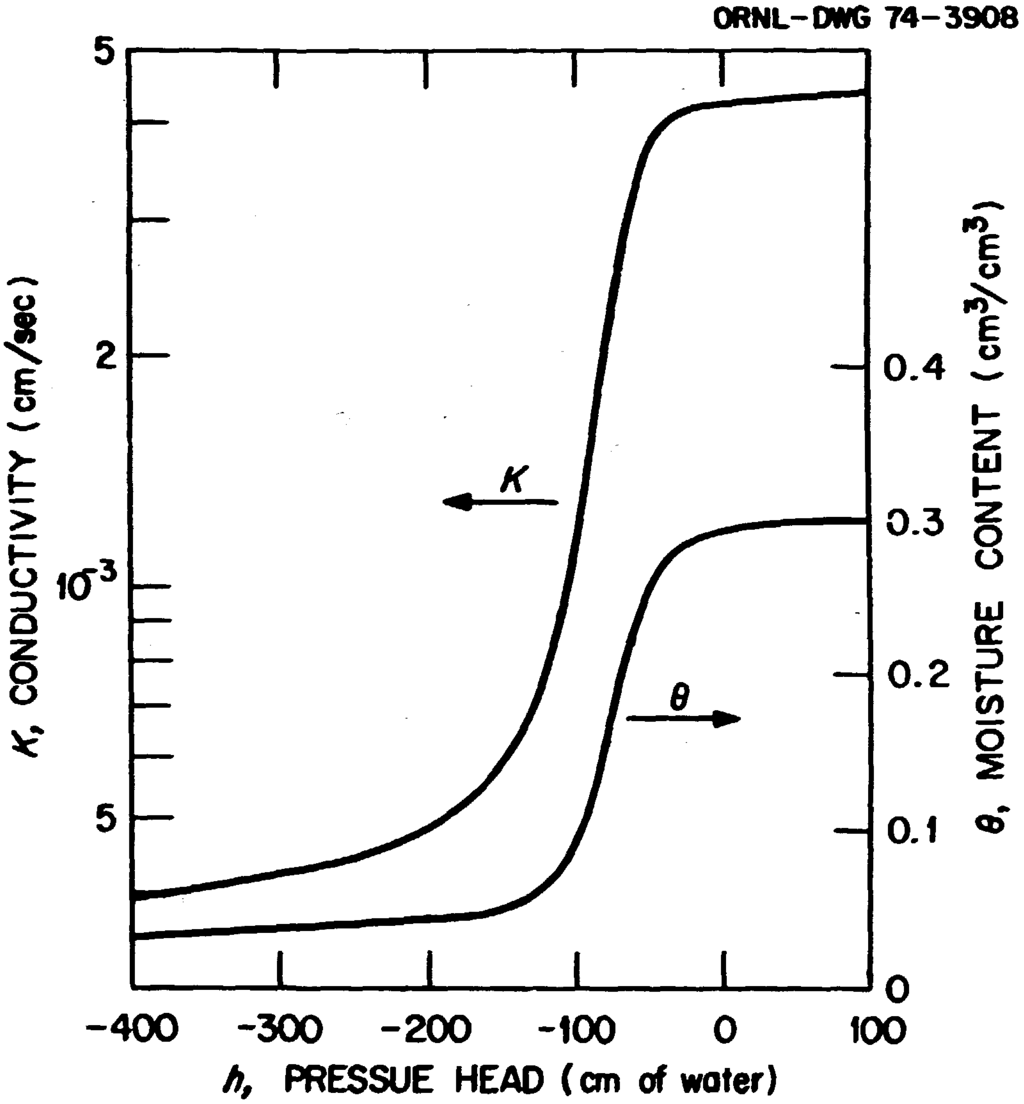
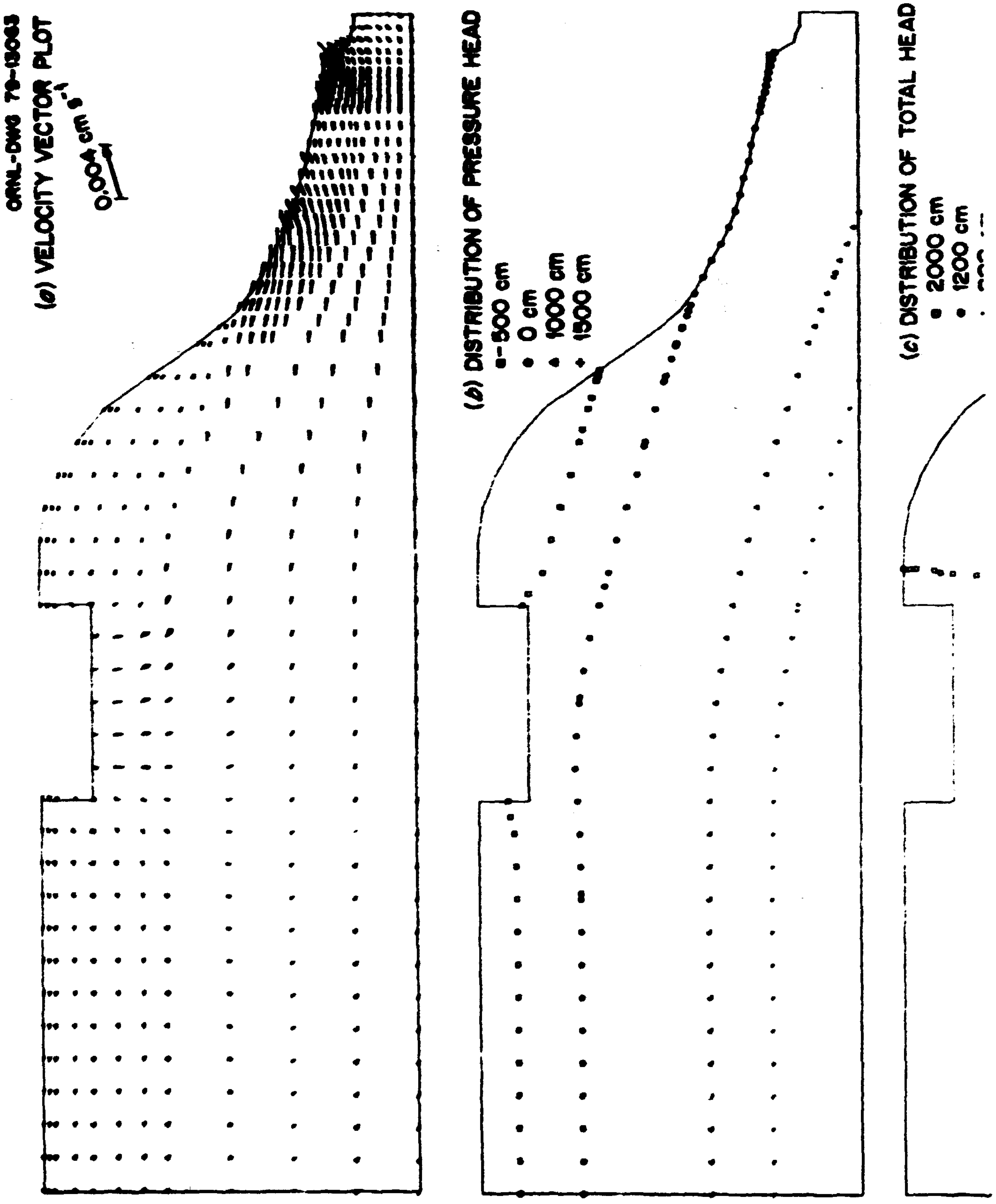


Fig. 6. Hydraulic conductivity and soil-moisture characteristics of a hypothetical sandy soil.

on this surface are either Dirichlet or Neumann points with the infiltration rate equal to the excess rainfall rate.

Figures 7a-d show the Darcy's velocity vector plot and the distribution of pressure head, total head, and moisture content as simulated by the original model (Reeves and Duguid 1975). Figures 8a-d depict those simulated by the present revised model. It is seen that two models yield almost identical results in pressure head, total head, and moisture content. However, the velocity field computed by the original code shows the discontinuity at every nodal point as can be seen from Fig. 7a, which illustrates the nonunique velocity vector at all nodal points. The severity of the discontinuity depends on the location ranging from several hundred percent to negligible. This discontinuity is completely eliminated with the revised model as can be seen from Fig. 8a. Figure 8a shows the unique velocity vector at all nodal points. Table 2 shows the comparison of the computed Darcy's velocity components simulated by the original and the revised models, respectively, for three selective nodal points. These three sample points are taken randomly from computer output to illustrate the difference when two codes are used. It is seen that at nodal point no. 2, the vertical velocity component as computed from element no. 2 is about 2.58 times that computed from element no. 1. The values of the horizontal component, V_x, at nodal point no. 179 as computed from element nos. 159 and 160 are about 1.41 times those computed from element nos. 152 and 153; while the values of the vertical component, V_z, at the same point as computed from element nos. 153 and 160 are about 4.69 times those computed from element nos. 152 and 159. At nodal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(a) VELOCITY VECTOR PLOT
0.004 cm s^{-1}
(b) DISTRIBUTION OF PRESSURE HEAD
-500 cm
0 cm
1000 cm
1500 cm
(c) DISTRIBUTION OF TOTAL HEAD
2000 cm
1200 cm

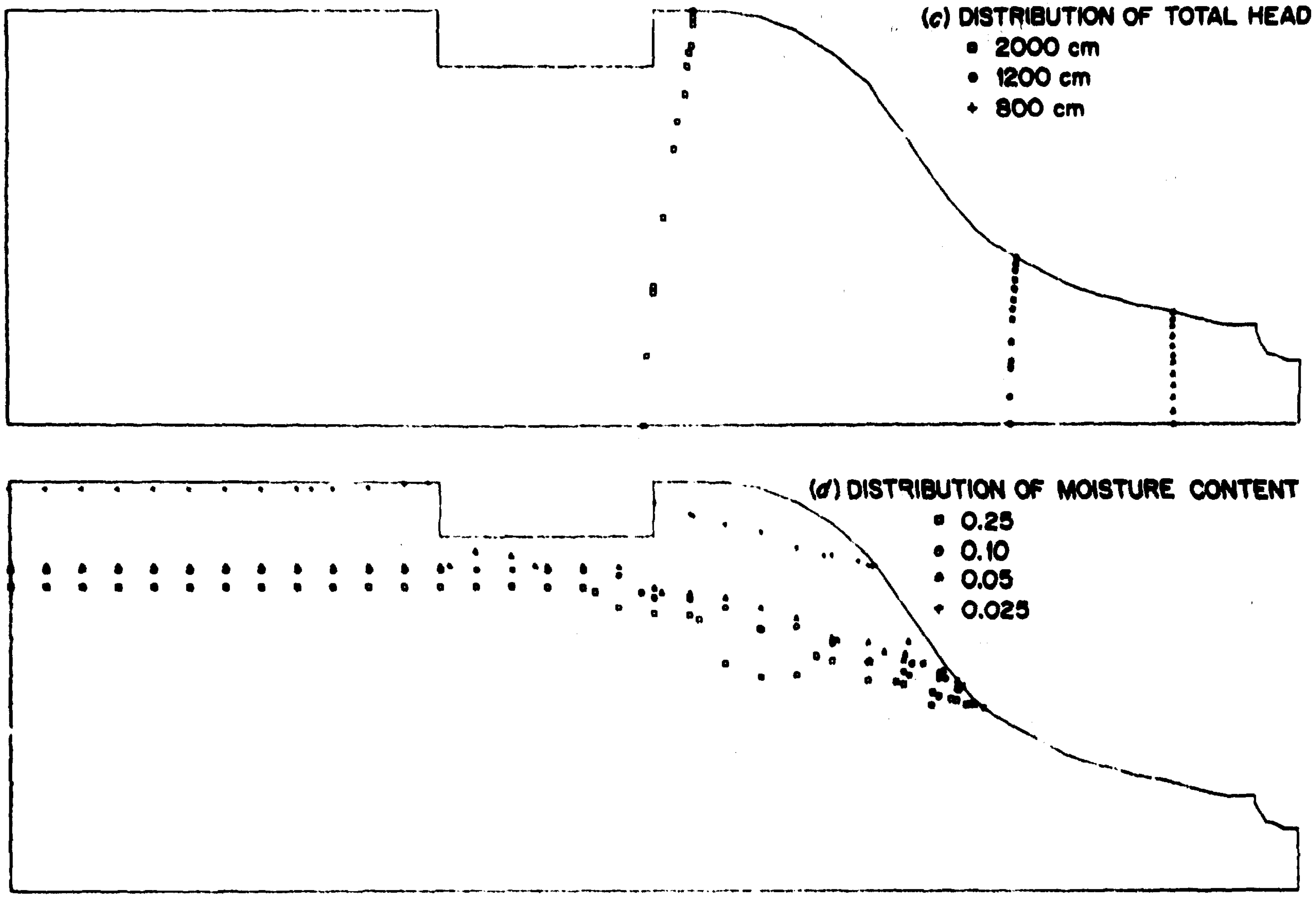

Fig. 7. Flow variables of seepage pond as simulated by Reeves and Duguid model: (a) velocity vector plot, (b) distribution of pressure head, (c) distribution of total head, (d) distribution of moisture content.

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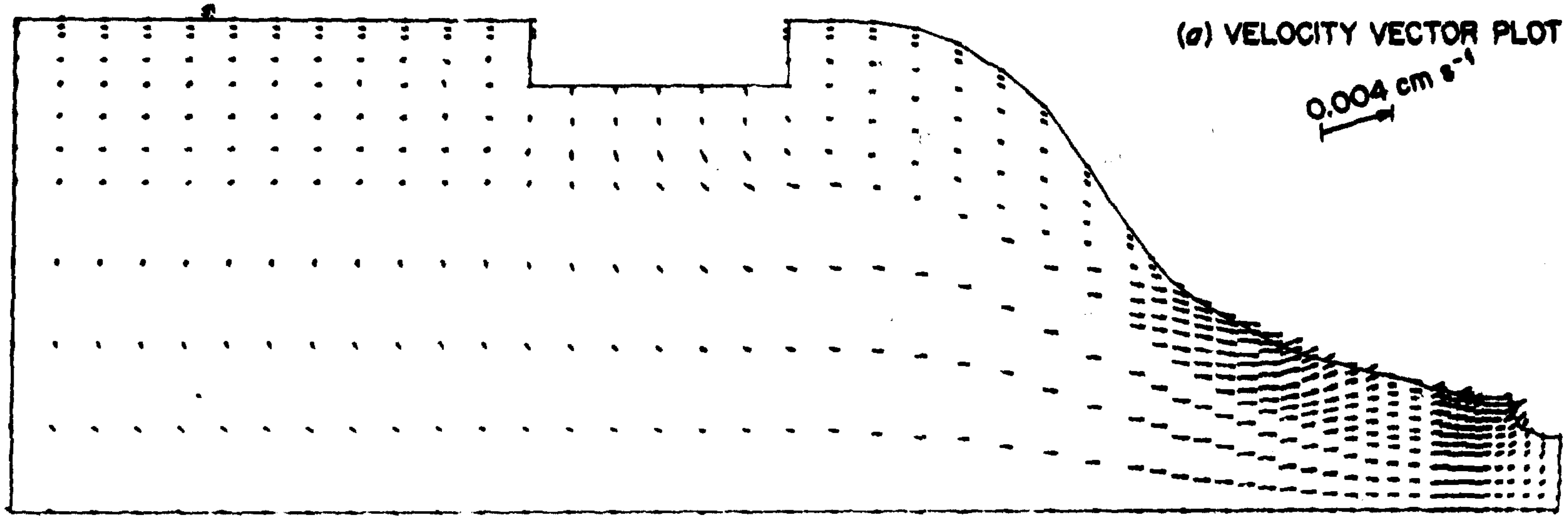
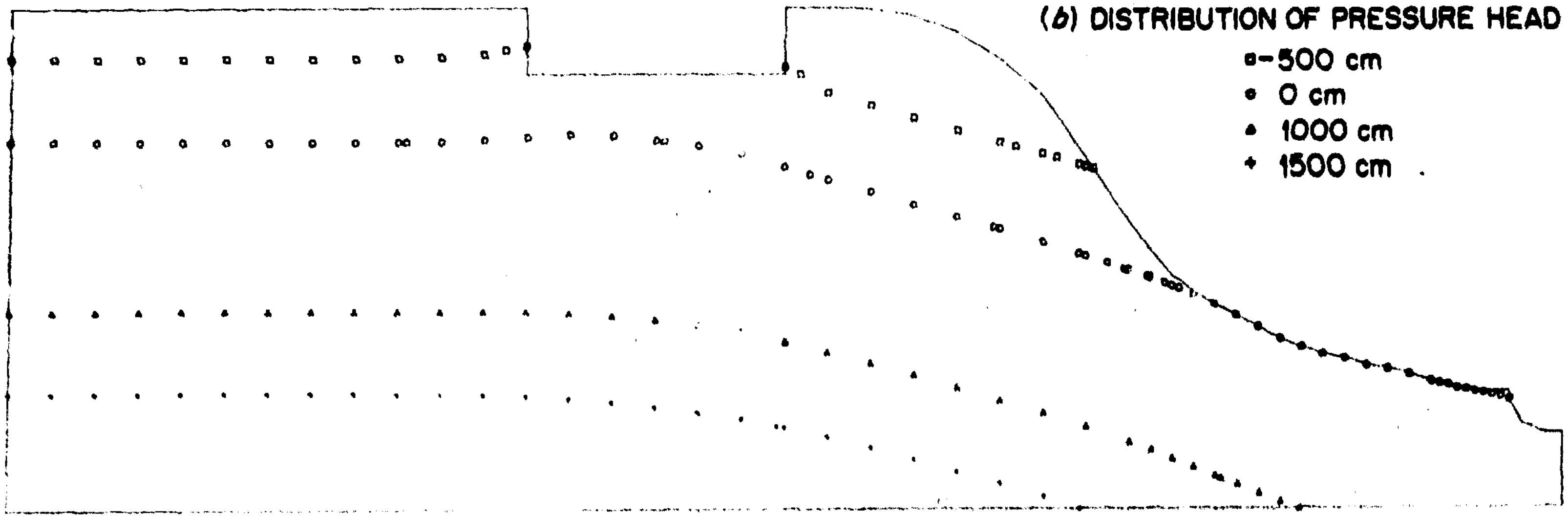

(a) VELOCITY VECTOR PLOT


(b) DISTRIBUTION OF PRESSURE HEAD

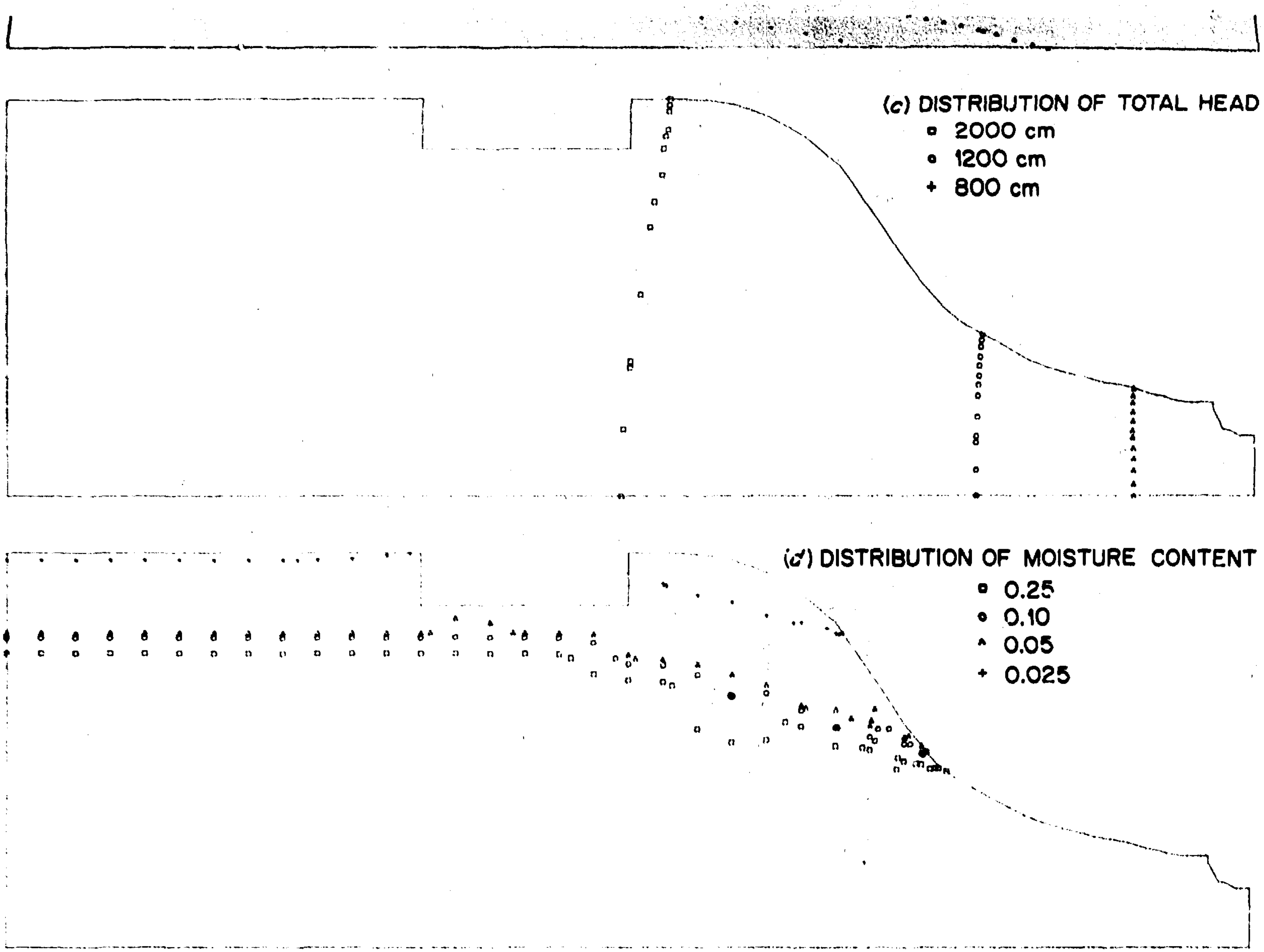


Fig. 8. Flow variables of seepage pond as simulated by present model: (a) velocity vector plot, (b) distribution of pressure head, (c) distribution of total head, (d) distribution of moisture content.

Table 2. Comparison of velocity components simulated by the original and revised codes, respectively, at selected points

Node no.	Element no.	Original code V_x (cm s^{-1})	Original code V_z (cm s^{-1})	Revised code V_x (cm s^{-1})	Revised code V_z (cm s^{-1})
2	1	2.33E-8	-2.53E-8	1.24E-8	-4.44E-8
	2	2.33E-8	-6.54E-8	1.24E-8	-4.44E-8
179	152	2.26E-5	-9.15E-5	3.03E-5	-2.94E-4
	153	2.26E-5	-4.31E-4	3.03E-5	-2.94E-4
	159	3.31E-5	-9.15E-5	3.03E-5	-2.94E-4
	160	3.31E-5	-4.31E-4	3.03E-5	-2.94E-4
587	521	6.28E-5	1.85E-4	1.23E-5	1.84E-4
	522	6.28E-5	2.36E-4	1.23E-5	1.84E-4
	528	7.89E-10	1.85E-4	1.23E-5	1.84E-4

point no. 587, the vertical velocity component, V_z, as computed from element no. 522 is about 1.27 times that computed from element nos. 521 and 528. On the other hand, results from the revised model show that the values of velocity components are identical at the same point, which is the case one should expect. Fig. 8 is the plot of computer output with numerical scheme no. 2. Since the steady state solution is sought, numerical scheme nos. 1, 3, 4, 5, and 6 yield identical results as expected.

2. Freeze Transient Problem

A very small laboratory-sized watershed measuring 6 x 3 m was presented by Freeze (1972) to test his finite-difference computer code. The same watershed was also used by Reeves and Duguid (1975) to debug and test their finite-element model. This watershed is again employed in the present report to compare our revised finite-element model with the Reeves and Duguid's original model (1975).

The flow system is shown in Fig. 9. It is composed of highly permeable sand, the unsaturated properties of which were shown in Fig. 6. To obtain initial conditions, pressure-head values were prescribed along the stream channel, part of the slope, and the upper plateau. Taking all other boundaries to be impermeable, a steady state solution was determined which was the initial condition for the transient calculation.

Using Freeze's transient boundary condition (Fig. 9b) and Reeves and Duguid's finite-element discretization #2 (Fig. 9c), selected results obtained by the original and revised models are presented in Figs. 10 and 11, respectively. Again, almost identical pressure head, total head, and moisture-content distributions are obtained. However, the original model again displays the discontinuity of velocity vector at all nodal points, while our revised model has completely eliminated this inconsistency. Furthermore, Table 3 shows that the mass balance has not been satisfied by the original model. At the end of about a 3-hr simulation time, the total net mass through all boundaries is only about 76.2% of the mass accumulated in the media as computed by numerical scheme 1 of the original code. In other words, a 23.8% of

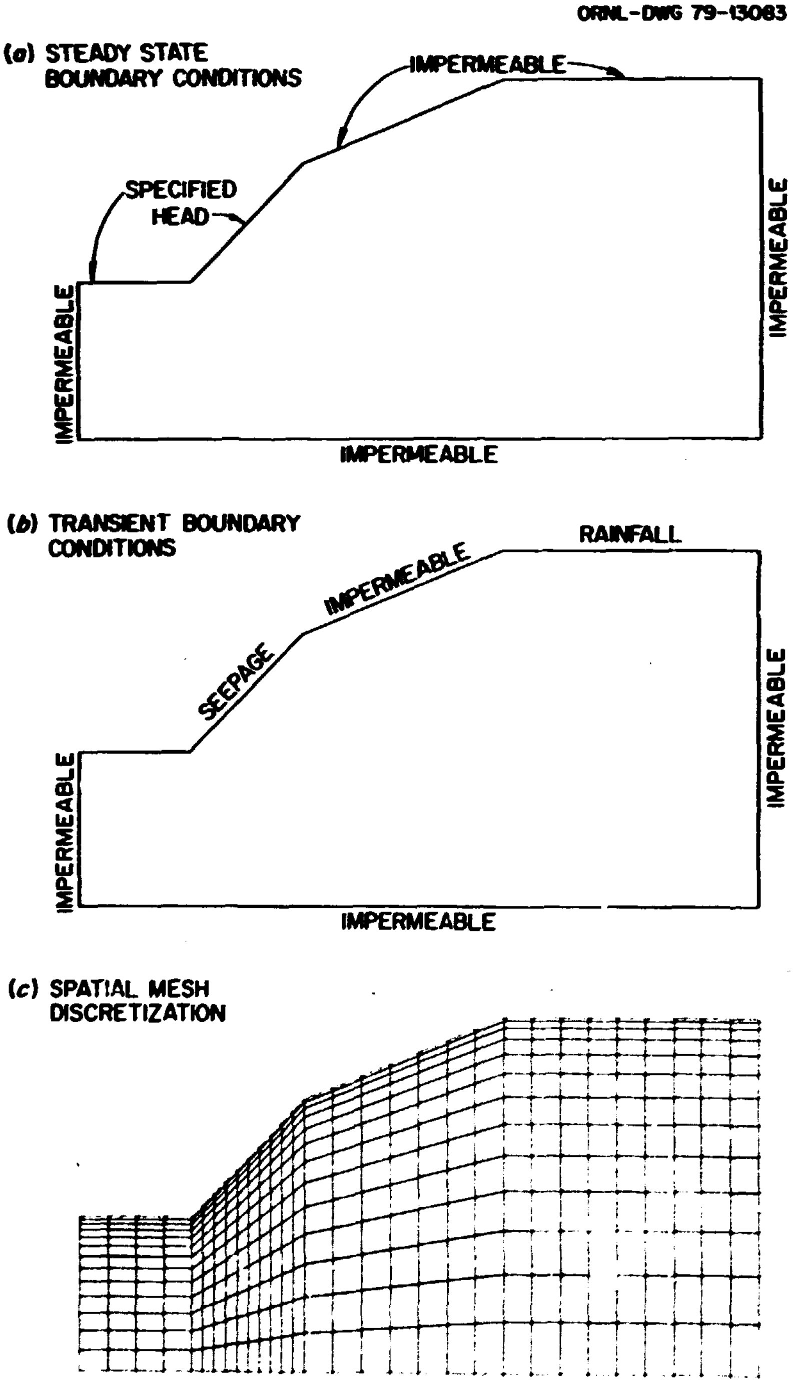


Fig. 9. Configuration of water transport in Freeze's experimental watershed; (a) steady state boundary condition, (b) transient boundary condition, (c) spatial mesh discretization

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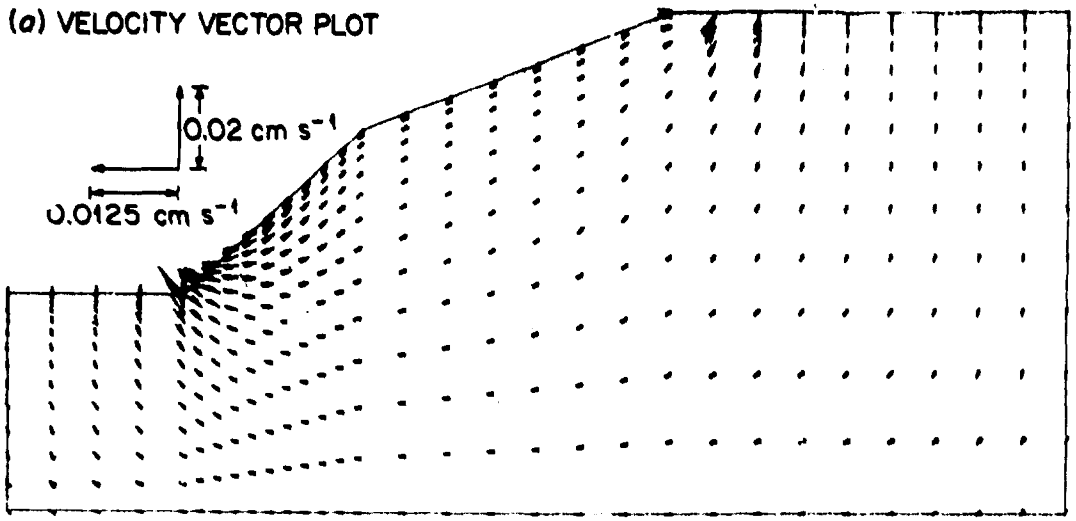
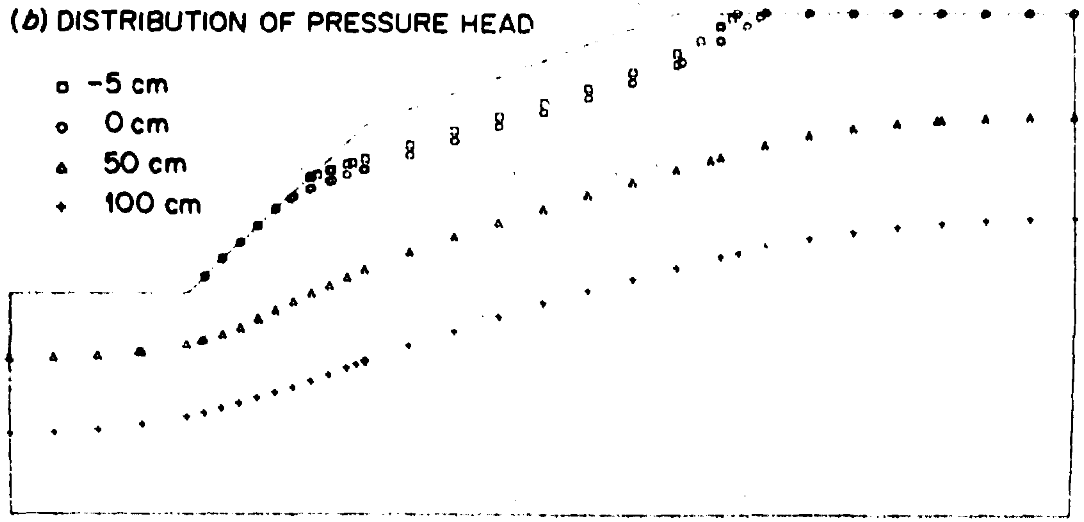
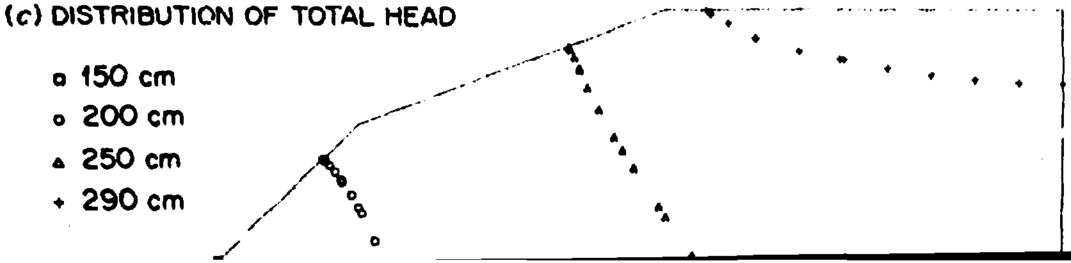
(*a*) VELOCITY VECTOR PLOT



(*b*) DISTRIBUTION OF PRESSURE HEAD



(*c*) DISTRIBUTION OF TOTAL HEAD



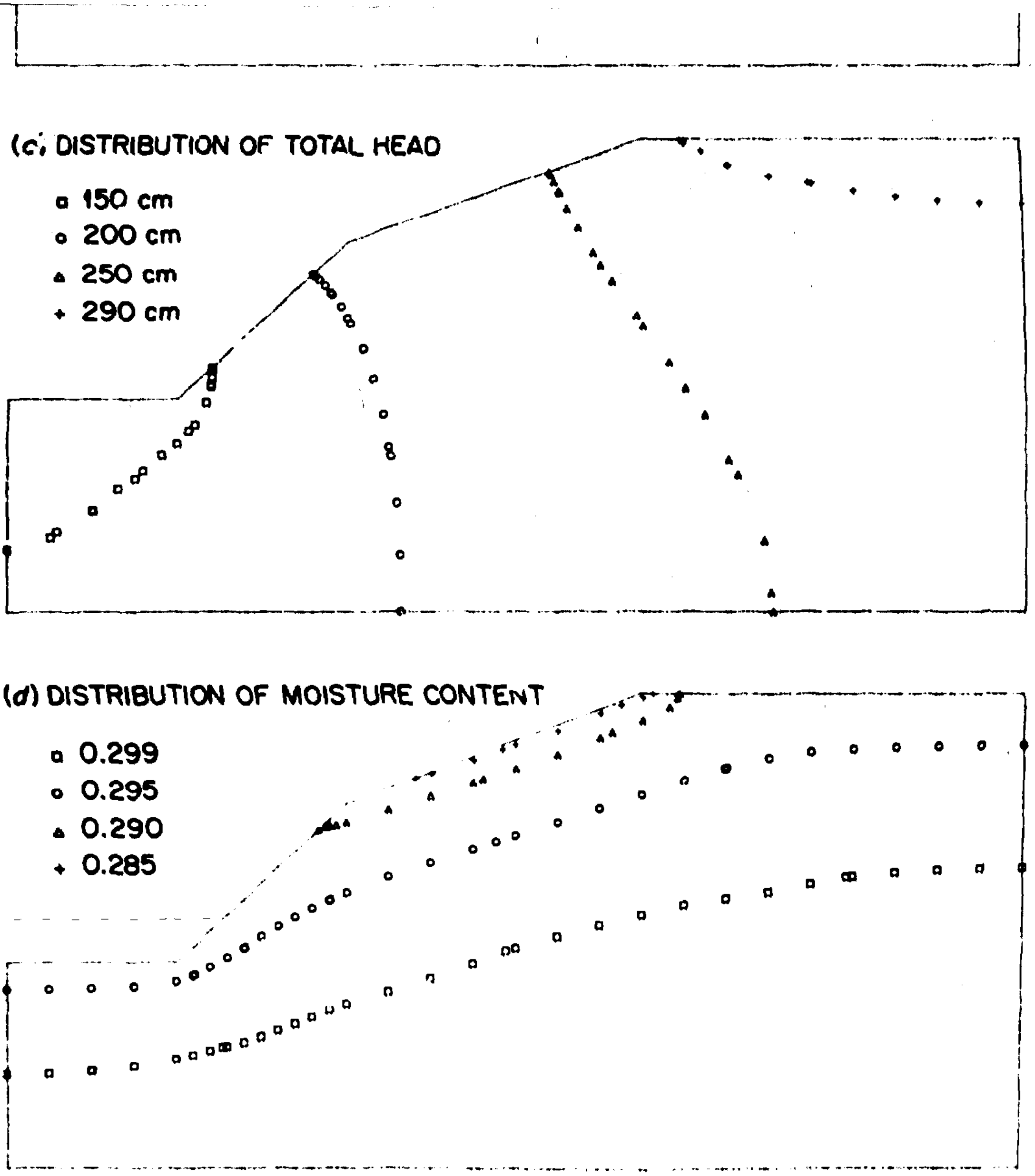
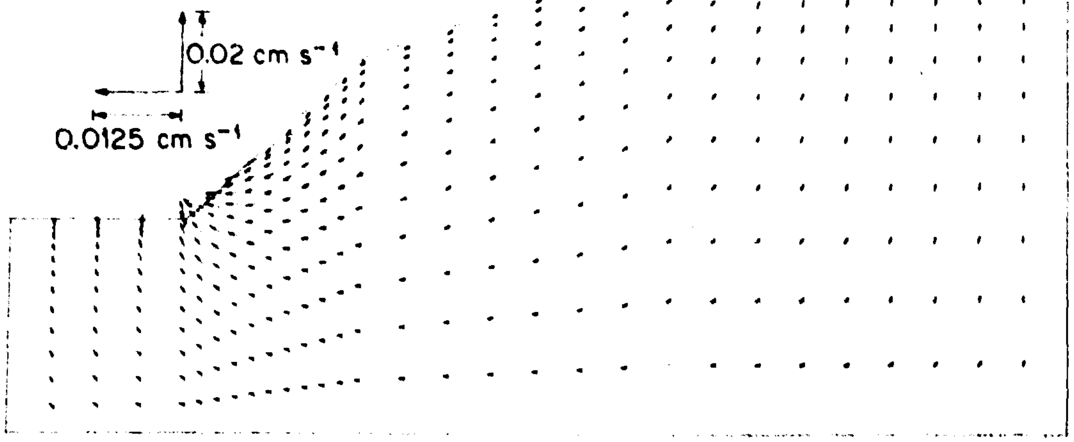


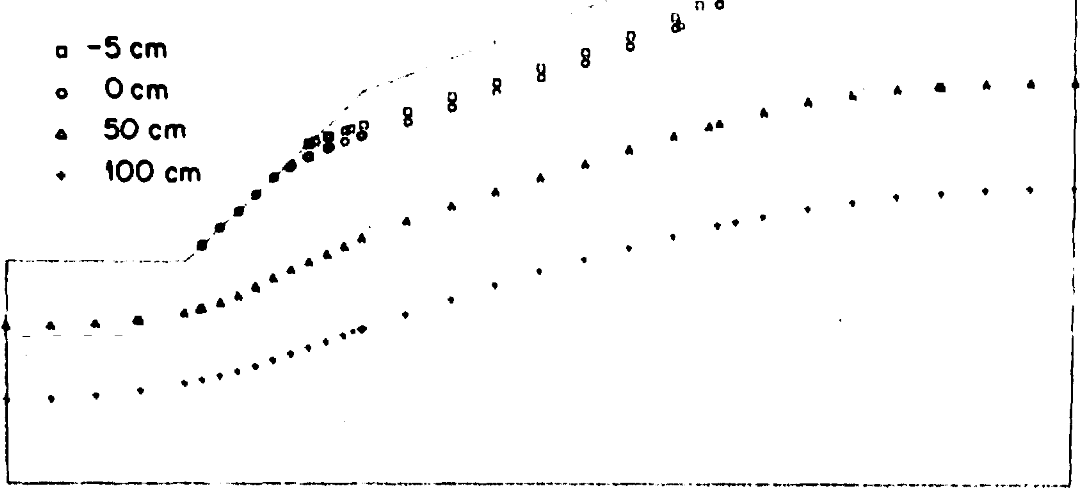
Fig. 10. Flow variables at time equal to 2.96 hr of Freeze's transient problem as simulated by Reeves and Duguid model: (a) velocity vector plot, (b) distribution of pressure head, (c) distribution of total head, (d) distribution of moisture content

ORNL-DWG 79-13067

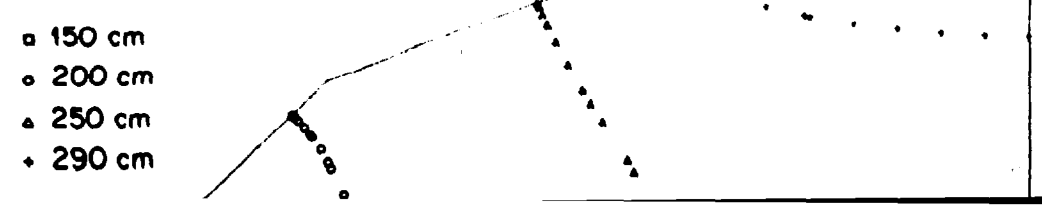
(*a*) VELOCITY VECTOR PLOT

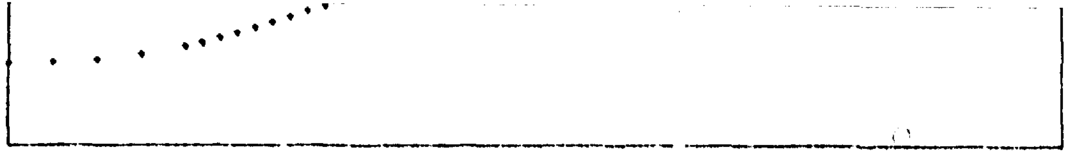


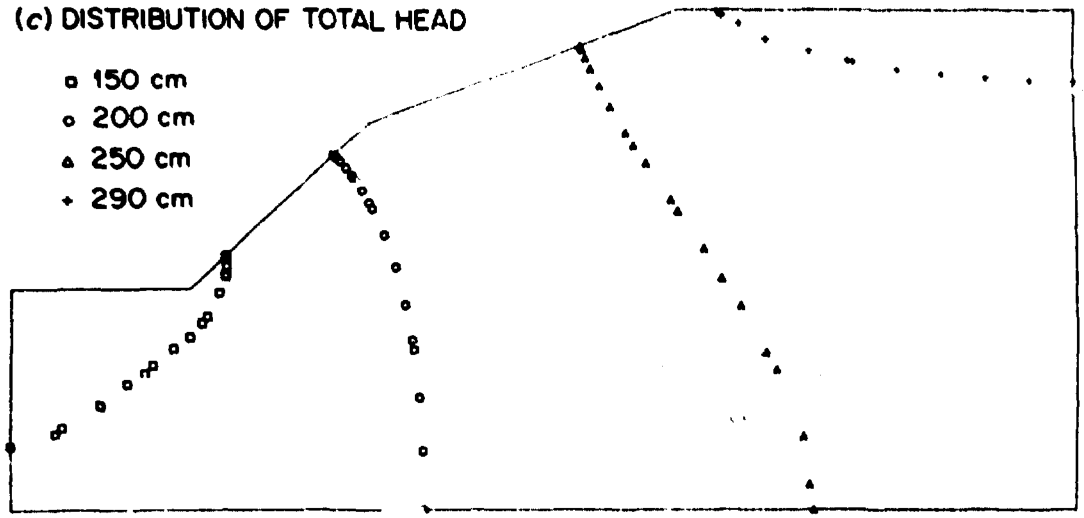
(*b*) DISTRIBUTION OF PRESSURE HEAD



(*c*) DISTRIBUTION OF TOTAL HEAD







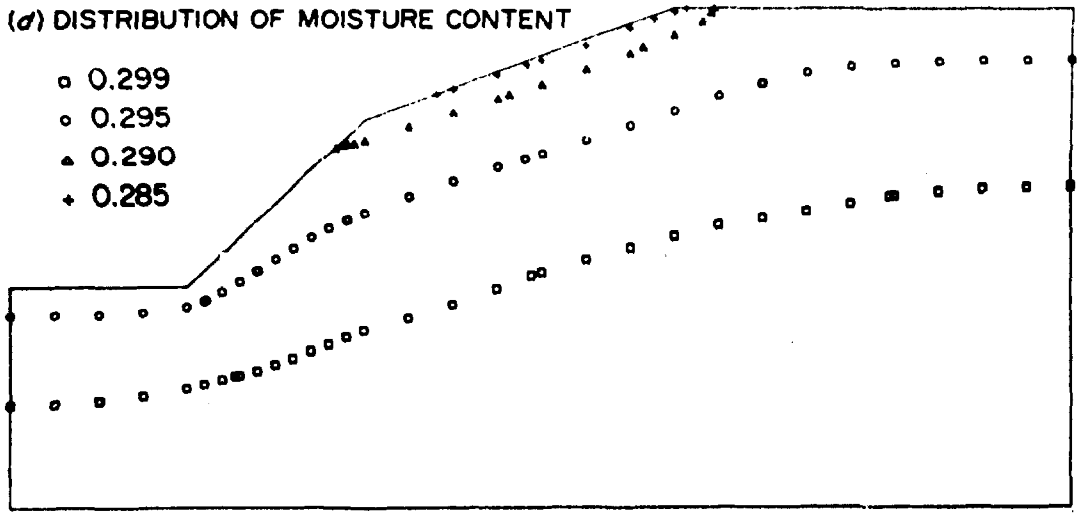


Fig. 11. Flow variables at time equal to 2.96 hr of Freeze's transient problem as simulated by Yeh and Ward model: (a) velocity vector plot, (b) distribution of pressure head, (c) distribution of total head, (d) distribution of moisture content.

Table 3. Comparison of percentage of mass loss of Freeze's transient problem as simulated by the original and revised model

Code/Schemes	1	2	3	4	5	6
Old	23.8	29.7	N/A[a]	N/A	N/A	N/A
Revised	2.2	-3.6	8.9	3.0	-3.2	-3.3

[a] N/A = not available.

mass has not been accounted for, i.e., has been lost through boundaries. Reeves and Duguid (1975) speculated that this large loss of mass might be eliminated by adding the triangular elements. However, without using triangular elements, our revised model only yields 2.2% of mass loss by eliminating the discontinuity of the velocity and by using a new method to evaluate a moisture-increasing rate in the region. An even larger mass loss of 29.7% is obtained by numerical scheme 2 of the original model. The revised model on the other hand renders a 3.6% of mass gain. Thus, the error of mass balance (positive for loss, negative for gain) by the revised model is much smaller than that by the original model.

Table 3 also shows the percentage of mass loss by all alternative numerical schemes. It is noted that the central difference standard Galerkin scheme in the revised model yields the best results. This is not surprising since the water transport equation does not contain advection (convection) terms. Figures 12 through 14 show the plots of flow variables as simulated by numerical scheme 1 of the revised model at time equal to 0.00 hr, 0.46 hr, and 1.85 hr, respectively. They

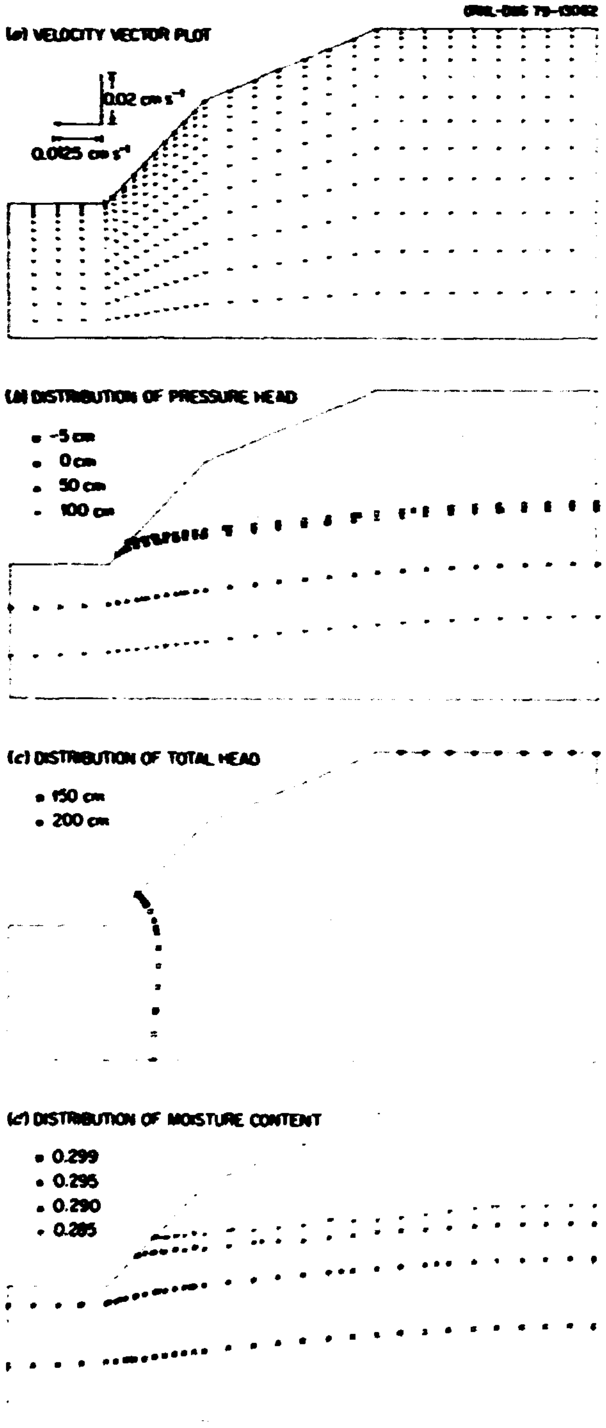


Fig. 12. Flow variables of Freeze's transient problem at time equal to 0.00 hr: (a) velocity vector plot, (b) distribution of pressure head, (c) distribution of total head, (d) distribution of moisture content.

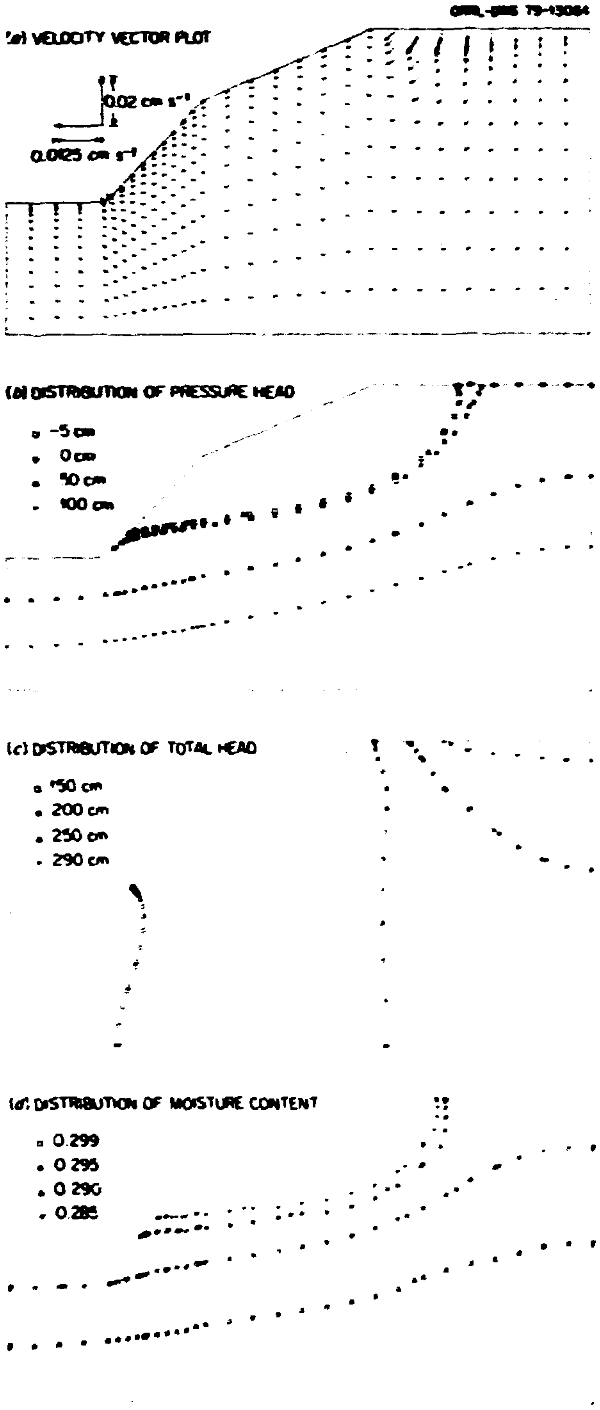


Fig. 13. Flow variables of Freeze's transient problem at time equal to 0.46 hr: (a) velocity vector plot, (b) distribution of pressure head, (c) distribution of total head, (d) distribution of moisture content.

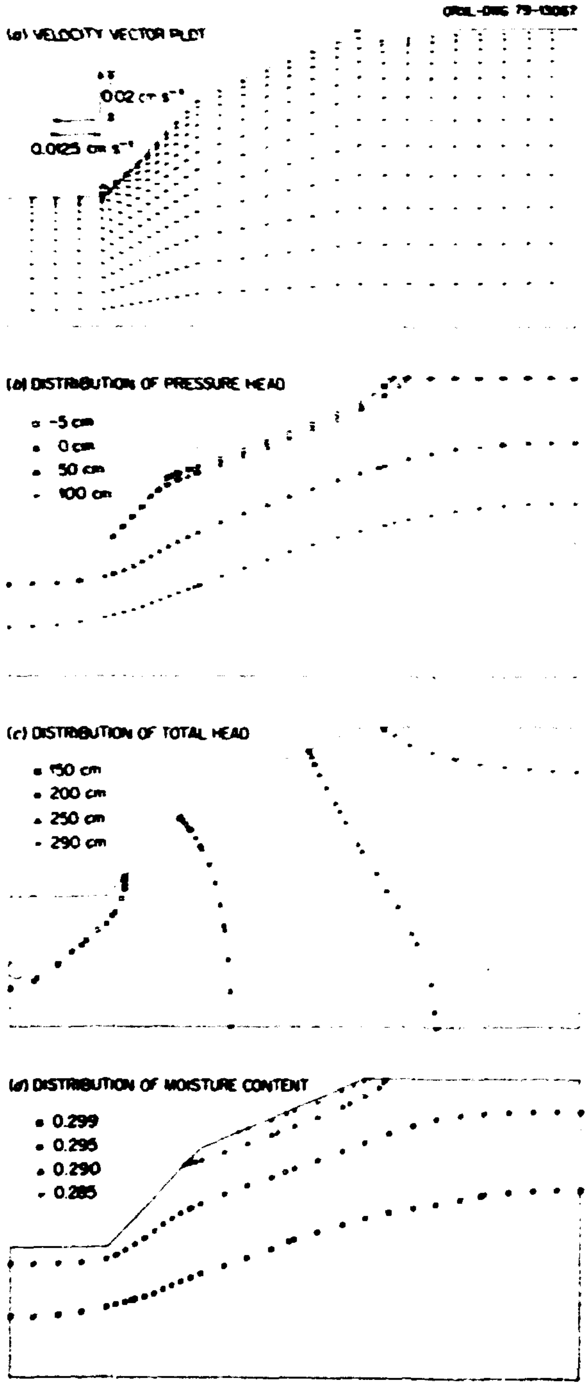


Fig. 14. Flow variables of Freeze's transient problem at time equal to 1.85 hr: (a) velocity vector plot, (b) distribution of pressure head, (c) distribution of total head, (d) distribution of moisture content.

show that the experimental watershed has been first gradually drained and then progressively wetted by the rainfall. Computer outputs on flow variables by all other alternative schemes show that comparable values are obtained at long simulation times.

To conclude this chapter, we state that the revised model (1) yields a continuous velocity field, (2) reduces mass loss through boundaries to as small as possible, and (3) provides four additional alternative numerical schemes, all of which are operational and render comparable results.

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VI. GLOSSARY OF NOTATIONS

B	Boundary line
B_1, B_2, B_3	Segments of boundary line
$\{B_i\}$	Global column matrix, the assembly of element column matrix, $\{Q_i\}$
$[C_{ij}]$	Element matrix whose component C_{ij} is defined by Eq. (24a)
$\{D_i\}$	An element column matrix whose component D_i is defined by Eq. (14)
$\{D_{xi}\}$	An element column matrix, whose component D_{xi} is defined by Eq. (19)
$\{D_{zi}\}$	An element column matrix, whose component D_{zi} is defined by Eq. (20)
e	Reference to the e-th element
F	Generalized storage coefficient
h	Pressure head
$\hat{h}$	Approximate pressure head
$\{h_j\}$	Pressure head column matrix
$\{\dot{h}_j\}$	Time derivative of $\{h_j\}$
h_0	Initial pressure head
h_1	Prescribed pressure head at Dirichlet boundary nodes
h_3	Prescribed pressure head at the rainfall-seepage boundary nodes
H	Total head
J	Determinant of $[J]$
$[J]$	Jacobian matrix for the e-th element
K_{xx}, K_{xz}, K_{zx}, K_{zz}	Tensor components of the hydraulic conductivity
L	Differential operator

$\left[M_{ij}\right]$	Element mass matrix, whose component M_{ij} is defined by Eq. (12)
n	Porosity
n_x	Directional cosine with the x-axis of a boundary line
n_z	Directional cosine with the y-azis of a boundary line
N_i, N_j	Basis functions
q_2	Prescribed fluxes on the Newman boundary segment
q_3	Prescribed fluxes on the rainfall-seepage boundary segment
Q	Withdrawal rate
$\left\{Q_i\right\}$	An element column matrix, whose component Q_i is defined by Eq. (15)
R	A region
R_e	An element region
$\left\{R_i\right\}$	A column matrix defined by Eq. (24c)
$\left[S_{ij}\right]$	The element stiff matrix, whose component S_{ij} is defined by Eq. (13)
$\left[S_{ij}\right]$	The element stiff matrix, whose component S'_{ij} is defined by Eq. (18)
t	Time
Δt	Time step
$\left[T_{ij}\right]$	Global coefficient matrix
V_x	Darcy velocity component in the x-direction
V_z	Darcy velocity component in the z-direction
x	Global coordinate in the horizontal direction
x_i, x_j	The global x-coordinate of nodal points, i and j
$\left\{Y_i\right\}$	Global column matrix

z	Global coordinate in the vertical direction
z_j, z_j	The global/z-coordinate of nodal points, i and j
α'	Modified coefficient of compressibility of the medium
β'	Modified coefficient of compressibility of water
θ	Moisture content
ξ	Local coordinate in the horizontal direction
ξ_i	Local ξ-coordinate of the point i
η	Local coordinate in the vertical coordinate
η_i	Local η-coordinate of the nodal point, i

APPENDIX A

DATA INPUT GUIDE

APPENDIX A:
DATA INPUT GUIDE

Data Set 1 - General Information Card.

This card is used to identify the job and to indicate if the diagnostic output is required. Only one card is required.

Card 1	Format (I5, 9A2, 1X, 2I1)
NPROB	Problem Number
TITLE	Array for the title of the problems
IBUG	An integer indicating if the diagnostic information of iteration is to be line-printed, = 0 no, = 1 yes
ICHNG	An integer indicating if the boundary-condition-changing information is to be line-printed, = 0 no, = 1 yes

Data Set 2 - Basic Integer Parameters

Only two cards are required per problem.

Card 1	Format (16 I 5)
NNP	Number of nodal points
NEL	Number of elements
NMAT	Number of different materials
NCM	Number of elements with material properties to be corrected
NTI	Number of time increments
KSS	Steady state control; 0 = steady state solution, 1 = transient solution
KSP	Soil property control; 0 = analytical function, 1 = tabular data
NSPPM	Number of points in tabular soil property definition, or number of soil property parameters to describe the analytical function
NSTR	Auxilary storage control; 0 = no storage, 1 = output stored (disk or tape)

KCP	Conductivity control; 0 = conductivity input, 1 = permeability input
KGRAV	Gravity control; 0 = gravity term included, 1 = omission of gravity term
NSTRT	Number of logical records to be read from auxilary storage for restarting calculation; 0 = no restart
MAXIT	Maximum number of iterations per time step
MAXCY	Maximum number of cycles for rainfall - seepage boundary condition adjustments
NMPPM	Number of material parameter per material
Card 2	Format (16 Z 5)
ILUMP	Matrix lumping control; 0 = no lumping, 1 = matrix lumped
IMID	Mid-difference time derivative control; 0 = Crank-Nicolson or backward difference, 1 = mid-difference

Data Set 3 - Basic Real Parameters

Two cards are required for each problem

Card 1	Format (8 F 10.0)
DELT	Time increment
CHNG	Multiplier for increasing time increment
DELMAX	Maximum value of DELT
TMAX	Value of maximum simulation time
FE	Angle between coordinate axes and principal directions of conductivity tensor in degrees
TOLA	Steady-state convergence criteria
TOLB	Transient-state convergence criteria
RHO	Density of water
Card 2	Format (8 F 10.0)
GRAV	Acceleration of gravity

VISC	Dynamic viscosity of water
W	Time derivative weighting; 0.5 = Crank-Nicolson, 1.0 = backward

Data Set 4 - Output Control

Two group of cards are required. One group is for printer output control and the other for auxilary storage output control. The number of cards in each group is determined by the number of time increments, NTI, i.e., No. of Cards, NGD = (NTI + 1)/80 + 1

Card Group 1	Format (80 I 1)
KPRO	Printer control for steady-state and initial conditions; 0 = No printout, 1 = FLOW, FRATE, TFLOW only, 2 = above (0) plus H, 3 = above (2) plus HT, 4 = above (3) plus TH, 5 = above (4) plus VX, VZ
KPR(1)	Printer control for transient selection similar to KPRO
KPR(NTI)	as a function of time index ITM

Card Group 2	Format (80 I 1)
KDSKO	Auxilary storage control; 0 = no auxilary storage, 1 = yes
KDSK(1) KDSK(NTI)	Auxilary storage control for transient solution similar to KDSKO as a function of time index ITM

Data Set 5 - Material Properties

A total of NMAT groups of cards are required. One group for each material. The number of cards in each group depends on NMPPM, i.e., the No. of cards, NOCD = (NMPPM)/8 + 1

Card Group J

PROP(J,1)	Modified coefficient of compressibility of media, J
PROP(J,2)	Modified coefficient of compressibility of water
PROP(J,3)	Porosity of porous media, J
PROP(J,4)	Component of conductivity in the x-direction for media, J
PROP(J,5)	Component of conductivity in the z-direction for media, J

Data Set 6 - Analytical Soil Parameters

Input cards for this data set are needed if and only if KSP = 0. Two sets of cards are required, one for the moisture-content parameters and the other for the conductivity (permeability) parameters. Each set of cards consist of NMAT groups of cards, one group for each material. The number of cards in each group is determined by the number of soil property parameters per material, NSPPM. NOCD = (NSPPM/8) + 1

Card Set 1	This set of cards is for THPROP(I,J)
Card Group 1	Format (8 F 10.0)
THPROP(1,1)	Analytical moisture content parameter 1 of material 1
THPROP(1,2)	Analytical moisture content parameter 2 of material 1
.	.
.	.
.	.
THPROP(1,NSPPM)	Analytical moisture content parameter NSPPM of material 1 NOCD cards are required for this Card Group
Card Group 2	Format (8 F 10.0)
THPROP (2,1)	Analytical moisture content parameter of material 2
THPROP (2,2)	Analytical moisture content parameter of material 2
.	.
.	.
.	.
THPROP(2,NSPPM)	Analytical moisture content parameter NSPPM of material 2 NOCD cards are required for this Card Group
	.
.	
.	
.	
Card Group NMAT	FORMAT (8F10.0)
.	
.	
.	

Total number of cards = NMAT * NOCD

Card Set 2:	This set of cards is for ARPROP(I,J)
Card Group 1	Format (8F10.0) = for material 1
AKPROP(1,1)	Analytical conductivity parameter 1 of material 1
AKPROP(1,2)	Analytical conductivity parameter 2 of material 1
.	
.	
.	
AKPROP(1,NSPPM)	Analytical conductivity parameter NSPPM of material 1. NOCD cards are required for this Card Group
Card Group 2	Format (8F10.0) = for material 2
AKPROP(2,1)	Analytical conductivity parameter 1 of material 2
AKPROP(2,2)	Analytical conductivity parameter 2 of material 2
.	.
.	.
.	.
AKPROP(2,NSPPM)	Analytical conductivity parameter NSPPM of material 2 NOCD cards are required for this Card Group
.	
.	
.	
Card Group NMAT	Format (8F10.0) for material NMAT
.	
.	
.	

Total number of cards = NMAT * NOCD

Data Set 7 - Soil properties in Tabular Form

Input cards for this data set are needed if and only if KSP ≠ 0. Four sets of cards are required, one for pressure, HPROP, one for water content, THPROP, one for conductivity (permeability), AKPROP, and one for water capacity, CAPROP. Each set of cards consist of NMAT groups of cards, one group for each material. The number of cards in each group is determined by the number of soil property data permit per material, NSPPM. NOCD = (NSPPM/8) + 1

Card Set 1:	This set of cards is for HPROP(I,J)
Card Group 1	Format (8F10.0)
HPROP(1,1)	1st point of the tabular pressure for material 1
HPROP(1,2)	2nd point of the tabular pressure for material 1
⋮	⋮
HPROP(1,NSPPM)	NSPPM-th point of the tabular pressure for material 1. NOCD cards are required for this Card Group
Card Group 2	Format (8F10.0)
HPROP(2,1)	1st point of the tabular pressure for material 2
HPROP(2,2)	2nd point of the tabular pressure for material 2
⋮	⋮
HPROP(2,NSPPM)	NSPPM-th point of the tabular pressure for material 2. NOCD cards are required for this Card Group
⋮	
Card Group NMAT	Format (8F10.0)
⋮	

Total number of cards for this card set = NMAT ≠ NOCD

Card Set 2:	This set of cards is for THPROP(I,J)
Card Group 1	Format (8F10.0)
THPROP(1,1)	1st point of the tabular moisture-content for material 1
THPROP(1,2)	2nd point of the tabular moisture-content for material 1
. . .	. . .
THPROP(1,NSPPM)	NSPPM-th point of the tabular moisture-content for material 1. NOCD cards are required for this Card Group
Card Group 2	Format (8F10.0)
THPROP(2,1)	1st point of the tabular moisture-content for material 2
THPROP(2,2)	2nd point of the tabular moisture-content for material 2
. . .	. . .
THPROP(2,NSPPM)	NSPPM-th point of the tabular moisture-content for material 2. NOCD cards are required for this Card Group
. . .	
Card Group NMAT	Format (8F10.0)
. . .	

Total number of cards for this card set = NMAT * NOCD

Card Set 3:	This set of cards is for AKPROP(I,J)
Card Group 1	Format (8F10.0)
AKPROP(1,1)	1st tabular value of conductivity for material 1
AKPROP(1,2)	2nd tabular value of conductivity for material 1
.	.
.	.
.	.
AKPROP(1,NSPPM)	NSPPM-th tabular value of conductivity for material 1. NOCD cards are required for this Card Group
Card Group 2	Format (8F10.0)
AKPROP(2,1)	1st tabular value of conductivity for material 2
AKPROP(2,2)	2nd tabular value of conductivity for material 2
.	.
.	.
.	.
AKPROP(2,NSPPM)	NSPPM-th tabular value of conductivity for material 2. NOCD cards are required for this Card Group
.	
.	
.	
Card Group NMAT	Format (8F10.0)
.	
.	
.	

Total number of cards for this card set = NMAT ≠ NOCD

Card Set 4:	This set of cards is for CAPROP(I,J)
Card Group 1	Format (8F10.0)
CAPROP(1,1)	1st tabular value of water capacity for material 1
CAPROP(1,2)	2nd tabular value of water capacity for material 1
⋮	⋮
CAPROP(1,NSPPM)	NSPPM-th tabular value of conductivity for material 1. NOCD cards are required for this Card Group
Card Group 2	Format (8F10.0)
CAPROP(2,1)	1st tabular value of water capacity for material 2
CAPROP(2,2)	2nd tabular value of water capacity for material 2
⋮	⋮
CAPROP(2,NSPPM)	NSPPM-th tabular value of water capacity for material 2. NOCD cards are required for this Card Group

⋮

Card Group NMAT	Format (8F10.0)
⋮	

Total number of cards for this card set = NMAT ≠ NOCD

Data Set 8 - Nodal Point Coordinates

Usually one card per node is needed, i.e., a total of NNP cards. However, if some nodes fall on a straight line and are equidistant, data for only the first and last points of this data set are needed. Intermediate nodal positions are automatically generated by linear interpolation.

Card 1	Format (I5, 2F10.3)
NJ	Node number
X(NJ)	X-coordinate of node NJ
Z(NJ)	Z-coordinate of node NJ
Card 2	Format (I2, 2F10.3)

.
.
.

Data Set 9 - Element incidences.

Usually one card per element is needed, i.e., a total of NEL cards. However, for a rectangular blocks of elements, it is only necessary to specify the first element, the width and length of the block. The subsequent elements to the first one in the block will be generated automatically.

Card 1	Format (16I5)
MI	Element number
IE(MI,1)	Node numbers of element MI beginning with lower left and progressing around element in counter clockwise direction
IE(MI,2)	
IE(MI,3)	
IE(MI,4)	
IE(MI,5)	Material type of element MI
MODL	Number of elements in width of a block
NLAY	Number of elements in length of a block
Card 2	Format (16I5)

⋮

Data Set 10 - Material Corrections

Usually, one card is required per material change. However, in those cases where numbers of the affected elements range from a lower limit of MI to an upper limit of MK with an increment MINC, automatic correction may be used. Fields MK and MINC are left blank if the automatic-generation facility is not used.

Card 1	Format (16I5)
MI	Material correction element number
MTYP	Type of material correction element
MK	Upper limit of automatic correction
MINC	Element Increment of automatic correction (MK = 0, MINC = 0 for no automatically generated correction)
Card 2	Format (16I5)

.
.
.

Data Set 11 - Initial or heinatial Pressure Head

The data set is necessary only if NSTRT = 0. In the most general case, one card per node is required, i.e., a total of NNT cards. Frequently, however, groups of neighboring nodal points NJ have indentical values H(NJ). All gaps will be filled with value at lower bound of the gap.

Card 1	Format (I5, 5X, F10.0)
NJ	Node number
H(NJ)	Initial head for node NJ
Card 2	Format (I5, 5X, F10.0)
NJ	Node number
H(NJ)	Initial head for node NJ

.
.
.

Card NNP

.
.
.

Data Set 12 - Steady State Integer Parameters

One card is required for one problem. It is needed if and only if KSS = 0.

Card 1	Format (16I5)
NBC	Number of constant Dirichlet nodes
NST	Number of element-sides with Neumann conditions
NRFPR	Number of rainfall profiles
NRFPAR	Number of parameters in each rainfall profile
NRSEL	Number of rainfall-seepage elements
NRSN	Number of rainfall-seepage nodes

Data Set 13 - Steady State Rainfall Profiles

These cards are necessary if and only if the number of rainfall-seepage nodes, NRSN > 0 and the number of rainfall profiles NRFPR > 0. If NRSN > 0 and NRFPR = 0, a rainfall rate of zero is assumed.

The number of cards required will depend on both NRFPR and NRFPAR, the number of parameters within each profile. NRFPR sets of cards are required. Each set consists of two groups of cards, one for the rainfall occurring time and the other for the rainfall rate. The number of cards in each group, NOCD = NRFPAR/8 + 1

Card Set 1: This set of cards if for rainfall profile 1

Card Group 1	Format (8F10.0)
TRF(1,1)	1st point of time-occurring value for rainfall profile 1
TRF(1,2)	2nd point of time-occurring value for rainfall profile 1
.	.
.	.
.	.
TRF(1,NRFPAR)	NRFPAR-th point of time-occurring value for rainfall profile 1. NOCD cards are required for this Card Group

Card Group 2	Format (8F10.0)
RF(1,1)	1st point of time-occurring value for rainfall profile 1
RF(1,2)	2nd point of time-occurring value for rainfall profile 1
.	.
.	.
.	.
RF(1,NRFPAR)	NRFPAR-th point of time-occurring value for rainfall profile 1. NOCD cards are required for this Card Group

Card Set 2:	This set of cards is for rainfall-profile 2
Card Group 1	Format (8F10.0)
TRF(2,1)	1st point of time-occurring value for rainfall profile 2
TRF(2,2)	2nd point of time-occurring value for rainfall profile 2
.	.
.	.
.	.
TRF(2,NRFPAR)	NRFPAR-th point of time-occurring value for rainfall profile 2. NOCD cards are required for this Card Group
Card Group 2	Format (8F10.0)
RF(2,1)	1st point of time-occurring value for rainfall profile 2
RF(2,2)	2nd point of time-occurring value for rainfall profile 2
.	.
.	.
.	.
RF(2,NRFPAR)	NRFPAR-th point of time-occurring value for rainfall profile 2. NOCD cards are required for this Card Group

.
.
.

Card Set NRFPR:	This set of cards is for rainfall-profile NRFPR

.
.
.

.
.
.

Total number of cards for this data set = NRFPR * (2 * NOCD)

Data Set 14 - Steady-State Rainfall types and Ponding Depth

Card input is required if and only if NRSN > 0. Typically, one card is required per rainfall - see page node.

Card I	Format (3I5, 5X, 2F10.0)
NI	Node number of rainfall-seepage node
IRFTYP(NII)	Rainfall-type parameter used to identify the rainfall profile to be used at node NI
NPINC(NII)	Automatic generation increment
HCON(NII)	Ponding depth at node NI

Note: NII is the compressed index for node number NI. If NPINC ≠ 0, automatic generation mechanism will be made. If the card immediately preceeding is for node, NJ, then nodes NJ + NPINC, NJ + 2 * NPINC, ..., NK will be given rainfall type IRFTYP(NJ) and ponding depth HCON(NJ), where NK is the largest integer in the above sequence that is less than the current nodal value NI.

Data Set 15 - Steady-state Rainfall-seepage Surface Elements

As in the previous two data set, input is necessary if and only if NRSN > 0. Typically one card is required for each side of each element on which the rainfall-seepage boundary condition is applied. However, automatic generation may be made similar to data set 14.

Card MP	Format (16I5)
NRSE(MP)	Element number of MP-th side
IS(MP,1)	Global node number of the first node of MP-th side
IS(MP,2)	Global node number of the second node of MP-th side
KINC	Automatic generation increments for NRSE and IS

<u>Data Set 16</u> - Steady-state Dirichlet Pressure-type Boundary conditions

Input cards are required for this data set if and only if NBC > 0. Normally, one card is required for each node with Dirichlet boundary condition. However, automatic generation may be made, if applicable, similar to data set 14.

Card NPP	Format (2I5, 2F10.0)
NN(NPP)	Global node number of NPP-th Dirichlet node
NPINC	Automatic generation increment
BB(NPP)	Specified pressure head at NPP-th Dirichlet node

<u>Data Set 17</u> - Steady-state Neumann flux-type Boundary Condition

Input cards for this set of data are required if and only if NST > 0. Usually a number of cards equal to NST must be used. However, automatic generation may be made, if applicable, similar to Data Set 15

Card MPP	Format (3I5, 5X, 2F10.0)
NI	First global node number of MPP-th element-side with Neumann flux-type Boundary condition
NJ	Second global node number of MPP-th element-side with Neumann flux-type Boundary condition
KINC	Automatic generation increment for NI and NJ
EI	Dot product of flux at NI with outwardly directed unit vector normal to the element side MPP
EJ	Dot product of flux at NJ with outwardly directed unit vector normal to the element side MPP

<u>Data Set 18</u>, <u>Data Set 19</u>, <u>Data Set 20</u>, <u>Data Set 21</u>, <u>Data Set 22</u>, and <u>Data Set 23</u> are for transient simulation and are identical to <u>Data Sets 12-17</u>. Those data inputs are necessary only if NTI > 0. <u>If NTI = 0</u>, there will be no transient calculation, and transient-state boundary conditions are not necessary

Note: If KSS = 0 and NTI = 0, only steady-state solution is desired. If KSS = 0 and NTI > 0, both steady-state solution and transient-state simulation are desired and the steady-state solution is used as the initial condition of transient simulation. If KSS = 1 and NTI > 0, only transient solution is desired and the initial condition for the transient simulation must be inputed. The case of KSS = 1 and NTI = 0 is physically not possible and should be avoided.

APPENDIX B
SAMPLE INPUT OF SEEPAGE POND PROBLEM

```
C
C
C ------- CARD GROUP 1  TITLE CARD
C
 1273   WATER FLOW IN SATURATED-UNSATURATED AQUIFER FROM SEEPAGE POND                    CARD 001
C
C
C ------- CARD GROUP 2  BASIC INTEGER PARAMETERS
C
  595  528    1    0    0    0    1   15    1    1    0    0   20   15    5            CARD 002
    0    0                                                                              CARD 003
C
C
C ------- CARD GROUP 3 BASIC REAL PARAMETERS
C
300.      .5        86400.    0.        0.        .01       .1        1.              CARD 004
980.6     .013      1.                                                                  CARD 005
C
C
C ------- CARD GROUP 4  PRINTER OUTPUT AND DISK STORE CONTROL
C
55                                                                                      CARD 006
11                                                                                      CARD 007
C
C
C ------- CARD GROUP 5  MATERIAL PROPERTIES
C
0.        0.        .3                  .58E-7    .58E-7                                CARD 008
C
C
C ------- CARD GROUP 6  ANALYTICAL SOIL PARAMETERS ARE NOT REQUIRED
C ------- SINCE KSP IS NOT EQUAL TO 0
C
C
C
C ------- CARD GROUP 7  SOIL PROPERTIES IN TABULAR FORM
C
C ------- PRESSURE HEAD DATA POINT
C
 -800.0    -400.     -200.     -175.     -150.     -125.     -100.     -62.5            CARD 009
 -50.0     -37.5     -25.      -12.5     0.        50.       100.      2000.            CARD 010
C
C ------- MOISTURE-CONTENT DATA POINT
C
.024      .032      .0425     .045      .050      .0525     .09       .21               CARD 011
.25       .275      .285      .290      .2925     .2975     .2995     .3                CARD 012
C
C ------- RELATIVE HYDRAULIC CONDUCTIVITY DATA POINT
C
 .10057E-5 .11886E-5 .14857E-5 .16000E-5 .18286E-5 .21715E-5 .36555E-5 .91430E-5        CARD 013
```

Appendix B (continued)

```
 .10972E-4 .12114E-4 .12572E-4 .12800E-4 .12800E-4 .13029E-4 .13257E-4 .13257E-4      CARD 014
C
C ------- WATER CAPACITY (DTH/DH) DATA POINT
C
   0.          .52E-4     .10E-3     .20E-3     .50E-3     .11E-2     .32E-2     .32E-2      CARD 015
  .20E-2      .80E-3     .40E-3     .20E-3     .10E-3     .40E-4     .25E-6     0.          CARD 016
C
C
C ------- CARD GROUP 8  NODAL POINTS POSITION
C
    1      0.0         0.0                                                                 CARD 017
    2      0.0       500.000                                                               CARD 018
    3      0.0      1000.000                                                               CARD 019
    4      0.0      1500.000                                                               CARD 020
    5      0.0      2000.000                                                               CARD 021
    6      0.0      2200.000                                                               CARD 022
    7      0.0      2400.000                                                               CARD 023
    8      0.0      2600.000                                                               CARD 024
    9      0.0      2750.000                                                               CARD 025
   10      0.0      2900.000                                                               CARD 026
   11      0.0      2950.000                                                               CARD 027
   12      0.0      3000.000                                                               CARD 028
   13    500.000       0.0                                                                 CARD 029
   14    500.000     500.000                                                               CARD 030
   15    500.000    1000.000                                                               CARD 031
   16    500.000    1500.000                                                               CARD 032
   17    500.000    2000.000                                                               CARD 033
   18    500.000    2200.000                                                               CARD 034
   19    500.000    2400.000                                                               CARD 035
   20    500.000    2600.000                                                               CARD 036
   21    500.000    2750.000                                                               CARD 037
   22    500.000    2900.000                                                               CARD 038
   23    500.000    2950.000                                                               CARD 039
   24    500.000    3000.000                                                               CARD 040
   25   1000.000       0.0                                                                 CARD 041
   26   1000.000     500.000                                                               CARD 042
   27   1000.000    1000.000                                                               CARD 043
   28   1000.000    1500.000                                                               CARD 044
   29   1000.000    2000.000                                                               CARD 045
   30   1000.000    2200.000                                                               CARD 046
   31   1000.000    2400.000                                                               CARD 047
   32   1000.000    2600.000                                                               CARD 048
   33   1000.000    2750.000                                                               CARD 049
   34   1000.000    2900.000                                                               CARD 050
   35   1000.000    2950.000                                                               CARD 051
   36   1000.000    3000.000                                                               CARD 052
   37   1500.000       0.0                                                                 CARD 053
   38   1500.000     500.000                                                               CARD 054
   39   1500.000    1000.000                                                               CARD 055
   40   1500.000    1500.000                                                               CARD 056
```

Appendix B (continued)

```
41   1500.000   2000.000                                         CARD 057
42   1500.000   2200.000                                         CARD 058
43   1500.000   2400.000                                         CARD 059
44   1500.000   2600.000                                         CARD 060
45   1500.000   2750.000                                         CARD 061
46   1500.000   2900.000                                         CARD 062
47   1500.000   2950.000                                         CARD 063
48   1500.000   3000.000                                         CARD 064
49   2000.000      0.0                                           CARD 065
50   2000.000    500.000                                         CARD 066
51   2000.000   1000.000                                         CARD 067
52   2000.000   1500.000                                         CARD 068
53   2000.000   2000.000                                         CARD 069
54   2000.000   2200.000                                         CARD 070
55   2000.000   2400.000                                         CARD 071
56   2000.000   2600.000                                         CARD 072
57   2000.000   2750.000                                         CARD 073
58   2000.000   2900.000                                         CARD 074
59   2000.000   2950.000                                         CARD 075
60   2000.000   3000.000                                         CARD 076
61   2500.000      0.0                                           CARD 077
62   2500.000    500.000                                         CARD 078
63   2500.000    1000.00                                         CARD 079
64   2500.000   1500.000                                         CARD 080
65   2500.000   2000.000                                         CARD 081
66   2500.000   2200.000                                         CARD 082
67   2500.000   2400.000                                         CARD 083
68   2500.000   2600.000                                         CARD 084
69   2500.000   2750.000                                         CARD 085
70   2500.000   2900.000                                         CARD 086
71   2500.000   2950.000                                         CARD 087
72   2500.000   3000.000                                         CARD 088
73   3000.000      0.0                                           CARD 089
74   3000.000    500.000                                         CARD 090
75   3000.000   1000.000                                         CARD 091
76   3000.000   1500.000                                         CARD 092
77   3000.000   2000.000                                         CARD 093
78   3000.000   2200.000                                         CARD 094
79   3000.000   2400.000                                         CARD 095
80   3000.000   2600.000                                         CARD 096
81   3000.000   2750.000                                         CARD 097
82   3000.000   2900.000                                         CARD 098
83   3000.000   2950.000                                         CARD 099
84   3000.000   3000.000                                         CARD 100
85   3500.000      0.0                                           CARD 101
86   3500.000    500.000                                         CARD 102
87   3500.000   1000.000                                         CARD 103
88   3500.000   1500.000                                         CARD 104
89   3500.000   2000.000                                         CARD 105
90   3500.000   2200.000                                         CARD 106
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Appendix B (continued)

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 91   3500.000   2400.000                    CARD 107
 92   3500.000   2600.000                    CARD 108
 93   3500.000   2750.000                    CARD 109
 94   3500.000   2900.000                    CARD 110
 95   3500.000   2950.000                    CARD 111
 96   3500.000   3000.000                    CARD 112
 97   4000.000      0.0                      CARD 113
 98   4000.000    500.000                    CARD 114
 99   4000.000   1000.000                    CARD 115
100   4000.000   1500.000                    CARD 116
101   4000.000   2000.000                    CARD 117
102   4000.000   2200.000                    CARD 118
103   4000.000   2400.000                    CARD 119
104   4000.000   2600.000                    CARD 120
105   4000.000   2750.000                    CARD 121
106   4000.000   2900.000                    CARD 122
107   4000.000   2950.000                    CARD 123
108   4000.000   3000.000                    CARD 124
109   4500.000      0.0                      CARD 125
110   4500.000    500.000                    CARD 126
111   4500.000   1000.000                    CARD 127
112   4500.000   1500.000                    CARD 128
113   4500.000   2000.000                    CARD 129
114   4500.000   2200.000                    CARD 130
115   4500.000   2400.000                    CARD 131
116   4500.000   2600.000                    CARD 132
117   4500.000   2750.000                    CARD 133
118   4500.000   2900.000                    CARD 134
119   4500.000   2950.000                    CARD 135
120   4500.000   3000.000                    CARD 136
121   5000.000      0.0                      CARD 137
122   5000.000    500.000                    CARD 138
123   5000.000   1000.000                    CARD 139
124   5000.000   1500.000                    CARD 140
125   5000.000   2000.000                    CARD 141
126   5000.000   2200.000                    CARD 142
127   5000.000   2400.000                    CARD 143
128   5000.000   2600.000                    CARD 144
129   5000.000   2750.000                    CARD 145
130   5000.000   2900.000                    CARD 146
131   5000.000   2950.000                    CARD 147
132   5000.000   3000.000                    CARD 148
133   5500.000      0.0                      CARD 149
134   5500.000    500.000                    CARD 150
135   5500.000   1000.000                    CARD 151
136   5500.000   1500.000                    CARD 152
137   5500.000   2000.000                    CARD 153
138   5500.000   2200.000                    CARD 154
139   5500.000   2400.000                    CARD 155
140   5500.000   2600.000                    CARD 156
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Appendix B (continued)

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141   5500.000   2750.000                                  CARD 157
142   5500.000   2900.000                                  CARD 158
143   5500.000   2950.000                                  CARD 159
144   5500.000   3000.000                                  CARD 160
145   6000.000      0.0                                    CARD 161
146   6000.000    500.000                                  CARD 162
147   6000.000   1000.000                                  CARD 163
148   6000.000   1500.000                                  CARD 164
149   6000.000   2000.000                                  CARD 165
150   6000.000   2200.000                                  CARD 166
151   6000.000   2400.000                                  CARD 167
152   6000.000   2600.000                                  CARD 168
153   6000.000   2750.000                                  CARD 169
154   6000.000   2900.000                                  CARD 170
155   6000.000   2950.000                                  CARD 171
156   6000.000   3000.000                                  CARD 172
157   6500.000      0.0                                    CARD 173
158   6500.000    500.000                                  CARD 174
159   6500.000   1000.000                                  CARD 175
160   6500.000   1500.000                                  CARD 176
161   6500.000   2000.000                                  CARD 177
162   6500.000   2200.000                                  CARD 178
163   6500.000   2400.000                                  CARD 179
164   6500.000   2600.000                                  CARD 180
165   7000.000      0.0                                    CARD 181
166   7000.000    500.000                                  CARD 182
167   7000.000   1000.000                                  CARD 183
168   7000.000   1500.000                                  CARD 184
169   7000.000   2000.000                                  CARD 185
170   7000.000   2200.000                                  CARD 186
171   7000.000   2400.000                                  CARD 187
172   7000.000   2600.000                                  CARD 188
173   7500.000      0.0                                    CARD 189
174   7500.000    500.000                                  CARD 190
175   7500.000   1000.000                                  CARD 191
176   7500.000   1500.000                                  CARD 192
177   7500.000   2000.000                                  CARD 193
178   7500.000   2200.000                                  CARD 194
179   7500.000   2400.000                                  CARD 195
180   7500.000   2600.000                                  CARD 196
181   8000.000      0.0                                    CARD 197
182   8000.000    500.000                                  CARD 198
183   8000.000   1000.000                                  CARD 199
184   8000.000   1500.000                                  CARD 200
185   8000.000   2000.000                                  CARD 201
186   8000.000   2200.000                                  CARD 202
187   8000.000   2400.000                                  CARD 203
188   8000.000   2600.000                                  CARD 204
189   8500.000      0.0                                    CARD 205
190   8500.000    500.000                                  CARD 206
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Appendix B (continued)

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191   8500.000   1000.000                                        CARD 207
192   8500.000   1500.000                                        CARD 208
193   8500.000   2000.000                                        CARD 209
194   8500.000   2200.000                                        CARD 210
195   8500.000   2400.000                                        CARD 211
196   8500.000   2600.000                                        CARD 212
197   9000.000      0.0                                          CARD 213
198   9000.000    500.000                                        CARD 214
199   9000.000   1000.000                                        CARD 215
200   9000.000   1500.000                                        CARD 216
201   9000.000   2000.000                                        CARD 217
202   9000.000   2200.000                                        CARD 218
203   9000.000   2400.000                                        CARD 219
204   9000.000   2600.000                                        CARD 220
205   9000.000   2750.000                                        CARD 221
206   9000.000   2900.000                                        CARD 222
207   9000.000   2950.000                                        CARD 223
208   9000.000   3000.000                                        CARD 224
209   9500.000      0.0                                          CARD 225
210   9500.000    500.000                                        CARD 226
211   9500.000   1000.000                                        CARD 227
212   9500.000   1500.000                                        CARD 228
213   9500.000   2000.000                                        CARD 229
214   9500.000   2200.000                                        CARD 230
215   9500.000   2400.000                                        CARD 231
216   9500.000   2600.000                                        CARD 232
217   9500.000   2750.000                                        CARD 233
218   9500.000   2900.000                                        CARD 234
219   9500.000   2950.000                                        CARD 235
220   9500.000   3000.000                                        CARD 236
221  10000.000      0.0                                          CARD 237
222  10000.000    480.000                                        CARD 238
223  10000.000    990.000                                        CARD 239
224  10000.000   1500.000                                        CARD 240
225  10000.000   1979.999                                        CARD 241
226  10000.000   2179.999                                        CARD 242
227  10000.000   2379.999                                        CARD 243
228  10000.000   2559.999                                        CARD 244
229  10000.000   2739.999                                        CARD 245
230  10000.000   2889.999                                        CARD 246
231  10000.000   2939.999                                        CARD 247
232  10000.000   2989.999                                        CARD 248
233  10500.000      0.0                                          CARD 249
234  10500.000    460.000                                        CARD 250
235  10500.000    960.000                                        CARD 251
236  10500.000   1460.000                                        CARD 252
237  10500.000   1920.000                                        CARD 253
238  10500.000   2129.999                                        CARD 254
239  10500.000   2320.000                                        CARD 255
240  10500.000   2520.000                                        CARD 256
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Appendix B (continued)

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241 10500.000   2700.000                                                    CARD 257
242 10500.000   2850.000                                                    CARD 258
243 10500.000   2900.000                                                    CARD 259
244 10500.000   2950.000                                                    CARD 260
245 11000.000      0.0                                                      CARD 261
246 11000.000    450.000                                                    CARD 262
247 11000.000    910.000                                                    CARD 263
248 11000.000   1380.000                                                    CARD 264
249 11000.000   1809.999                                                    CARD 265
250 11000.000   2020.000                                                    CARD 266
251 11000.000   2200.000                                                    CARD 267
252 11000.000   2389.999                                                    CARD 268
253 11000.000   2570.000                                                    CARD 269
254 11000.000   2750.000                                                    CARD 270
255 11000.000   2800.000                                                    CARD 271
256 11000.000   2850.000                                                    CARD 272
257 11500.000      0.0                                                      CARD 273
258 11500.000    400.000                                                    CARD 274
259 11500.000    850.000                                                    CARD 275
260 11500.000   1250.000                                                    CARD 276
261 11500.000   1659.999                                                    CARD 277
262 11500.000   1859.999                                                    CARD 278
263 11500.000   2059.999                                                    CARD 279
264 11500.000   2250.000                                                    CARD 280
265 11500.000   2439.999                                                    CARD 281
266 11500.000   2589.999                                                    CARD 282
267 11500.000   2639.999                                                    CARD 283
268 11500.000   2689.999                                                    CARD 284
269 12000.000      0.0                                                      CARD 285
270 12000.000    360.000                                                    CARD 286
271 12000.000    750.000                                                    CARD 287
272 12000.000   1100.000                                                    CARD 288
273 12000.000   1500.000                                                    CARD 289
274 12000.000   1700.000                                                    CARD 290
275 12000.000   1859.999                                                    CARD 291
276 12000.000   2020.000                                                    CARD 292
277 12000.000   2200.000                                                    CARD 293
278 12000.000   2370.000                                                    CARD 294
279 12000.000   2420.000                                                    CARD 295
280 12000.000   2470.000                                                    CARD 296
281 12500.000      0.0                                                      CARD 297
282 12500.000    300.000                                                    CARD 298
283 12500.000    650.000                                                    CARD 299
284 12500.000    950.000                                                    CARD 300
285 12500.000   1330.000                                                    CARD 301
286 12500.000   1450.000                                                    CARD 302
287 12500.000   1639.999                                                    CARD 303
288 12500.000   1759.999                                                    CARD 304
289 12500.000   1879.999                                                    CARD 305
290 12500.000   2000.000                                                    CARD 306
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Appendix B (continued)

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291 12500.000  2050.000          CARD 307
292 12500.000  2100.000          CARD 308
293 13000.000     0.0            CARD 309
294 13000.000   270.000          CARD 310
295 13000.000   570.000          CARD 311
296 13000.000   850.000          CARD 312
297 13000.000  1140.000          CARD 313
298 13000.000  1210.000          CARD 314
299 13000.000  1300.000          CARD 315
300 13000.000  1400.000          CARD 316
301 13000.000  1510.000          CARD 317
302 13000.000  1620.000          CARD 318
303 13000.000  1670.000          CARD 319
304 13000.000  1720.000          CARD 320
305 13250.000     0.0            CARD 321
306 13250.000   250.000          CARD 322
307 13250.000   530.000          CARD 323
308 13250.000   770.000          CARD 324
309 13250.000  1030.000          CARD 325
310 13250.000  1120.000          CARD 326
311 13250.000  1200.000          CARD 327
312 13250.000  1300.000          CARD 328
313 13250.000  1370.000          CARD 329
314 13250.000  1450.000          CARD 330
315 13250.000  1500.000          CARD 331
316 13250.000  1550.000          CARD 332
317 13500.000     0.0            CARD 333
318 13500.000   220.000          CARD 334
319 13500.000   460.000          CARD 335
320 13500.000   700.000          CARD 336
321 13500.000   920.000          CARD 337
322 13500.000  1010.000          CARD 338
323 13500.000  1100.000          CARD 339
324 13500.000  1180.000          CARD 340
325 13500.000  1250.000          CARD 341
326 13500.000  1300.000          CARD 342
327 13500.000  1350.000          CARD 343
328 13500.000  1400.000          CARD 344
329 13750.000     0.0            CARD 345
330 13750.000   200.000          CARD 346
331 13750.000   440.000          CARD 347
332 13750.000   650.000          CARD 348
333 13750.000   830.000          CARD 349
334 13750.000   910.000          CARD 350
335 13750.000  1000.000          CARD 351
336 13750.000  1080.000          CARD 352
337 13750.000  1140.000          CARD 353
338 13750.000  1200.000          CARD 354
339 13750.000  1250.000          CARD 355
340 13750.000  1300.000          CARD 356
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Appendix B (continued)

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341 14000.000       0.0                                                          CARD  357
342 14000.000     190.000                                                        CARD  358
343 14000.000     400.000                                                        CARD  359
344 14000.000     590.000                                                        CARD  360
345 14000.000     750.000                                                        CARD  361
346 14000.000     830.000                                                        CARD  362
347 14000.000     900.000                                                        CARD  363
348 14000.000     980.000                                                        CARD  364
349 14000.000    1050.000                                                        CARD  365
350 14000.000    1120.000                                                        CARD  366
351 14000.000    1170.000                                                        CARD  367
352 14000.000    1220.000                                                        CARD  368
353 14250.000       0.0                                                          CARD  369
354 14250.000     170.000                                                        CARD  370
355 14250.000     350.000                                                        CARD  371
356 14250.000     540.000                                                        CARD  372
357 14250.000     670.000                                                        CARD  373
358 14250.000     750.000                                                        CARD  374
359 14250.000     820.000                                                        CARD  375
360 14250.000     900.000                                                        CARD  376
361 14250.000     960.000                                                        CARD  377
362 14250.000    1050.000                                                        CARD  378
363 14250.000    1100.000                                                        CARD  379
364 14250.000    1150.000                                                        CARD  380
365 14500.000       0.0                                                          CARD  381
366 14500.000     150.000                                                        CARD  382
367 14500.000     320.000                                                        CARD  383
368 14500.000     470.000                                                        CARD  384
369 14500.000     610.000                                                        CARD  385
370 14500.000     690.000                                                        CARD  386
371 14500.000     760.000                                                        CARD  387
372 14500.000     830.000                                                        CARD  388
373 14500.000     900.000                                                        CARD  389
374 14500.000     980.000                                                        CARD  390
375 14500.000    1030.000                                                        CARD  391
376 14500.000    1080.000                                                        CARD  392
377 14750.000       0.0                                                          CARD  393
378 14750.000     140.000                                                        CARD  394
379 14750.000     270.000                                                        CARD  395
380 14750.000     430.000                                                        CARD  396
381 14750.000     560.000                                                        CARD  397
382 14750.000     630.000                                                        CARD  398
383 14750.000     700.000                                                        CARD  399
384 14750.000     760.000                                                        CARD  400
385 14750.000     840.000                                                        CARD  401
386 14750.000     910.000                                                        CARD  402
387 14750.000     960.000                                                        CARD  403
388 14750.000    1010.000                                                        CARD  404
389 15000.000       0.0                                                          CARD  405
390 15000.000     120.000                                                        CARD  406
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Appendix B (continued)

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351 15000.000    250.000                                            CARD 407
392 15000.000    390.000                                            CARD 408
393 15000.000    520.000                                            CARD 409
394 15000.000    590.000                                            CARD 410
395 15000.000    650.000                                            CARD 411
396 15000.000    720.000                                            CARD 412
397 15000.000    800.000                                            CARD 413
398 15000.000    860.000                                            CARD 414
399 15000.000    910.000                                            CARD 415
400 15000.000    960.000                                            CARD 416
401 15250.000      0.0                                              CARD 417
402 15250.000    110.000                                            CARD 418
403 15250.000    230.000                                            CARD 419
404 15250.000    370.000                                            CARD 420
405 15250.000    480.000                                            CARD 421
406 15250.000    550.000                                            CARD 422
407 15250.000    610.000                                            CARD 423
408 15250.000    680.000                                            CARD 424
409 15250.000    750.000                                            CARD 425
410 15250.000    820.000                                            CARD 426
411 15250.000    870.000                                            CARD 427
412 15250.000    920.000                                            CARD 428
413 15500.000      0.0                                              CARD 429
414 15500.000    100.000                                            CARD 430
415 15500.000    210.000                                            CARD 431
416 15500.000    330.000                                            CARD 432
417 15500.000    440.000                                            CARD 433
418 15500.000    500.000                                            CARD 434
419 15500.000    560.000                                            CARD 435
420 15500.000    640.000                                            CARD 436
421 15500.000    710.000                                            CARD 437
422 15500.000    790.000                                            CARD 438
423 15500.000    840.000                                            CARD 439
424 15500.000    890.000                                            CARD 440
425 15750.000      0.0                                              CARD 441
426 15750.000    100.000                                            CARD 442
427 15750.000    200.000                                            CARD 443
428 15750.000    300.000                                            CARD 444
429 15750.000    400.000                                            CARD 445
430 15750.000    470.000                                            CARD 446
431 15750.000    540.000                                            CARD 447
432 15750.000    610.000                                            CARD 448
433 15750.000    690.000                                            CARD 449
434 15750.000    750.000                                            CARD 450
435 15750.000    800.000                                            CARD 451
436 15750.000    850.000                                            CARD 452
437 16000.000      0.0                                              CARD 453
438 16000.000    100.000                                            CARD 454
439 16000.000    200.000                                            CARD 455
440 16000.000    290.000                                            CARD 456
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Appendix B (continued)

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441 16000.000    350.000                                   CARD 457
442 16000.000    450.000                                   CARD 458
443 16000.000    510.000                                   CARD 459
444 16000.000    550.000                                   CARD 460
445 16000.000    660.000                                   CARD 461
446 16000.000    730.000                                   CARD 462
447 16000.000    780.000                                   CARD 463
448 16000.000    830.000                                   CARD 464
449 16250.000      0.0                                     CARD 465
450 16250.000     90.000                                   CARD 466
451 16250.000    190.000                                   CARD 467
452 16250.000    280.000                                   CARD 468
453 16250.000    360.000                                   CARD 469
454 16250.000    440.000                                   CARD 470
455 16250.000    490.000                                   CARD 471
456 16250.000    560.000                                   CARD 472
457 16250.000    630.000                                   CARD 473
458 16250.000    700.000                                   CARD 474
459 16250.000    750.000                                   CARD 475
460 16250.000    800.000                                   CARD 476
461 16500.000      0.0                                     CARD 477
462 16500.000     90.000                                   CARD 478
463 16500.000    180.000                                   CARD 479
464 16500.000    270.000                                   CARD 480
465 16500.000    350.000                                   CARD 481
466 16500.000    410.000                                   CARD 482
467 16500.000    480.000                                   CARD 483
468 16500.000    540.000                                   CARD 484
469 16500.000    600.000                                   CARD 485
470 16500.000    660.000                                   CARD 486
471 16500.000    710.000                                   CARD 487
472 16500.000    760.000                                   CARD 488
473 16600.000      0.0                                     CARD 489
474 16600.000     90.000                                   CARD 490
475 16600.000    180.000                                   CARD 491
476 16600.000    270.000                                   CARD 492
477 16600.000    350.000                                   CARD 493
478 16600.000    400.000                                   CARD 494
479 16600.000    460.000                                   CARD 495
480 16600.000    520.000                                   CARD 496
481 16600.000    590.000                                   CARD 497
482 16600.000    650.000                                   CARD 498
483 16600.000    700.000                                   CARD 499
484 16600.000    750.000                                   CARD 500
485 16700.000      0.0                                     CARD 501
486 16700.000     90.000                                   CARD 502
487 16700.000    180.000                                   CARD 503
488 16700.000    260.000                                   CARD 504
489 16700.000    340.000                                   CARD 505
490 16700.000    400.000                                   CARD 506
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Appendix B (continued)

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491 16700.000    460.000                                                    CARD  507
492 16700.000    510.000                                                    CARD  508
493 16700.000    570.000                                                    CARD  509
494 16700.000    640.000                                                    CARD  510
495 16700.000    690.000                                                    CARD  511
496 16700.000    740.000                                                    CARD  512
497 16800.000      0.0                                                      CARD  513
498 16800.000     90.000                                                    CARD  514
499 16800.000    180.000                                                    CARD  515
500 16800.000    260.000                                                    CARD  516
501 16800.000    340.000                                                    CARD  517
502 16800.000    400.000                                                    CARD  518
503 16800.000    450.000                                                    CARD  519
504 16800.000    500.000                                                    CARD  520
505 16800.000    560.000                                                    CARD  521
506 16800.000    620.000                                                    CARD  522
507 16800.000    670.000                                                    CARD  523
508 16800.000    720.000                                                    CARD  524
509 16900.000      0.0                                                      CARD  525
510 16900.000     90.000                                                    CARD  526
511 16900.000    180.000                                                    CARD  527
512 16900.000    260.000                                                    CARD  528
513 16900.000    340.000                                                    CARD  529
514 16900.000    390.000                                                    CARD  530
515 16900.000    450.000                                                    CARD  531
516 16900.000    500.000                                                    CARD  532
517 16900.000    550.000                                                    CARD  533
518 16900.000    610.000                                                    CARD  534
519 16900.000    660.000                                                    CARD  535
520 16900.000    710.000                                                    CARD  536
521 17000.000      0.0                                                      CARD  537
522 17000.000     90.000                                                    CARD  538
523 17000.000    180.000                                                    CARD  539
524 17000.000    260.000                                                    CARD  540
525 17000.000    340.000                                                    CARD  541
526 17000.000    390.000                                                    CARD  542
527 17000.000    450.000                                                    CARD  543
528 17000.000    500.000                                                    CARD  544
529 17000.000    550.000                                                    CARD  545
530 17000.000    600.000                                                    CARD  546
531 17000.000    650.000                                                    CARD  547
532 17000.000    700.000                                                    CARD  548
533 17100.000      0.0                                                      CARD  549
534 17100.000     90.000                                                    CARD  550
535 17100.000    180.000                                                    CARD  551
536 17100.000    260.000                                                    CARD  552
537 17100.000    340.000                                                    CARD  553
538 17100.000    390.000                                                    CARD  554
539 17100.000    450.000                                                    CARD  555
540 17100.000    500.000                                                    CARD  556
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Appendix B (continued)

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541 17100.000     550.000                                                   CARD 557
542 17100.000     600.000                                                   CARD 558
543 17100.000     650.000                                                   CARD 559
544 17100.000     700.000                                                   CARD 560
545 17250.000       0.0                                                     CARD 561
546 17250.000      90.000                                                   CARD 562
547 17250.000     180.000                                                   CARD 563
548 17250.000     260.000                                                   CARD 564
549 17250.000     340.000                                                   CARD 565
550 17250.000     390.000                                                   CARD 566
551 17250.000     450.000                                                   CARD 567
552 17250.000     500.000                                                   CARD 568
553 17200.000     550.000                                                   CARD 569
554 17200.000     600.000                                                   CARD 570
555 17200.000     650.000                                                   CARD 571
556 17200.000     700.000                                                   CARD 572
557 17400.000       0.0                                                     CARD 573
558 17400.000      90.000                                                   CARD 574
559 17400.000     180.000                                                   CARD 575
560 17400.000     260.000                                                   CARD 576
561 17400.000     340.000                                                   CARD 577
562 17400.000     390.000                                                   CARD 578
563 17400.000     450.000                                                   CARD 579
564 17400.000     500.000                                                   CARD 580
565 17350.000     550.000                                                   CARD 581
566 17300.000     600.000                                                   CARD 582
567 17300.000     650.000                                                   CARD 583
568 17300.000     700.000                                                   CARD 584
569 17600.000       0.0                                                     CARD 585
570 17600.000      90.000                                                   CARD 586
571 17600.000     180.000                                                   CARD 587
572 17600.000     260.000                                                   CARD 588
573 17600.000     340.000                                                   CARD 589
574 17600.000     390.000                                                   CARD 590
575 17600.000     450.000                                                   CARD 591
576 17550.000     500.000                                                   CARD 592
577 17500.000     550.000                                                   CARD 593
578 17450.000     600.000                                                   CARD 594
579 17400.000     650.000                                                   CARD 595
580 17400.000     700.000                                                   CARD 596
581 17800.000       0.0                                                     CARD 597
582 17800.000      90.000                                                   CARD 598
583 17800.000     180.000                                                   CARD 599
584 17800.000     260.000                                                   CARD 600
585 17800.000     340.000                                                   CARD 601
586 17800.000     390.000                                                   CARD 602
587 17800.000     450.000                                                   CARD 603
588 17650.000     490.000                                                   CARD 604
589 18000.000       0.0                                                     CARD 605
590 18000.000      90.000                                                   CARD 606
```

```
  591 18000.000   180.000                                                   CARD 607
  592 18000.000   260.000                                                   CARD 608
  593 18000.000   340.000                                                   CARD 609
  594 18000.000   390.000                                                   CARD 610
  595 18000.000   450.000                                                   CARD 611
C
C
C -------  CARD GROUP 9  ELEMENT INCIDENCE DEFINITION
C
    1   1  13  14   2   1  11  12                                           CARD 612
  133 145 157 158 146   1                                                   CARD 613
  139 151 163 164 152   1                                                   CARD 614
  140 157 165 166 158   1   7   5                                           CARD 615
  175 197 209 210 198   1  11  31                                           CARD 616
  516 569 581 582 570   1                                                   CARD 617
  522 575 587 588 576   1                                                   CARD 618
  523 581 589 590 582   1                                                   CARD 619
  528 586 594 595 587   1                                                   CARD 620
C
C
C ------- CARD GROUP 10  MATERIAL CORRECTIONS ARE NOT REQUIRED
C -------  SINCE NCM = 0
C
C
C
C
C ------- CARD GROUP 11  CARD INPUT FOR INITIAL CONDITIONS
C
    1   0.                                                                  CARD 621
  595   0.                                                                  CARD 622
C
C
C ------- CARD GROUP 12  STEADY STATE INTEGER PARAMETERS
C
    7   6   0   0  29  29                                                   CARD 623
C
C
C ------- CARD GROUP 13  STEADY STATE RAINFALL PROFILES ARE NOT REQUIRED
C -------  SINCE NRPFR = 0
C
C
C
C
C ------- CARD GROUP 14  STEADY STATE RAINFALL TYPES AND PONDING DEPTH
C
  244           0.                                                          CARD 624
  580      12   0.                                                          CARD 625
C
C
C ------- CARD GROUP 15  STEADY STATE RAINFALL-SEEPAGE SURFACE ELEMENT-SIDES
C
  218 244 256   0                                                           CARD 626
```

Appendix B (continued)

```
   515   568   580    11                                                                                   CARD 627
   515   579   580     0                                                                                   CARD 628
C
C
C ------- CARD GROUP 16  STEADY STATE DIRICHLET -TYPE BOUNDARY CONDITIONS
C
   579             0.0                                                                                     CARD 629
   578            50.0                                                                                     CARD 630
   577           100.0                                                                                     CARD 631
   576           150.0                                                                                     CARD 632
   588           160.0                                                                                     CARD 633
   587           200.0                                                                                     CARD 634
   595           200.0                                                                                     CARD 635
C
C
C ------- CARD GROUP 17  STEADY STATE NEUMANN FLUX BOUNDARY CONDITIONS
C
   152   164     0           -4.E-4     -4.E-4                                                             CARD 636
   196   204     1           -4.E-4     -4.E-4                                                             CARD 637
C
C ------- FINIALLY A BLANK CARD TO END THE JOB
C
                                                                                                           CARD 638
```

APPENDIX C

LISTING OF FORTRAN IV SOURCE PROGRAM

APPENDIX C
LISTING OF FORTRAN IV SOURCE PROGRAM

```
C
C   THIS COMPUTER CODE IS CONTAINED IN THE FOLLOWING REPORT:
C
C   YEH, G. T. AND D. S. WARD, 1979. "FEMWATER: A FINITE-ELEMENT MODE.
C   OF WATER FLOW THROUGH SATURATED-UNSATURATED POROUS MEDIA", ORNL-5567,
C   OAK RIDGE NATIONAL LABORATORY, OAK RIDGE, TN 37830
C
C   A SLIGHTLY UPDATED VERSION IS CONTAINED IN FECWATER (ORNL/TM----)
C
C   FOR ANY QUESTION, PLEASE CONTACT DR. G. T. YEH AT (615) 574-7285
C
C   ADDITIONAL REFERENCES IS:
C
C   REEVES, M. AND J. DUGUID, 1975. "WATER MOVEMENT THROUGH SATURATED-
C   UNSATURATED POROUS MEDIA: A GALERKIN FINITE ELEMENT MODEL",
C   ORNL 4927, OAK RIDGE NATIONAL LABORATORY, OAK RIDGE,
C   TENNESSEE 37830
C
C
C ------- MAIN PROGRAM
C
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*4 PMAT,THPAR,AKPAR,SUBHD
C
      DIMENSION X(595),Z(595),IE(528,5)
C
      DIMENSION C(595,16),R(595),H(595),HP(595),HW(595),HT(595),
     > TH(528,4),DTH(528,4),VX(595),VZ(595),
     > AKX(528,4),AKZ(528,4),NPCNV(595)
C
      DIMENSION DLB(199),DCOSXB(199),DCOSZB(199),BFLX(200),BFLXP(200),
     > NBE(199),ISB(199,4),NPB(200)
C
      DIMENSION DL(99),DCOSX(99),DCOSZ(99),DCYFLX(100),FLX(100),
     > RSFLX(100),HCCN(100),NRSE(99),IS(99,4),NPRS(100),NPCON(100),
     > NPFLX(100),IRFTYP(100),TRF(3,20),RF(3,20),RFALL(3)
C
C
      DIMENSION RP(30),NPST(30), BB(40),NN(40)
C
      DIMENSION PROP(3,5),THPROP(3,52),AKPROP(3,52),HPROP(3,52),
     > CAPROP(3,52)
C
      DIMENSION PMAT(3,5),AKPAR(3,8),THPAR(3,8)
C
      DIMENSION KPR(500),KDSK(500)
C
      DIMENSION SUBHD(8,3),FRATE(10),FLOW(10),TFLOW(10)
C
      COMMON /GEOM/ SNFE,CSFE,NNP,NEL,IBAND
```

```
      COMMON /CNTRL/ NTI,MAXCY,MAXIT,NSTRT,KSTR,KPRO,KDSKO,KSS,KSP
      COMMON /TOTLNS/ TOLA,TOLB
      COMMON /PARAM/ DELT,CHNG,DELMAX,TMAX
      COMMON /BRSND/ NBEL,NBN,NRSEL,NRSN,NRFPR,NRFPAR
      COMMON /BCST/ NBC,NST,NSTN
      COMMON /MTL/ NMAT,NMPPM,NSPPM
      COMMON /OPT/ ILUMF,IMID
C
      DATA MAXEL,MAXNP,MAXHBP /528,595,16/
      DATA MAXBEL,MAXBNP /199,200/
      DATA MXRSEL,MXRSNP,MXRFPR,MXRPAR /99,100,3,20/
      DATA MXSTEL,MXSTNP,MAXBCN /29,30,40/
      DATA MAXMAT,MXSPPM,MXMPPM, NTHPPM,NAKPPM/ 3,52,5,8,3/
      DATA MAXNTI /500/
C
      DATA PMAT/4H    ,4H ALP,4H    ,4H   B,4HETAP,4H    ,4H    ,
     > 4H POR,4H    ,4H  KX ,4H    ,4H    ,4H  KZ ,4H    /
      DATA THPAR/4H    ,4H TH1,4H    ,4H    ,4H TH2,4H    ,
     > 4H  H0 ,4H    ,4H    ,4H  A1,4H    ,4H    ,4H  A2,4H    ,
     > 4H  R1,4H    ,4H    ,4H  R2,4H    ,4H    ,4H   C,4H    /
C
      DATA AKPAR/4H    ,4H  B1,4H    ,4H    ,4H  B2,4H    ,18*4H    /
C
      DATA SUBHD/4HINPU,4HT IN,4HITIA,4HL CO,4HNDIT,4HIONS,2*4H    ,
     > 4HSTEA,4HDY-S,4HTATE,4H INI,4HTIAL,4H CON,4HDITI,4HONS , 8*
     > 4H    /
C
C
C ------- INITIATE ARRAYS FOR NODAL POINTS
C
      DO 100 NP=1,MAXNP
         X(NP)=0.0
         Z(NP)=0.0
         R(NP)=0.0
         H(NP)=0.0
         HP(NP)=0.0
         HW(NP)=0.0
         HT(NP)=0.0
         VX(NP)=0.0
         VZ(NP)=0.0
         DO 100 IQ=1,MAXHBP
 100        C(NP,IQ)=0.0
C
C
C ------- INITIATE ARRAYS FOR ELEMENTS
C
      DO 150 MP=1,MAXEL
         DO 120 IQ=1,5
 120        IE(MP,IQ)=0
C
```

```
         DO 140 IQ=1.4
            TH(MP.IQ)=0.0
  140       DTH(MP.IQ)=0.0
C
  150    CONTINUE
C
C
C
C ------- INITIATE ARRAYS FOR BOUNDARY ELEMENTS
C
      DO 200 MP=1.MAXBEL
         DLB(MP)=0.0
         DCOSXB(MP)=0.0
         DCOSZB(MP)=0.0
         NBE(MP)=0
         DO 200 IQ=1.4
            ISB(MP.IQ)=0
  200    CONTINUE
C
C
C ------- INITIATE ARRAYS FOR BOUNDARY NODAL POINTS
C
      DO 250 NP=1.MAXBNF
         BFLX(NP)=0.0
         BFLXP(NP)=0.0
  250    NPB(NP)=0
C
      DO 300 MP=1.MXRSEL
         DL(MP)=0.0
         DCOSX(MP)=0.0
         DCOSZ(MP)=0.0
         NRSE(MP)=0
         DO 300 IQ=1.4
            IS(MP.IQ)=0
  300    CONTINUE
C
C
C ------- INITIATE ARRAYS FOR RAINFALL-SEEPAGE BOUNDARY NODAL POINTS
C
      DO 350 NP=1.MXRSNF
         DCYFLX(NP)=0.0
         FLX(NP)=0.0
         RSFLX(NP)=0.0
         HCON(NP)=0.0
         NPRS(NP)=0
         NPCON(NP)=0
         NPFLX(NP)=0
  350    IRFTYP(NP)=0
C
C
```

```
C ------- INITIATE ARRAYS FOR RAINFALL INFORMATION
C
      DO 360 I=1,MXRFPR
         RFALL(I)=0.0
         DO 360 J=1,MXRPAR
            TRF(I,J)=0.0
  360       RF(I,J)=0.0
C
C
C ------- INITIATE ARRAYS FOR SURFACCE TERM POINT FLUX
C
      DO 500 NP=1,MXSTNF
         NPST(NP)=0
  500    RP(NP)=0.0
C
C
C ------- INITIATE ARRAYS FOR DIRICHLENT BOUNDARY CONDITIONS
C
      DO 510 NP=1,MAXBCN
         BB(NP)=0.0
  510    NN(NP)=0
C
C
C ------- INITIATE ARRAYS FOR MATERIAL PROPERTIES
C
      DO 650 I=1,MAXMAT
         DO 610 J=1,MXMFPM
  610       PROP(I,J)=0.0
C
         DO 630 J=1,MXSFPM
            THPROP(I,J)=0.0
            AKPROP(I,J)=0.0
            HPROP(I,J)=0.0
  630       CAPROP(I,J)=0.0
C
  650    CONTINUE
C
C
C ------- INITIATE ARRAYS FOR FLOW THROUGH VARIOUS TYPES OF BOUNDARIES
C
      DO 700 I=1,10
         FRATE(I)=0.0
         FLOW(I)=0.0
  700    1FLOW(I)=0.0
C
C
C ------- PASS THE PROGRAM TO GW2DXZ
C
      CALL GW2DXZ(X,Z,IE, C,R,H,HP,HW,HT,TH,DTH,VX,VZ,AKX,AKZ,NPCNV,
     > DLB,DCOSXB,DCOSZB,BFLX,BFLXP,NBE,ISB,NPB,  DL,DCOSX,DCOSZ,
```

```
     > DCYFLX,FLX,RSFLX,HCON,NRSE,IS,NPRS,NPCON,NPFLX,IRFTYP,TRF,RF,            MAIN1005
     > RFALL,                        RP,NPST, BB,NN, PROP,THPROP,               MAIN1010
     > AKPROP,HPROP,CAPROP, MAXEL,MAXNP,MAXHBP, MAXBEL,MAXBNP, MXRSEL,          MAIN1015
     > MXRSNP,MXRFPR,MXRPAR,              MXSTEL,MXSTNP, MAXBCN,                MAIN1020
     > MAXMAT,MXMPPM,MXSPPM,NTHPPM,NAKPPM, MAXNTI,    FRATE,FLOW,TFLOW,         MAIN1025
     > PMAT,AKPAR,THPAR,SUBHD,KPR,KDSK)                                         MAIN1030
C                                                                               MAIN1035
      STOP                                                                      MAIN1040
      END                                                                       MAIN1045
```

```
      SUBROUTINE GW2DXZ(X,Z,IE, C,R,H,HP,HW,HT,TH,DTH,VX,VZ,AKX,AKZ,        GW2D 005
     > NPCNV,   DLB,DCOSXB,DCOSZB,BFLX,BFLXP,NBE,ISB,NPB,   DL,DCOSX,       GW2D 010
     > DCOSZ,DCYFLX,FLX,RSFLX,HCON,NRSE,IS,NPRS,NPCON,NPFLX,IRFTYP,TRF,     GW2D 015
     > RF,RFALL,                          RP,NPST, BB,NN, PROP,THPROP,      GW2D 020
     > AKPROP,HPROP,CAPROP, MAXEL,MAXNP,MAXHBP, MAXBEL,MAXBNP, MXRSEL,      GW2D 025
     > MXRSNP,MXRFPR,MXRPAR,              MXSTEL,MXSTNP, MAXBCN,            GW2D 030
     > MAXMAT,MXMPPM,MXSPPM,NTHPPM,NAKPPM, MAXNTI,   FRATE,FLOW,TFLOW,      GW2D 035
     > PMAT,AKPAR,THPAR,SUBHD,KPR,KDSK)                                     GW2D 040
C                                                                           GW2D 045
      IMPLICIT REAL*8(A-H,O-Z)                                              GW2D 050
      REAL*4 PMAT,THPAR,AKPAR,SUBHD                                         GW2D 055
C                                                                           GW2D 060
      DIMENSION TITLE(9)                                                    GW2D 065
      DIMENSION X(MAXNP),Z(MAXNP),IE(MAXEL,5)                               GW2D 070
C                                                                           GW2D 075
      DIMENSION C(MAXNP,MAXHBP),R(MAXNP),H(MAXNP),HP(MAXNP),HW(MAXNP),      GW2D 080
     > HT(MAXNP),TH(MAXEL,4),DTH(MAXEL,4),VX(MAXNP),VZ(MAXNP),              GW2D 085
     > AKX(MAXEL,4),AKZ(MAXEL,4),NPCNV(MAXNP)                               GW2D 090
C                                                                           GW2D 095
      DIMENSION DLB(MAXBEL),DCOSXB(MAXBEL),DCOSZB(MAXBEL),BFLX(MAXBNP),     GW2D 100
     > BFLXP(MAXBNP),NBE(MAXBEL),ISB(MAXBEL,4),NPB(MAXBNP)                  GW2D 105
C                                                                           GW2D 110
      DIMENSION DL(MXRSEL),DCOSX(MXRSEL),DCOSZ(MXRSEL),DCYFLX(MXRSNP),      GW2D 115
     > FLX(MXRSNP),RSFLX(MXRSNP),HCON(MXRSNP),NRSE(MXRSEL),IS(MXRSEL,4),    GW2D 120
     > NPRS(MXRSNP),NPCON(MXRSNP),NPFLX(MXRSNP),IRFTYP(MXRSNP),             GW2D 125
     > TRF(MXRFPR,MXRPAR),RF(MXRFPR,MXRPAR),RFALL(MXRFPR)                   GW2D 130
C                                                                           GW2D 135
      DIMENSION RP(MXSTNP),NPST(MXSTNP),BB(MAXBCN),NN(MAXBCN)               GW2D 140
C                                                                           GW2D 145
      DIMENSION PROP(MAXMAT,MXMPPM),THPROP(MAXMAT,MXSPPM),                  GW2D 150
     > AKPROP(MAXMAT,MXSPPM),HPROP(MAXMAT,MXSPPM),CAPROP(MAXMAT,MXSPPM)     GW2D 155
C                                                                           GW2D 160
      DIMENSION FRATE(10),FLOW(10),TFLOW(10)                                GW2D 165
      DIMENSION PMAT(3,MXMPPM),AKPAR(3,NAKPPM),THPAR(3,NTHPPM)              GW2D 170
      DIMENSION SUBHD(8,3)                                                  GW2D 175
      DIMENSION KPR(MAXNTI),KDSK(MAXNTI)                                    GW2D 180
C                                                                           GW2D 185
      COMMON /GEOM/ SNFE,CSFE,NNP,NEL,IBAND                                 GW2D 190
      COMMON /CNTRL/ NTI,MAXCY,MAXIT,NSTRT,KSTR,KPRO,KDSKO,KSS,KSP          GW2D 195
      COMMON /TOTLNS/ TOLA,TOLB                                             GW2D 200
      COMMON /PARAM/ DELT,CHNG,DELMAX,TMAX                                  GW2D 205
      COMMON /BRSND/ NBEL,NBN,NRSEL,NRSN,NRFPR,NRFPAR                       GW2D 210
      COMMON /BCST/ NBC,NST,NSTN                                            GW2D 215
      COMMON /MTL/ NMAT,NMPPM,NSPPM                                         GW2D 220
      COMMON /OPT/ ILUMP,IMID                                               GW2D 225
C                                                                           GW2D 230
C                                                                           GW2D 235
C   PROBLEM  IDENTIFICATION  AND  DESCRIPTION                               GW2D 240
C                                                                           GW2D 245
   10 READ 10000,NPROB, (TITLE(I),I=1,9),IBUG,ICHNG                         GW2D 250
```

```
      IF (NPROB.LE.0) GC TO 270
      PRINT 10100,NPROB,(TITLE(I),I=1,9)
C
C   READ AND PRINT INPUT DATA
C
      KOUT=0
      KSS=1
C
C
      CALL DATAIN(X,Z,IE, H,HT,TH,VX,VZ,  DLB,DCOSXB,DCOSZB,NBE,
     > ISB,NPB,  DL,DCCSX,DCOSZ,HCON,NRSE,IS,NPRS,NPCON,NPFLX,IRFTYP,
     > TRF,RF,                                 RP,NPST, BB,NN,
     > PROP,THPROP,AKPRCP,HPROP,CAPROP,  MAXEL,MAXNP,MAXHBP,
     > MAXBEL,MAXBNP, MXRSEL,MXRSNP,MXRFPR,MXRPAR,
     > MXSTEL,MXSTNP, MAXBCN, MAXMAT,MXNPPM,MXSPPM,NTHPPM,NAKPPM,
     > MAXNTI, PMAT,AKPAR,THPAR, KPR,KDSK, ISTOP,MAXDIF,W,TIME,
     > TITLE,NPROB)
C
      KDIG=NSTRT
      IF (ISTOP.GT.0) GC TO 270
C
C   COMPUTE BAND-WIDTH VARIABLES
C
      IHALFB=MAXDIF
      IBAND=2*IHALFB+1
      IHBP=IHALFB+1
      IF (IHBP.GT.MAXHBP) GO TO 260
C
C   PREPARE INITIAL VARIABLES
C
      CALL SPROP(IE, H,TH,DTH,AKX,AKZ,PROP,THPROP,AKPROP,HPROP,
     >          CAPROP, MAXEL,MAXNP, MAXMAT,MXMPPM,MXSPPM, NEL,KSP)
C
      CALL VELT(X,Z,IE, C,H,HT,VX,VZ,AKX,AKZ, MAXEL,MAXNP,MAXHBP)
C
      KFLOW=-1
C
      CALL SFLOW(X,Z,IE, H,VX,VZ, DLB,DCOSXB,DCOSZB,BFLX,BFLXP,ISB,
     > NBE,NPB, NPRS,       NPST,NN, FRATE,FLOW,TFLOW,  MAXNP,MAXEL,
     > MAXBEL,MAXBNP, MXRSNP,          MXSTNP,MAXBCN,KFLOW,DELT,DTH,H,HP,
     > PROP,MAXMAT,MXMPFM)
C
C
C   PRINT INITIAL VARIABLES
C
      KDIAG=0
C
      CALL PRINTT(VX,VZ,H,HT,TH, NPB,BFLX, NPRS,RSFLX,NPCON,NPFLX,
     > FRATE,FLOW,TFLOW, MAXNP,MAXEL, MAXBNP,MXRSNP, NNP,NEL, NBN,NRSN,
     > TIME,DELT,SUBHD(1,1),IBAND,KPRO,KOUT,KDIAG,-1)
```

```
C
      IF(KSTR.EQ.1 .AND. KSS.EQ.1 .AND. NSTRT.EQ.0 .AND. KDSKO.EQ.1)
     > CALL STORE(X.Z.IE. H.HT.TH.VX.VZ.DLB.DCOSXB.DCOSZB.NBE.ISB.NPB.
     > TITLE.TIME.MAXNP.MAXEL.MAXBNP.MAXBEL.NPROB.NNP.NEL.NBN.NBEL.NTI.
     > NPCON.NPFLX.MXRSNP.NRSN, NSTRT)
C
      IF (KSS.NE.0) GO TO 130
C
C  PERFORM STEADY-STATE CALCULATION
C
      IF (NRSN.EQ.0) GO TO 30
C
      DO 20 NPP=1.NRSN
         NPCON(NPP)=NPRS(NPP)
   20    NPFLX(NPP)=0
C
      NCHG=-1
      CALL BCPREP(IE. H.VX.VZ. DL.DCOSX.DCOSZ.DCYFLX.FLX.RSFLX.
     > HCON.NRSE.IS.NPRS.NPCON.NPFLX.IRFTYP.TRF.RF.RFALL.   MAXEL.MAXNP.
     > MXRSEL.MXRSNP.MXRFPR.MXRPAR. TIME.NCHG)
C
   30 DO 40 NP=1.NNP
   40    HP(NP)=H(NP)
C
      NIT=0
      KDIG=KDIG+1
      IF(IBUG.NE.0) PRINT 10400.KDIG.TIME.DELT
C
C
C  ITERATION LOOP ON THE SEEPAGE-RAINFALL BOUNDARY CONDITIONS BEGINS
C
      DO 100 ICY=1.MAXCY
         DO 50 NP=1.NNP
C 50        H(NP)=HP(NP)
C
C
C  ITERATION LOOP ON THE NON-LINEAR EQUATION BEGINS
C
         IF(IBUG.NE.0) PRINT 10401
         DO 80 IT=1.MAXIT
            NIT=NIT+1
C
C  EVALUATE SOIL PROPERTIES FOR PREVIOUS ITERATE
C
            CALL SPROP(IE. H.TH.DTH.AKX.AKZ. PROP.THPROP.AKPROP.HPROP.
     >            CAPROP. MAXEL.MAXNP. MAXMAT.MXMPPM.MXSPPM. NEL.KSP)
C
C  ASSEMBLE STEADY-STATE COEFFICIENT MATRICES A. B. AND C. AND CONSTRUCT
C  LOAD VECTOR R
C
            CALL ASEMBL(X.Z.IE. C.R.H.HP.TH.DTH.AKX.AKZ. PROP.
```

```
   >          MAXNP,MAXEL,MAXHBP, MAXMAT,MXMPFM, KSS,#,DELT)
C
C  APPLY STEADY-STATE BOUNDARY CONDITIONS
C
             CALL BC(C,R, FLX,HCON,NPCON,NPFLX, RP,NPST,BB,VN,
   >              MAXNP,MAXHBP, MXRSNP,MXSTNP,MAXBCN, KSS)
C
C  TRIANGULARIZE STEADY-STATE C MATRIX
C
             CALL BANSOL(1,C,R,NNP,IHBP,MAXNP,MAXHBP)
C
C  BACK-SUBSTITUTE FOR STEADY-STATE SOLUTION
C
             CALL BANSOL(2,C,R,NNP,IHBP,MAXNP,MAXHBP)
C
C  OBTAIN MAXIMUM RELATIVE DEVIATION FROM PREVIOUS ITERATE
C
             NPP=0
             RD=-1.
             RES=-1.
             DO 60 NP=1,NNP
                RESNP=DABS(R(NP)-H(NP))
                RES=DMAX1(RES,RESNP)
                IF (H(NP).NE.0.D0) RD=DMAX1(RD,DABS(RESNP/H(NP)))
                IF (RESNP.LE.TOLA) GO TO 60
                NPP=NPP+1
                NPCNV(NPP)=NP
   60           CONTINUE
C
C  UPDATE PRESSURE WITH CURRENT ITERATE
C
             NNCVN=NPP
             DO 70 NP=1,NNP
   70           H(NP)=R(NP)
C
C  ESCAPE FROM ITERATION LOOP IF THE MAXIMUM RESIDUAL IS
C  SUFFICIENTLY SMALL
C
             IF(IBUG.NE.0) PRINT 10200,NIT,RES,RD,NNCVN
             IF (IT.EQ.1) GO TO 80
             IF (RES.LT.TOLA) GO TO 90
   80        CONTINUE
C
C  END OF ITERATION LOOP ON THE NONO-LINEAR EQUATION
C
C
C
C  PRINT NONCONVERGING NODES
C
          IF(IBUG.EQ.0) GO TO 90
          PRINT 10500
```

```
          PRINT 10600,(NPCNV(NPP),NPP=1,NNCVN)
C
C
C    PRINT RAINFALL-SEEPAGE B. C. CHANGL INFORMATION
C
     90   IF(ICHNG.EQ.0) GO TO 95
          IF(NRSN.EQ.0) GO TO 95
          PRINT 10402
          DO 94 IRSN=1,NRSN
             NP=NPRS(IRSN)
             PRINT 10403,IRSN,NP,NPCON(IRSN),HCON(IRSN),NPFLX(IRSN),
       >      FLX(IRSN),DCYFLX(IRSN)
     94      CONTINUE
C
C    CALCULATE FLOW RATES
C
     95   CALL SPROP(IE, H,TH,DTH,AKX,AKZ, PROP,THPROP,AKPROP,HPROP,
       >         CAPROP, MAXEL,MAXNP, MAXMAT,MXMPPM,MXSPPM, NEL,KSP)
C
          CALL VELT(X,Z,IE, C,H,HT,VX,VZ,AKX,AKZ, MAXEL,MAXNP,MAXHBP)
C
          IF (NRSN.EQ.0) GO TO 110
C
          CALL BCPREP(IE, H,VX,VZ, DL,DCOSX,DCOSZ,DCYFLX,FLX,RSFLX,
       >   HCON,NRSE,IS,NPRS,NPCON,NPFLX,IRFTYP,TRF,RF,RFALL, MAXEL,
       >   MAXNP, MXRSEL,MXRSNP,MXRFPR,MXRPAR, TIME,NCHG)
          IF (NCHG.EQ.0) GO TO 110
    100   CONTINUE
C
C    END OF ITERATION LOOP ON THE SEEPAGE-RAINFALL BOUNDARY CONDITIONS
C
C
    110 KFLOW=-1
        CALL SFLOW(X,Z,IE, TH,VX,VZ, DLB,DCOSXB,DCOSZB,BFLX,BFLXP,IJB,
       > NBE,NPB, NPRS,       NPST,NN, FRATE,FLOW,TFLOW, MAXNP,MAXEL,
       > MAXBEL,MAXBNP, MXRSNP,          MXSTNP,MAXBCN,KFLOW,DELT,DTH,H,HP,
       > PROP,MAXMAT,MXMPPM)
C
        DO 120 I=1,6
           FLOW(I)=0.
    120    TFLOW(I)=0.
        FRATE(7)=0.
        FLOW(7)=0.
C
C
C    PRINT STEADY-STATE VARIABLES
C
        CALL PRINTT(VX,VZ,H,HT,TH, NPB,BFLX, NPRS,RSFLX,NPCON,NPFLX,
       > FRATE,FLOW,TFLOW, MAXNP,MAXEL, MAXBNP,MXRSNP, NNP,NEL, NBN,NRSN,
       > TIME,DELT,SUBHD(1,2),IBAND,KPRO,KOUT,KDIAG,0)
```

```
C
      IF(KSTR.EQ.1 .AND. KDSKO.EQ.1) CALL STORE(X,Z,IE,
     > H,HT,TH,VX,VZ,DLB,DCOSXB,DCOSZB,NBE,ISB,NPB,TITLE,TIME,MAXNP,
     > MAXEL,MAXBNP,MAXBEL,NPROB,NNP,NEL,NBN,NBEL,NTI, NPCON,NPFLX,
     > MXRSNP,NRSN, NSTRT)
      IF (NTI.EQ.0) GO TO 10
C
C  READ TRANSIENT BOUNDARY CONDITIONS
C
      CALL DATAIN(X,Z,IE, H,HT,TH,VX,VZ,  DLB,DCOSXB,DCOSZB,NBE,
     > ISB,NPB,  DL,DCOSX,DCOSZ,HCON,NRSE,IS,NPRS,NPCON,NPFLX,IRFTYP,
     > TRF,RF,                                     RP,NPST, BB,NN,
     > PROP,THPROP,AKPROP,HPROP,CAPROP, MAXEL,MAXNP,MAXHBP,
     > MAXBEL,MAXBNP, MXRSEL,MXRSNP,MXRFPR,MXRPAR,
     > MXSTEL,MXSTNP, MAXBCN, MAXMAT,MXMPPM,MXSPPM,NTHPPM,NAKPPM,
     > MAXNTI, PMAT,AKPAR,THPAR, KPR,KDSK, ISTOP,MAXDIF,W,TIME,
     > TITLE,NPROB)
C
      KSS=1
C
C  PERFORM TRANSIENT-STATE CALCULATION
C
  130 IF (NRSN.EQ.0) GO TO 160
      IF (NSTRT.GT.0) GO TO 150
C
      DO 140 NPP=1,NRSN
         NPCON(NPP)=NPRS(NPP)
  140    NPFLX(NPP)=0
C
  150 NCHG=-1
C
      CALL BCPREP(IE, H,VX,VZ, DL,DCOSX,DCOSZ,DCYFLX,FLX,RSFLX,
     > HCON,NRSE,IS,NPRS,NPCON,NPFLX,IRFTYP,TRF,RF,RFALL, MAXEL,MAXNP,
     > MXRSEL,MXRSNP,MXRFPR,MXRPAR, TIME,NCHG)
C
  160 TIME=TIME+DELT
      W1=W
      W2=1.-W
      KFLOW=1
C
C
C  BEGIN THE TIME-MARCHING LOOP
C
      DO 250 ITM=1,NTI
C
         DO 170 NP=1,NNP
  170       HP(NP)=H(NP)
C
         NIT=0
         KDIG=KDIG+1
```

```
      IF(IBUG.NE.0) PRINT 10400,KDIG,TIME,DELT
C
C  BEGIN THE ITERATION LOOP ON THE SEEPAGE-RAINFALL BOUNDARY CONDITIONS
C
      DO 230 ICY=1,MAXCY
         IF(IBUG.NE.0) PRINT 10401
C
         DO 180 NP=1,NNP
 180        HW(NP)=HP(NP)
C
C  BEGIN THE ITERATION LOOP ON THE NON-LINEAR EQUATION
C
         DO 210 IT=1,MAXIT
            NIT=NIT+1
C
C  EVALUATE SOIL PROPERTIES FOR PREVIOUS ITERATE
C
C              CALL SPROP(IE,HW,TH,DTH,AKX,AKZ, PROP,THPROP,AKPROP,
               CALL SPROP(IE,H, TH,DTH,AKX,AKZ, PROP,THPROP,AKPROP,
     >          HPROP,CAPROP,MAXEL,MAXNP,MAXMAT,MXMPPM,MXSPPM,NEL,KSS)
C
C  ASSEMBLE COEFFICIENT MATRICES A, B, AND C, AND CONSTRUCT LOAD
C  VECTOR R
C
               CALL ASEMBL(X,Z,IE, C,R,H,HP,TH,DTH,AKX,AKZ, PROP,
     >          MAXNP,MAXEL,MAXHBP, MAXMAT,MXMPPM, KSS,W,DELT)
C
C  APPLY BOUNDARY CONDITIONS
C
               CALL BC(C,R, FLX,HCON,NPCON,NPFLX, RP,NPST, BB,NN,
     >              MAXNP,MAXHBP, MXRSNP,MXSTNP,MAXBCN, KSS)
C
C  TRIANGULARIZE C MATRIX
C
               CALL BANSOL(1,C,R,NNP,IHBP,MAXNP,MAXHBP)
C
C  BACK-SUBSTITUTE
C
               CALL BANSOL(2,C,R,NNP,IHBP,MAXNP,MAXHBP)
C
C  OBTAIN MAXIMUM RELATIVE DEVIATION FROM PREVIOUS ITERATE
C
               NPP=0
               RD=-1.
               RES=-1.
               DO 190 NP=1,NNP
                  RESNP=DABS(R(NP)-H(NP))
                  RES=DMAX1(RES,RESNP)
                  IF (H(NP).NE.0.D0) RD=DMAX1(RD,DABS(RESNP/H(NP)))
                  IF (RESNP.LE.TOLB) GO TO 190
```

```
                  NPP=NFP+1
                  NPCNV(NPP)=NP
 190              CCNTINUE
C
               NNCVN=NPF
C
C  UPDATE PRESSLRE WITH CURRENT ITERATE
C
               DO 200 NP=1,NNP
                  H(NP)=R(NP)
 200              HW(NP)=W1*H(NP)+W2*HP(NP)
C
C  ESCAPE FROM ITERATICN LOOP IF THE MAXIMUM RESIDJAL IS
C  SUFFICIENTLY SMALL
C
               IF(IBUG.NE.0) PRINT 10200,NIT,RES,RD,NNCVN
               IF (IT.EQ.1.AND.ITN.EQ.1) GO TO 210
               IF (RES.LT.TOLB) GO TO 220
 210           CONTINUE
C
C  END THE ITERATION LCCP ON THE NON-LINEAR EQUATION
C
            IF(IBUG.EQ.0) GO TO 220
C
C  PRINT NONCONVERGING NODES
C
            PRINT 10500
            PRINT 10600,(NPCNV(NPP),NPP=1,NNCVN)
C
C  PRINT RAINFALL-SEEPAGE BOUNDARY CONDITION CHANGE INFORMATION
C
 220        IF(ICHNG.EQ.0) GO TO 225
            IF(NRSN.EQ.0) GC TO 225
            PRINT 10402
            DC 224 IRSN=1,NRSN
               NP=NPRS(IRSN)
               PRINT 10403,IRSN,NP,NPCON(IRSN),HCON(IRSN),NPFLX(IRSN),
     >          FLX(IRSN),DCYFLX(IRSN)
 224           CONTINUE
C
C  CALCULATE FLOW RATES
C
 225        CALL SPROP(IE, H,TH,DTH,AKX,AKZ, PROP,THPROP,AKPROP,HPROP,
     >          CAPROP,MAXEL,MAXNP,MAXMAT,MXMPPM,MXSPPM,NEL,KSP)
C
            CALL VELT(X,Z,IE, C,H,HT,VX,VZ,AKX,AKZ, MAXEL,MAXNP,MAXHBP)
C
            IF (NRSN.EC.0) GO TO 240
C
            CALL BCPREP(IE, H,VX,VZ, DL,DCOSX,DCOSZ,DCYFLX,FLX,RSF_X,
```

```
     >        HCON,NRSE,IS,NPRS,NPCON,NPFLX,IRFTYP,TRF,RF,RFALL, MAXEL,
     >        MAXNP, MXRSEL,MXRSNP,MXRFPR,MXRPAR, TIME,NCHG)
             IF (NCHG.EQ.0) GO TO 240
  230        CONTINUE
C
C  END THE ITERATION LOOP ON THE SEEPAGE-RAINFALL BOUNDARY CONDITIONS
C
C
  240     IF(IMID.EQ.0) GO TO 245
          DO 243 I=1,NNP
  243     H(I)=2.0D0*H(I) - HP(I)
C
          DO 244 I=1,NBC
          NI=NN(I)
  244     H(NI)=BB(I)
C
  245     CALL SFLOW(X,Z,IE, TH,VX,VZ, DLB,DCOSXB,DCOSZB,BFLX,BFLXP, ISB,
     > NBE,NPB, NPRS,     NPST,NN, FRATE,FLOW,TFLOW, MAXNP,MAXEL,
     > MAXBEL,MAXBNP, MXRSNP,        MXSTNP,MAXBCN,KFLOW,DELT,DTH,H, HP,
     > PROP,MAXMAT,MXMPPM)
C
C  PRINT VARIABLES AT EACH TIME STEP
C
       CALL PRINTT(VX,VZ,H,HT,TH, NPB,BFLX, NPRS,RSFLX,NPCON,NPFLX,
     > FRATE,FLOW,TFLOW, MAXNP,MAXEL, MAXBNP,MXRSNP, NNP,NEL, NBN,NRSN,
     > TIME,DELT,SUBHD(1,3),IBAND,KPR(ITM),KOUT,KDIAG,ITM)
C
       IF(KSTR.EQ.1 .AND.KDSK(ITM).EQ.1) CALL STORE(X,Z,IE,H,HT,TH,VX,VZ,
     >    DLB,DCOSXB,DCOSZB,NBE,ISB,NPB,TITLE,TIME,MAXNP,MAXEL,MAXBNP,
     >    MAXBEL,NPROB,NNP,NEL,NBN,NDEL,NTI, NPCON,NPFLX,MXRSNP,NRSN,
     >    NSTRT)
C
C  PREPARE FOR NEXT TIME STEP
C
          IF (TIME.GT.TMAX) GO TO 10
          DELT=DELT*(1.+CHNG)
          DELT=DMIN1(DELT,DELMAX)
          TIME=TIME+DELT
  250     CONTINUE
C
C  END OF TIME-MARCHING LOOP
C
C
       GO TO 10
  260 PRINT 10300,IHBP,MAXHBP
C
  270 RETURN
C
10000 FORMAT(I5,9A8,1X,2I1)
10100 FORMAT(/8H1PROBLEM,I5,3H.. ,9A8/)
```

Appendix C (continued)

```
10200 FORMAT(5X,I10,3X,E12.4,3X,E12.4,15X,I10)                          GW2D2255
10300 FORMAT(///26H HALF-BANDWIDTH-PLUS-ONE =,I4,                       GW2D2260
     > 25H EXCEEDS MAX. ALLOWABLE =,I4)                                 GW2D2265
10400 FORMAT(1H1,52H****************************************************GW2D2270
     ` 62H**************************************************************GW2D2275
     > 5H*****///17H DIAGNOSTIC TABLE,I4,12H.. AT TIME =,1PD12.4,       GW2D2280
     > 9H .(DELT = 1PD12.4,1H))                                         GW2D2285
10401 FORMAT(///30H TABLE OF ITERATIVE PARAMETERS// 5X,                 GW2D2290
     > 9HITERATION,7X,8HRESIDUAL,6X,9HDEVIATION,6X,                     GW2D2295
     > 19HNO. NON-CONV. NODES)                                          GW2D2300
10402 FORMAT(//44H TABLE OF RAINFALL-SEEPAGE B. C. INFORMATION,/ 5X,    GW2D2305
     > 87HIRSN   NPRS(IRSN)     NPCON(IRSN)    HCON(NPRS)     NPF_X(IRSN)GW2D2310
     > FLX(NPRS)    DCYFLX(NPRS))                                       GW2D2315
10403 FORMAT(1H ,I10,I13,I15,E13.4,I15,E13.3,E15.3)                     GW2D2320
10500 FORMAT(//30H TABLE OF NON-CONVERGING NODES)                       GW2D2325
10600 FORMAT(/(5X,20I5))                                                GW2D2330
      END                                                               GW2D2335
```

```
      SUBROUTINE DATAIN(X,Z,IE, H.HT.TH.VX.VZ, DLB,DCOSXB,DCOSZB,NBE,
     > ISB,NPB,  DL,DCOSX,DCOSZ,HCON,NRSE,IS,NPRS,NPCON,NPFLX,IRFTYP,
     > TRF,RF,                              RP,NPST, BB,NN,
     > PROP,THPROP,AKPROP,HPROP,CAPROP, MAXEL,MAXNP,MAXHBP,
     > MAXBEL,MAXBNP, MXRSEL,MXRSNP,MXRFPR,MXRPAR,
     > MXSTEL,MXSTNP, MAXBCN, MAXMAT,MXMPPM,MXSPPM,NTHPPM,NAKPPM,
     > MAXNTI, PMAT,AKPAR,THPAR, KPR,KDSK, ISTOP,MAXDIF,W,TIME,
     >TITLE,NPROB)
C
C
C   FUNCTION OF SUBROUTINE--TO READ, PRINT, AND CHECK VARIABLES
C   PERTAINING TO SIMULATION TIME, GEOMETRY OF THE SYSTEM, ITS SOIL
C   PROPERTIES, BOUNDARY-INITIAL CONDITIONS FOR BOTH STEADY-STATE AND
C   TRANSIENT CASES, AND NUMERICAL CONVERGENCE CRITERIA.
C
C
C
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*4 PMAT,THPAR,AKPAR
C
      DIMENSION TITLE(S)
      DIMENSION X(MAXNP),Z(MAXNP),IE(MAXEL,5)
C
      DIMENSION H(MAXNP),HT(MAXNP),TH(MAXEL,4),VX(MAXNP),VZ(MAXNP)
C
      DIMENSION DLB(MAXBEL),DCOSXB(MAXBEL),DCOSZB(MAXBEL),NBE(MAXBEL),
     > ISB(MAXBEL,4),NPB(MAXBNP)
C
      DIMENSION DL(MXRSEL),DCOSX(MXRSEL),DCOSZ(MXRSEL),HCON(MXRSNP),
     > NRSE(MXRSEL),IS(MXRSEL,4),NPRS(MXRSNP),NPCON(MXRSNP),
     > NPFLX(MXRSNP),IRFTYP(MXRSNP),TRF(MXRFPR,MXRPAR),
     > RF(MXRFPR,MXRPAR)
C
      DIMENSION RP(MXSTNP),NPST(MXSTNP),BB(MAXBCN),NN(MAXBCN)
      DIMENSION PROP(MAXMAT,MXMPPM),THPROP(MAXMAT,MXSPPM),
     > AKPROP(MAXMAT,MXSPPM),HPROP(MAXMAT,MXSPPM),CAPROP(MAXMAT,MXSPPM)
C
      DIMENSION PMAT(3,MXMPPM),AKPAR(3,NAKPPM),THPAR(3,NTHPPM)
      DIMENSION KPR(MAXNTI),KDSK(MAXNTI)
C
      COMMON /GEOM/ SNFE,CSFE,NNP,NEL,IBAND
      COMMON /CNTRL/ NTI,MAXCY,MAXIT,NSTRT,KSTR,KPRO,KDSKO,KSS,KSP
      COMMON /TOTLNS/ TCLA,TOLE
      COMMON /PARAM/ DELT,CHNG,DELMAX,TMAX
      COMMON /BRSND/ NBEL,NBN,NRSEL,NRSN,NRFPR,NRFPAR
      COMMON /BCST/ NBC,NST,NSTN
      COMMON /MTL/ NMAT,NMPPM,NSPPM
      COMMON /CPT/ ILUMP,IMID
C
      IF (KSS.EQ.0) GO TO 505
```

Appendix C (continued)

```
      ISTOP=0
C
      READ 12000,NNP,NEL,NMAT,NCM,NTI,KSS,KSP,NSPPM,KSTR,KCP,KGRAV,
     >           NSTRT,MAXIT,MAXCY,NMPPM
      READ 12000, ILUMP,IMID
      READ 12300, DELT,CHNG,DELMAX,TMAX,FE,TOLA,TOLB,RHO,GRAV,VISC,W
      READ 12100,KPR0,(KPR(ITM),ITM=1,NTI)
      READ 12100, KDSK0,(KDSK(ITM),ITM=1,NTI)
C
      IF(TMAX.LE.0.0) TMAX=1.0E50
C
      PRINT 10000,NNP,NEL,NMAT,NCM,NTI,KSS,KSP,NSPPM,KSTR,KCP,KGRAV,
     > NSTRT,MAXIT,MAXCY
      PRINT 10001, ILUMP,IMID
      PRINT 10100,DELT,CHNG,DELMAX,TMAX,FE,TOLA,TOLB,RHO,GRAV,VISC,W
      PRINT 10200
      PRINT 12200,KPR0,(KPR(ITM),ITM=1,NTI)
      PRINT 10201
      PRINT 12200, KDSK0,(KDSK(ITM),ITM=1,NTI)
C
      PI=3.14159265
      FE=FE*PI/180.
      SNFE=DSIN(FE)
      CSFE=DCOS(FE)
      IF (KGRAV.EQ.1) SNFE=0.
      IF (KGRAV.EQ.1) CSFE=0.
C
C
C  READ AND PRINT MATERIAL PROPERTIES
C
   70 IF (NMPPM.LE.0) GO TO 90
      IF (NMAT.LE.0) GO TO 90
      PRINT 10300,((PMAT(I,J),I=1,3),J=1,NMPPM)
      DO 80 I=1,NMAT
         READ 12300,(PROP(I,J),J=1,NMPPM)
   80    PRINT 12500,I,(PROP(I,J),J=1,NMPPM)
   90 IF (KSP.EQ.1) GO TO 120
C
C
C  SOIL PROPERTIES ARE TO BE REPRESENTED BY ANALYTIC FUNCTIONS
C
C
C
C  READ AND PRINT MOISTURE-CONTENT PARAMETERS
C
      IF (NSPPM.EQ.0) GO TO 200
      PRINT 10500,((THPAR(I,J),I=1,3),J=1,NSPPM)
      DO 100 I=1,NMAT
         READ 12300, (THPROP(I,J),J=1,NSPPM)
         PRINT 12700, I,(THPROP(I,J),J=1,NSPPM)
  100    CONTINUE
```

```
C
C  READ AND PRINT CONDUCTIVITY PARAMETERS
C
      PRINT 10600,((AKPAR(I,J),I=1,3),J=1,NSPPM)
      DO 110 I=1,NMAT
         READ 12300, (AKPROP(I,J),J=1,NSPPM)
         PRINT 12700, I,(AKPROP(I,J),J=1,NSPPM)
  110    CONTINUE
      GO TO 200
  120 IF (NSPPM.EQ.0) GO TO 200
C
C  SOIL PROPERTIES ARE TO BE GIVEN IN TABULAR FORM
C
C
C  READ PRESSURES
C
      DO 130 I=1,NMAT
         READ 12300, (HPROP(I,J),J=1,NSPPM)
  130    CONTINUE
C
C  READ WATER CONTENTS
C
      DO 140 I=1,NMAT
         READ 12300, (THPROP(I,J),J=1,NSPPM)
  140    CONTINUE
C
C  READ CONDUCTIVITIES OR PERMEABILITIES
C
      DO 150 I=1,NMAT
         READ 12300, (AKPROP(I,J),J=1,NSPPM)
  150    CONTINUE
C
C  READ WATER CAPACITIES
C
      DO 160 I=1,NMAT
         READ 12300, (CAPROP(I,J),J=1,NSPPM)
  160    CONTINUE
      PRINT 10400
      DO 170 I=1,NMAT
         PRINT 12600,I,(HPROP(I,J),THPROP(I,J),AKPROP(I,J),CAPROP(I,J),
     >     J=1,NSPPM)
  170    CONTINUE
      IF (KCP.EQ.0) GO TO 200
C
C  CONVERT FROM PERMEABILITY TO CONDUCTIVITY IF NECESSARY
C
      DO 190 I=1,NMAT
         PKCF=RHO*GRAV/VISC
         PROP(I,4)=PROP(I,4)*PKCF
         PROP(I,5)=PROP(I,5)*PKCF
```

Appendix C (continued)

```
         DO 180 J=1,NSPPM
  180       AKPROP(I,J)=AKPROP(I,J)*PKCF
  190    CONTINUE
C
C  READ AND PRINT NODAL-POINT DATA
C
  200 NI=1
  210 READ 12800, NJ,X(NJ),Z(NJ)
      IF (NJ-NI) 220,250,230
  220 PRINT 15100, NJ
      PRINT 12900, NJ,X(NJ),Z(NJ)
      ISTOP=ISTOP+1
      GO TO 210
  230 DF=NJ+1-NI
      DX=(X(NJ)-X(NI-1))/DF
      DZ=(Z(NJ)-Z(NI-1))/DF
  240 CONTINUE
      X(NI)=X(NI-1)+DX
      Z(NI)=Z(NI-1)+DZ
  250 NI=NI+1
      IF (NJ-NI) 260,250,240
  260 IF (NI.LE.NNP) GO TO 210
      PRINT 10700
      KLINE=0
C
      DO 265 NI=1,NNP,4
         NJMN=NI
         NJMX=MIN0(NI+3,NNP)
         PRINT 12900,(NJ,X(NJ),Z(NJ),NJ=NJMN,NJMX)
         KLINE=KLINE+1
  265 IF(MOD(KLINE,50).EQ.0) PRINT 10700
C
C
C  READ AND PRINT ELEMENT DATA
C
C  ALSO COMPUTE MAXIMUM NODAL DIFFERENCE FOR EACH ELEMENT
C
      PRINT 10800
      KLINE=0
      MAXDIF = 0
      MJ = 0
  270 READ 12000, MI,(IE(MI,I),I=1,5),MODL,NLAY
      MTYP=IE(MI,5)
      MND = 0
      DO 280 IQ=1,3
         IQ1 = IQ + 1
         DO 280 JQ=IQ1,4
            ND = IABS(IE(MI,IQ)-IE(MI,JQ))
            MND = MAX0(ND,MND)
  280       MAXDIF = MAX0(ND,MAXDIF)
```

```
250 MJ = MJ + 1                                                         DATA1005
    IF (MI-MJ) 300.330.310                                              DATA1010
300 PRINT 15200. MI                                                     DATA1015
    PRINT 13000. MI.(IE(MI.I).I=1.5).MND                                DATA1020
    ISTOP = ISTOP + 1                                                   DATA1025
310 DO 320 IQ=1.4                                                       DATA1030
320    IE(MJ.IQ) = IE(MJ-1.IQ) + 1                                      DATA1035
    IE(MJ.5) = IE(MJ-1.5)                                               DATA1040
330 PRINT 13000. MJ.(IE(MJ.I).I=1.5).MND                                DATA1045
    IF (MJ.LT.MI) GO TO 290                                             DATA1050
    IF (MJ.EQ.NEL) GC TO 370                                            DATA1055
    IF (MODL.LE.0) GC TO 270                                            DATA1060
    DO 360 I=1.NLAY                                                     DATA1065
       LL=2                                                             DATA1070
       DO 360 J=1.MODL                                                  DATA1075
          IF (MJ.EQ.MI) GO TO 350                                       DATA1080
          DO 340 KQ=1.4                                                 DATA1085
340             IE(MJ.KQ)    IE(MJ-1.KQ) + LL                           DATA1090
          IE(MJ.5)=IE(MJ-1.5)                                           DATA1095
          PRINT 13000. MJ.(IE(MJ.K).K=1.5).MND                          DATA1100
          KLINE=KLINE+1                                                 DATA1105
          IF(MOD(KLINE.50).EQ.0) PRINT 10800                            DATA1110
350       LL = 1                                                        DATA1115
360       MJ = MJ + 1                                                   DATA1120
    MJ = MJ - 1                                                         DATA1125
    IF (MJ.LT.NEL) GC TO 270                                            DATA1130
370 CONTINUE                                                            DATA1135
C                                                                       DATA1140
C  MODIFY MATERIAL TYPES FOR SELECTED ELEMENTS IF NECESSARY             DATA1145
C                                                                       DATA1150
    IF (NCM.LE.0) GO TO 410                                             DATA1155
    PRINT 10900                                                         DATA1160
    L=0                                                                 DATA1165
380 READ 12000. MI.MTYP.MK.MINC                                         DATA1170
    IE(MI.5) = MTYP                                                     DATA1175
    PRINT 13100. MI.IE(MI.5)                                            DATA1180
    L = L + 1                                                           DATA1185
    IF (MK.LE.MI) GO TO 400                                             DATA1190
    IF (MINC.LE.0) MINC = 1                                             DATA1195
    MI = MI + MINC                                                      DATA1200
    DO 390 MJ=MI.MK.MINC                                                DATA1205
       IE(MJ.5) = MTYP                                                  DATA1210
       PRINT 13100. MJ.IE(MJ.5)                                         DATA1215
390    L = L + 1                                                        DATA1220
400 IF (L.LT.NCM) GO TO 380                                             DATA1225
410 CONTINUE                                                            DATA1230
    DO 420 M=1.NEL                                                      DATA1235
       MTYP=IE(M.5)                                                     DATA1240
       IF (MTYP.GT.0.AND.MTYP.LE.NMAT) GO TO                            DATA1245
       PRINT 15900.M                                                    DATA1250
```

```
         ISTOP=ISTOP+1
  420    CONTINUE
      IF(ISTOP.EQ.0) GO TO 430
      PRINT 15000, ISTOP
      STOP
C
C  READ INITIAL CONDITIONS
C
  430 TIME=0.0D0
      IF (NSTRT.EQ.0) GO TO 450
      REWIND 1
      REWIND 2
      READ(2) (DUM,I=1,9),IDUM,NPT,NET,NBN,NBEL,IDJM,NRSN
      IF (KSTR.EQ.1) WRITE(1) (TITLE(I),I=1,9),NPROB,NNP,NEL,NBN,NBEL,
     > NTI,NRSN
      READ(2) (X(NP),NP=1,NPT),(Z(NP),NP=1,NPT),((IE(M,IQ),M=1,NET),IQ=
     > 1,4),(DLB(M),M=1,NBEL),(DCOSXB(M),M=1,NBEL),
     > (DCOSZB(M),M=1,NBEL),(NBE(M),M=1,NBEL),((ISB(M,IQ),M=1,NBEL),IQ=
     > 1,4),(NPB(NP),NP=1,NBN)
      IF (KSTR.EQ.1) WRITE(1) (X(NP),NP=1,NNP),(Z(NP),NP=1,NNP), ((IE(M,
     > IQ),M=1,NEL),IQ=1,4),(DLB(M),M=1,NBEL),(DCOSXB(M),M=1,NBEL),
     > (DCOSZB(M),M=1,NBEL),(NBE(M),M=1,NBEL),((ISB(M,IQ),M=1,NBEL),IQ=
     > 1,4),(NPB(NP),NP=1,NBN)
      DO 440 ITM=1,NSTRT
         READ(2) TIME,(H(NP),NP=1,NPT),(HT(NP),NP=1,NPT),((TH(M,IQ),M=1,
     >      NET),IQ=1,4),(VX(NP),NP=1,NPT),(VZ(NP),NP=1,NPT),
     >               (NPCON(NP),NP=1,NRSN),(NPFLX(NP),NP=1,NRSN)
         IF (KSTR.EQ.0) GO TO 440
         WRITE(1) TIME,(H(NP),NP=1,NNP),(HT(NP),NP=1,NNP),((TH(M,IQ),M=
     >     1,NEL),IQ=1,4),(VX(NP),NP=1,NNP),(VZ(NP),NP=1,NNP),
     >     (NPCON(NP),NP=1,NRSN),(NPFLX(NP),NP=1,NRSN)
  440    CONTINUE
      GO TO 500
  450 NI = 0
      NJ = 0
  460 IF (NJ.EQ.NNP) GO TO 500
      READ 13600,NJ,H(NJ)
  470 NI = NI + 1
      IF (NI.GT.1) GO TO 480
      IF (NJ.EQ.1) GO TO 480
      PRINT 15300,NJ
      ISTOP=ISTOP+1
      GO TO 500
  480 IF (NJ.EQ.NI) GO TO 460
      IF (NJ.GT.NI) GO TO 490
      PRINT 15300,NJ
      ISTOP=ISTOP+1
      GO TO 500
  490 H(NI)=H(NI-1)
      GO TO 470
```

```
C
C  IDENTIFY BOUNDARY ELEMENTS AND COMPUTE DIRECTION COSINES OF
C  BOUNDARY SIDES
C
  500 CALL SURF(X.Z.IE, DLB.DCOSXB.DCOSZB.NBE,ISB,NPB,
     > MAXNP.MAXEL. MAXBEL.MAXBNP)
      IF(KSS.EQ.1) GO TO 505
      NRSN=0
C
C  READ  STEADY STATE OR TRANSIENT PARAMETERS
C
  505 READ 12000.NBC.NST.NRFPR.NRFPAR.NRSEL.NRSN
C
      PRINT 11000.NBC.NST.NRFPR.NRFPAR.NRSEL.NRSN
C
C
C  READ AND PRINT STEADY STATE OR TRANSIENT RAINFALL-SEEPAGE INFORMAT.
C
  570 IF (NRSN.EQ.0) GO TO 800
C
C  STEADY STATE OR TRANSIENT RAINFALL PROFILES
C
      IF (NRFPR.EQ.0) GO TO 590
      PRINT 11400
      DO 580 I=1.NRFPR
         READ 12300.(TRF(I.J).J=1.NRFPAR)
         READ 12300.(RF(I.J).J=1.NRFPAR)
         PRINT 11500.I
         DO 580 J=1.NRFPAR
  580       PRINT 12400.(TRF(I.J).RF(I.J))
C
C  STEADY STATE OR TRANSIENT RAINFALL TYPES AND PONDING DEPTH
C
  590 CONTINUE
      NPP=0
  610 IF (NPP.EQ.NRSN) GO TO 670
      IF (NPP.LT.NRSN) GO TO 620
      PRINT 14800.NRSN
      ISTOP=ISTOP+1
      GO TO 670
  620 READ 13400.NI.ITYP.NPINC.HCONI
      IF (NPINC.GT.0) GO TO 640
  630 NPP=NPP+1
      NPRS(NPP)=NI
      IRFTYP(NPP)=ITYP
      HCON(NPP)=HCONI
      GO TO 610
  640 IF (NPP.GT.0) GO TO 650
      ISTOP=ISTOP+1
      PRINT 15500
```

```
  650 NJ=NPRS(NPP)                                                      DATA1755
      JTYP=IRFTYP(NPP)                                                  DATA1760
      HCONJ=HCON(NPP)                                                   DATA1765
      NJ=NJ+NPINC                                                       DATA1770
      NK=NI-1                                                           DATA1775
      DO 660 NP=NJ.NK.NPINC                                             DATA1780
          NPP=NPP+1                                                     DATA1785
          NPRS(NPP)=NP                                                  DATA1790
          IRFTYP(NPP)=JTYP                                              DATA1795
  660     HCON(NPP)=HCONJ                                               DATA1800
      GO TO 630                                                         DATA1805
  670 PRINT 11600                                                       DATA1810
      DO 680 NPP=1.NRSN                                                 DATA1815
          NP=NPRS(NPP)                                                  DATA1820
  680     PRINT 13500.NP.IRFTYP(NPP).HCON(NPP)                          DATA1825
C                                                                       DATA1830
C    STEADY STATE OR TRANSIENT RAINFALL-SEEPAGE ELEMENT SURFACE INFORMAT.DATA1835
C                                                                       DATA1840
      MPI=0                                                             DATA1845
  690 IF (MPI.EQ.NRSEL) GO TO 740                                       DATA1850
      READ 12000.MI.IS1.IS2.KINC                                        DATA1855
      IF (KINC.GT.0) GO TO 710                                          DATA1860
  700 MPI=MPI+1                                                         DATA1865
      NRSE(MPI)=MI                                                      DATA1870
      IS(MPI.1)=IS1                                                     DATA1875
      IS(MPI.2)=IS2                                                     DATA1880
      GO TO 690                                                         DATA1885
  710 IF (MPI.GT.0) GO TO 720                                           DATA1890
      ISTOP=ISTOP+1                                                     DATA1895
      PRINT 15000                                                       DATA1900
  720 NPINC=IS(MPI.2)-IS(MPI.1)                                         DATA1905
      MINC=IABS(NPINC)-1                                                DATA1910
      MINC=MAX0(MINC.1)                                                 DATA1915
      MJ=NRSE(MPI)+MINC                                                 DATA1920
      MK=MI-1                                                           DATA1925
      DO 730 M=MJ.MK.MINC                                               DATA1930
          MPJ=MPI                                                       DATA1935
          MPI=MPI+1                                                     DATA1940
          NRSE(MPI)=M                                                   DATA1945
          IS(MPI.1)=IS(MPJ.1)+NPINC                                     DATA1950
  730     IS(MPI.2)=IS(MPJ.2)+NPINC                                     DATA1955
      GO TO 700                                                         DATA1960
  740 PRINT 11700                                                       DATA1965
      DO 750 MP=1.NRSEL                                                 DATA1970
          M=NRSE(MP)                                                    DATA1975
  750     PRINT 13000.M.IS(MP,1).IS(MP.2)                               DATA1980
C                                                                       DATA1985
C   DETERMINE DIRECTION COSINES FOR STEADY STATE OR TRANSIENT           DATA1990
C   RAINFALL-SEEPAGE SURFACES                                           DATA1995
C                                                                       DATA2000
```

Appendix C (continued)

```
      DO 790 MPI=1,NRSEL
         MI=NRSE(MPI)
         DO 780 MPJ=1,NBEL
            MJ=NBE(MPJ)
            IF (MJ.NE.MI) GO TO 780
            IF (ISB(MPJ,1).EQ.IS(MPI,1).AND.ISB(MPJ,2).EQ.IS(MPI,2)) GO
     >        TO 760
            IF (ISB(MPJ,1).EQ.IS(MPI,2).AND.ISB(MPJ,2).EQ.IS(MPI,1)) GO
     >        TO 760
            GO TO 780
  760       DO 770 J=1,4
  770          IS(MPI,J)=ISB(MPJ,J)
            DL(MPI)=DLB(MPJ)
            DCOSX(MPI)=DCOSXB(MPJ)
            DCOSZ(MPI)=DCOSZB(MPJ)
            GO TO 790
  780       CONTINUE
         ISTOP=ISTOP+1
         PRINT 14900,MI
  790    CONTINUE
  800 DO 810 NP=1,MAXBCN
  810    RP(NP)=0.
      IF (NBC.EQ.0) GO TO 900
C
C  READ STEADY STATE OR TRANSIENT BOUNDARY CONDITIONS OF THE FORM H=BB
C
      NPP=0
  820 IF (NPP.EQ.NBC) GO TO 880
      IF (NPP.LT.NBC) GO TO 830
      PRINT 14300,NBC
      ISTOP=ISTOP+1
      GO TO 880
  830 READ 13300,NI,NPINC,BBI
      IF (NPINC.GT.0) GO TO 850
  840 NPP=NPP+1
      NN(NPP)=NI
      BB(NPP)=BBI
      GO TO 820
  850 IF (NPP.GT.0) GO TO 860
      ISTOP=ISTOP+1
      PRINT 15400
  860 NJ=NN(NPP)+NPINC
      BBJ=BB(NPP)
      NK=NI-1
      DO 870 NP=NJ,NK,NPINC
         NPP=NPP+1
         NN(NPP)=NP
  870    BB(NPP)=BBJ
      GO TO 840
  880 PRINT 11100
```

Appendix C (continued)

```
      DO 890 NPP=1.NBC                                                  DATA2255
  890    PRINT 13200.NN(NPP).BB(NPP)                                    DATA2260
  900 IF (NST.LE.0) GO TO 1000                                          DATA2265
C                                                                       DATA2270
C  READ STEADY STATE OR TRANSIENT SURFACE-TERM POINT FLUXES             DATA2275
C                                                                       DATA2280
      NPP=0                                                             DATA2285
      MP=0                                                              DATA2290
      PRINT 11200                                                       DATA2295
  910 IF (MP.EQ.NST) GO TO 960                                          DATA2300
      READ 13400.NI.NJ.KINC.EI.EJ                                       DATA2305
      IF (KINC.GT.0) GO TO 930                                          DATA2310
  920 MP=MP+1                                                           DATA2315
      DX=X(NI)-X(NJ)                                                    DATA2320
      DZ=Z(NI)-Z(NJ)                                                    DATA2325
      EL=DSQRT(DX*DX+DZ*DZ)                                             DATA2330
      PRINT 13500.NI.NJ.EI.EJ                                           DATA2335
      IF(MP.GT.1) GO TO 921                                             DATA2340
      NPP=NPP+1                                                         DATA2345
      NPST(NPP)=NI                                                      DATA2350
      NII=NPP                                                           DATA2355
      NPP=NPP+1                                                         DATA2360
      NPST(NPP)=NJ                                                      DATA2365
      NJJ=NPP                                                           DATA2370
      GO TO 928                                                         DATA2375
  921 DO 922 I=1.NPP                                                    DATA2380
         IJ=NPST(I)                                                     DATA2385
         IF(IJ.EQ.NI) GO TO 923                                         DATA2390
  922    CONTINUE                                                       DATA2395
      NPP=NPP+1                                                         DATA2400
      NPST(NPP)=NI                                                      DATA2405
      NII=NPP                                                           DATA2410
      GO TO 924                                                         DATA2415
  923 NII=I                                                             DATA2420
  924 DO 925 J=1.NPP                                                    DATA2425
         IJ=NPST(J)                                                     DATA2430
         IF(IJ.EQ.NJ) GO TO 926                                         DATA2435
  925    CONTINUE                                                       DATA2440
      NPP=NPP+1                                                         DATA2445
      NPST(NPP)=NJ                                                      DATA2450
      NJJ=NPP                                                           DATA2455
      GO TO 928                                                         DATA2460
  926 NJJ=J                                                             DATA2465
  928 RP(NII)=RP(NII)+EI*EL/3.0+EJ*EL/6.0                               DATA2470
      RP(NJJ)=RP(NJJ)+EI*EL/6.0+EJ*EL/3.0                               DATA2475
      EK=EJ                                                             DATA2480
      GO TO 910                                                         DATA2485
  930 IF (MP.GT.0) GO TO 940                                            DATA2490
      ISTOP=ISTOP+1                                                     DATA2495
      PRINT 15700                                                       DATA2500
```

```
  940 NPINC=IABS(NJ-NI)
      NPMIN=MAX0(NPST(NPP),NPST(NPP-1))
      NPMAX=MIN0(NI,NJ)-1
      DO 950 NK=NPMIN,NPMAX,NPINC
         NL=NK+NPINC
         MP=MP+1
         DX=X(NK)-X(NL)
         DZ=Z(NK)-Z(NL)
         EL=DSQRT(DX*DX+DZ*DZ)
         PRINT 13500,NK,NL,EK,EK
         IF(MP.GT.1) GO TO 941
         NPP=NPP+1
         NPST(NPP)=NK
         NKK=NPP
         NPP=NPP+1
         NPST(NPP)=NL
         NLL=NPP
         GO TO 948
  941    DO 942 K=1,NPP
            KL=NPST(K)
            IF(KL.EQ.NK) GO TO 943
  942       CONTINUE
         NPP=NPP+1
         NPST(NPP)=NK
         NKK=NPP
         GO TO 944
  943    NKK=K
  944    DO 945 L=1,NPP
            KL=NPST(L)
            IF(KL.EQ.NL) GO TO 946
  945       CONTINUE
         NPP=NPP+1
         NPST(NPP)=NL
         NLL=NPP
         GO TO 948
  946    NLL=L
  948    RP(NKK)=RP(NKK)+EK*EL/2.0
         RP(NLL)=RP(NLL)+EK*EL/2.0
  950    CONTINUE
      GO TO 920
  960 NSTN=NPP
C
C  APPLY STEADY STATE OR TRANSIENT DIRICHLET BOUNDARY CONDITIONS TO
C   INITIAL CONDITIONS
C
 1000 IF (NBC.EQ.0) GO TO 1020
      DO 1010 NPP=1,NBC
         NP=NN(NPP)
 1010    H(NP)=BB(NPP)
 1020 IF (ISTOP.EQ.0) GO TO 1030
```

```
      PRINT 15800, ISTOP                                                      DATA2755
C                                                                             DATA2760
C   READ STEADY STATE OR TRANSIENT NATURAL-DRAINAGE ELEMENT                   DATA2765
C   SURFACE INFORMATION                                                       DATA2770
C                                                                             DATA2775
 1030 CONTINUE                                                                DATA2780
C                                                                             DATA2785
      PRINT 20000, NBN,(NPB(I),I=1,NBN)                                       DATA2790
      PRINT 21000, NBEL,(NBE(I),I=1,NBEL)                                     DATA2795
      IF(NRSN.NE.0) PRINT 22000, NRSN,(NPRS(I),I=1,NRSN)                      DATA2800
      IF(NRSEL.NE.0) PRINT 23000, NRSEL,(NRSE(I),I=1,NRSEL)                   DATA2805
      IF(NST.NE.0) PRINT 26000, NST,NSTN,(NPST(I),I=1,NSTN)                   DATA2810
      IF(NBC.NE.0) PRINT 27000, NBC,(NN(I),I=1,NBC)                           DATA2815
C                                                                             DATA2820
      RETURN                                                                  DATA2825
C                                                                             DATA2830
C                                                                             DATA2835
10000 FORMAT(38H0INPUT TABLE 1.. BASIC PARAMETERS    // 5X,                   DATA2840
     > 40H NUMBER OF NODAL POINTS. . . . . . . . . . ..I5/ 5X,                DATA2845
     > 40H NUMBER OF ELEMENTS. . . . . . . . . . . . ..I5/ 5X,                DATA2850
     > 40H NUMBER OF DIFFERENT MATERIALS . . . . . ..I5/ 5X,                  DATA2855
     > 40H NUMBER OF CORRECTION MATERIALS. . . . . ..I5/ 5X,                  DATA2860
     > 40H NUMBER OF TIME INCREMENTS . . . . . . . ..I5/ 5X,                  DATA2865
     > 40H STEADY-STATE I.C. CONTROL . . . . . . . ..I5/ 5X,                  DATA2870
     > 40H SOIL-PROPERTY CONTROL . . . . . . . . . ..I5/ 5X,                  DATA2875
     > 40H NUMBER OF SOIL PARAMETERS . . . . . . . ..I5/ 5X,                  DATA2880
     > 40H AUXILIARY STORAGE CONTROL . . . . . . . ..I5/ 5X,                  DATA2885
     > 40H CONDUCTIVITY-PERMEABILITY CONTROL . . . ..I5/ 5X,                  DATA2890
     > 40H GRAVITY CONTROL . . . . . . . . . . . . ..I5/ 5X,                  DATA2895
     > 40H RESTART PARAMETER . . . . . . . . . . . ..I5/ 5X,                  DATA2900
     > 40H MAXIMUM ITERATIONS PER CYCLE. . . . . . ..I5/ 5X,                  DATA2905
     > 40H MAXIMUM CYCLES PER TIME STEP. . . . . . ..I5)                      DATA2910
10001 FORMAT(1H ,4X,                                                          DATA2915
     > 40H LUMPING INDICATOR, ILUMP. . . . . . . . ..I5/ 5X,                  DATA2920
     > 40H TIME-DIFFERENCE INDICATOR, IMID . . . . ..I5)                      DATA2925
10100 FORMAT(5X,40H TIME INCREMENT. . . . . . . . . . . . . ..F10.5/ 5X,      DATA2930
     > 40H MULTIPLIER FOR INCREASING DELT. . . . ..F10.6/ 5X,                 DATA2935
     > 40H MAXIMUM VALUE OF DELT . . . . . . . . ..D10.4/ 5X,                 DATA2940
     > 40H MAXIMUM VALUE OF TIME . . . . . . . . ..D10.4/ 5X,                 DATA2945
     > 40H DEGREES OF PRIN-AXIS INCLINATION. . . ..F10.6/ 5X,                 DATA2950
     > 40H STEADY-STATE TOLERANCE. . . . . . . . ..F10.6/ 5X,                 DATA2955
     > 40H TRANSIENT STATE TOLERANCE .............F10.6/ 5X,                  DATA2960
     > 40H DENSITY OF WATER. . . . . . . . . . . ..F10.6/ 5X,                 DATA2965
     > 40H ACCELERATION OF GRAVITY . . . . . . . ..F10.3/ 5X,                 DATA2970
     > 40H VISCOSITY OF WATER. . . . . . . . . . ..F10.6/ 5X,                 DATA2975
     > 40H TIME-INTEGRATION PARAMETER. . . . . . ..F10.6)                     DATA2980
10200 FORMAT(//6X,14HOUTPUT CONTROL)                                          DATA2985
10201 FORMAT(//6X,15HDISK OUTPUT CONTROL)                                     DATA2990
10300 FORMAT(36H1INPUT TABLE 2.. MATERIAL PROPERTIES// 9H MAT. NO., 9(        DATA2995
     > 3A4))                                                                  DATA3000
```

Appendix C (continued)

```
10400 FORMAT(53H1INPUT TABLE 3.. SOIL-PROPERTIES INTERPOLATION VALUES//         DATA3005
     > 9H MAT. NO.,9X,8HPRESSURE,13X,16HMOISTURE CONTENT,4X,                   DATA3010
     > 25HCONDUCTIVITY/PERMEABILITY,6X,14HWATER CAPACITY)                      DATA3015
10500 FORMAT(44H1INPUT TABLE 3.. MOISTURE-CONTENT PARAMETERS//                 DATA3020
     > 9H MAT. NO.,8(3A4))                                                     DATA3025
10600 FORMAT(40H1INPUT TABLE 4.. CONDUCTIVITY PARAMETERS// 9H MAT. NO.,         DATA3030
     > 2(3A4))                                                                 DATA3035
10700 FORMAT(32H1INPUT TABLE 5. NODAL POINT DATA//2X,                          DATA3040
     > 4HNODE,10X,1HX,10X,1HZ,4X,4HNODE,10X,1HX,10X,1HZ,4X,4HNODE,             DATA3045
     > 10X,1HX,10X,1HZ,4X,4HNODE,10X,1HX,10X,1HZ/                              DATA3050
     > 27H***************************,3X,27H***************************,       DATA3055
     >3X,27H***************************,3X,27H***************************      DATA3060
     >*/)                                                                      DATA3065
10800 FORMAT(29H1INPUT TABLE 6.. ELEMENT DATA// 11X,                           DATA3070
     > 31HGLOBAL INDICES OF ELEMENT NODES/7X,7HELEMENT,3X,1H1,7X,1H2,          DATA3075
     > 7X,1H3,7X,1H4,6X,8HMATERIAL,4X,9HNODE DIFF.)                            DATA3080
10900 FORMAT (64H CORRECTIONS TO MATERIAL TYPES AND CLASSES FOR SELECTED        DATA3085
     > ELEMENTS)                                                               DATA3090
11000 FORMAT(45H1INPUT TABLE 7.. STEADY-STATE B.C. PARAMETERS// 5X,            DATA3095
     > 40H NUMBER OF BOUNDARY CONDITIONS . . . . ..I5/ 5X,                     DATA3100
     > 40H NUMBER OF SURFACE TERMS . . . . . . . ..I5/ 5X,                     DATA3105
     > 40H NUMBER OF RAINFALL PROFILES . . . . . ..I5/ 5X,                     DATA3110
     > 40H NUMBER OF RAINFALL PARAMETERS . . . . ..I5/ 5X,                     DATA3115
     > 40H NUMBER OF RAINFALL-SEEPAGE ELEMENTS . ..I5/ 5X,                     DATA3120
     > 40H NUMBER OF RAINFALL-SEEPAGE NODES. . . ..I5)                         DATA3125
11100 FORMAT(53H1INPUT TABLE 8.. STEADY-STATE BOUNDARY CONDITIONS OF ,          DATA3130
     > 9HFORM H=BB//6H  NODE,7X,2HBB)                                          DATA3135
11200 FORMAT(43H1INPUT TABLE 9.. STEADY-STATE SURFACE TERMS,                   DATA3140
     > 33H E=EI AT NODE NI, E=EJ AT NODE NJ//8X,2HNI,8X,2HNJ,10X,2HEI,          DATA3145
     > 13X,2HEJ/)                                                              DATA3150
11300 FORMAT(43H1INPUT TABLE 10.. TRANSIENT B.C. PARAMETERS// 5X,              DATA3155
     > 40H NUMBER OF BOUNDARY CONDITIONS . . . . ..I5/ 5X,                     DATA3160
     > 40H NUMBER OF SURFACE TERMS . . . . . . . ..I5/ 5X,                     DATA3165
     > 40H NUMBER OF RAINFALL PROFILES . . . . . ..I5/ 5X,                     DATA3170
     > 40H NUMBER OF RAINFALL PARAMETERS . . . . ..I5/ 5X,                     DATA3175
     > 40H NUMBER OF RAINFALL-SEEPAGE ELEMENTS . ..I5/ 5X,                     DATA3180
     > 40H NUMBER OF RAINFALL-SEEPAGE NODES. . . ..I3)                         DATA3185
11400 FORMAT(31H1INPUT TABLE 11.. RAINFALL DATA)                               DATA3190
11500 FORMAT(/8H PROFILE,I5/8X,4HTIME,11X,4HRATE)                              DATA3195
11600 FORMAT(51H1INPUT TABLE 12.. RAINFALL DISTRIBUTION AND PONDING//          DATA3200
     > 6X,4HNODE,6X,4HTYPE,5X,5HDEPTH)                                         DATA3205
11700 FORMAT(54H1INPUT TABLE 13.. RAINFALL-SEEPAGE SURFACE INFORMATION//       DATA3210
     >  5X,7HELEMENT,2X,6HNODE 1,2X,6HNODE 2)                                  DATA3215
11701 FORMAT(54H1INPUT TABLE 13A. NATURAL DRAINAGE SURFACE INFORMATION//       DATA3220
     >  5X,7HELEMENT,2X,6HNODE 1,2X,6HNODE 2)                                  DATA3225
11800 FORMAT(50H1INPUT TABLE 14.. BOUNDARY CONDITIONS OF FORM H=BB//           DATA3230
     > 6H  NODE,7X,2HBB)                                                       DATA3233
11900 FORMAT(31H1INPUT TABLE 15.. SURFACE TERMS,                               DATA3240
     > 33H E=EI AT NODE NI, E=EJ AT NODE NJ// 5H   NI,5H   NJ,6X,2HEI,         DATA3245
     > 13X,2HEJ/)                                                              DATA3250
```

Appendix C (continued)

```
12000 FORMAT(16I5)                                                    DATA3255
12100 FORMAT(80I1)                                                    DATA3260
12200 FORMAT(10X,101I1)                                               DATA3265
12300 FORMAT(8F10.0)                                                  DATA3270
12400 FORMAT(2(1PD15.4))                                              DATA3275
12500 FORMAT(I8,9D12.4)                                               DATA3280
12600 FORMAT(I8,D19.4,3D25.4/(2X,4D25.4))                             DATA3285
12700 FORMAT(I8,9D12.4/(8X,9D12.4))                                   DATA3290
12800 FORMAT(I5,2F10.3)                                               DATA3295
12900 FORMAT(1H ,I5,2D11.3,3X,I5,2D11.3,3X,I5,2D11.3,3X,I5,2D11.3)    DATA3300
13000 FORMAT(I10,4I8,I10,I13)                                         DATA3305
13100 FORMAT(I10,32X,I10,32X,I10)                                     DATA3310
13200 FORMAT(I5,D15.4)                                                DATA3315
13300 FORMAT(2I5,2F10.0)                                              DATA3320
13400 FORMAT(3I5,5X,2F10.0)                                           DATA3325
13500 FORMAT(2I10,2(1PD15.4))                                         DATA3330
13600 FORMAT(I5,5X,F10.0)                                             DATA3335
14300 FORMAT(////37H CHECK BOUNDARY CONDITIONS, MAXIMUM =,I5///)      DATA3340
14800 FORMAT(////43H TOO MANY RAINFALL-SEEPAGE NODES, MAXIMUM =,I5///)DATA3345
14900 FORMAT(////34H ERROR IN SURFACE CARD FOR ELEMENT,I5///)         DATA3350
15000 FORMAT(////28H EXECUTION HALTED BECAUSE OF,I5,13H FATAL ERRORS///)DATA3355
15100 FORMAT(////30H ERROR IN NODAL-POINT CARD NO.,I5///)             DATA3360
15200 FORMAT(////26H ERROR IN ELEMENT CARD NO.,I5///)                 DATA3365
15300 FORMAT(////36H ERROR IN INITIAL-CONDITION CARD NO.,I5///)       DATA3370
15400 FORMAT(////49H ERROR IN FIRST H=BB TYPE BOUNDARY-CONDITION CARD //DATA3375
     >   /)                                                           DATA3380
15500 FORMAT(////48H ERROR IN FIRST RAINFALL-TYPE-PONDING-DEPTH CARD///)DATA3385
15600 FORMAT(////45H ERROR IN FIRST RAINFALL-SEEPAGE ELEMENT CARD///) DATA3390
15700 FORMAT(////33H ERROR IN FIRST SURFACE-TERM CARD///)             DATA3395
15800 FORMAT(////45H ASSEMBLY AND SOLUTION WILL NOT BE PERFORMED.,I5, DATA3400
     > 19H  FATAL CARD ERRORS///)                                     DATA3405
15900 FORMAT(////40H ERROR IN MATERIAL TYPE CODE FOR ELEMENT,I5///)   DATA3410
20000 FORMAT(1H1,5X,'CHECK ALL BOUNDARY NODAL AND ELEMENT INFORMATION'//DATA3415
     > /5X,'TOTAL NUMBER OF BOUNDARY NODES =',I5/5X,                  DATA3420
     > 'THEY ARE LISTED BELOW:'/(5X,10I5))                            DATA3425
21000 FORMAT(1H0,4X,'TOTAL NUMBER OF BOUNDARY ELEMENTS =',I5/5X,      DATA3430
     > 'THEY ARE LISTED BELOW:'/(5X,10I5))                            DATA3435
22000 FORMAT(1H0,4X,'TOTAL NUMBER OF RAINFALL-SEEPAGE BOUNDARY NODES =',DATA3440
     > I5/5X,'THEY ARE LISTED BELOW:'/(5X,10I5))                      DATA3445
23000 FORMAT(1H0,4X,'TOTAL NUMBER OF RAINFALL-SEEPAGE BOUNDARY ELEMENT =DATA3450
     > ',I5/5X,'THEY ARE LISTED BELOW:'/(5X,10I5))                    DATA3455
26000 FORMAT(1H0,4X,'TOTAL NUMBER OF SURFACE TERM BOUNDARY ELEMENTS =',DATA3460
     > I5/5X,'TOTAL NUMBER OF SURFACE TERM BOUNDARY NODES =',I5/5X,   DATA3465
     > 'THERY ARE LSITED BELOW:'/(5X,10I5))                           DATA3470
27000 FORMAT(1H0,4X,'TOTAL NUMBER OF DIRICHLET NODES =',I5/5X,        DATA3475
     > 'THEY ARE LISTED BELOW:'/(5X,10I5))                            DATA3480
      END                                                             DATA3485
```

```
      SUBROUTINE SURF(X,Z,IE, DLB,DCOSXB,DCOSZB,NBE,ISB,NPB,
     > MAXNP,MAXEL, MAXBEL,MAXBNP)
C
C
C   FUNCTION OF SUBROUTINE--TO IDENTIFY BOUNDING SIDES THROUGH THE ARRAY
C    ISB(MP,4), TO CALCULATE THEIR LENGTHS DLB(MP), AND TO DETERMINE THE
C   DIRECTION COSINES DCOSX(MP) AND DCOSZ(MP) OF THE OUTWARDLY DIRECTED
C   UNIT NORMAL  VECTOR FOR EACH BOUNDARY ELEMENT NBE(MP).
C
C
      IMPLICIT REAL*8(A-H,O-Z)
C
      DIMENSION X(MAXNP),Z(MAXNP),IE(MAXEL,5)
      DIMENSION DLB(MAXBEL),DCOSXB(MAXBEL),DCOSZB(MAXBEL),NBE(MAXBEL),
     > ISB(MAXBEL,4),NPB(MAXBNP)
C
      COMMON /GEOM/ SNFE,CSFE,NNP,NEL,IBAND
      COMMON /BRSND/ NBEL,NBN,NRSEL,NRSN,NRFPR,NRFPAR
C
C   FIND SURFACE SIDES BY LOCATING NONDUPLICATED SIDES
C
      NBEL=0
      NBN=0
      DO 40 MI=1,NEL
         DO 30 IQ=1,4
            IQ1=IQ+1
            IF (IQ.EQ.4) IQ1=1
            DO 20 MJ=1,NEL
               IF (MJ.EQ.MI) GO TO 20
               DO 10 JQ=1,4
                  JQ1=JQ+1
                  IF (JQ.EQ.4) JQ1=1
                  IF (IE(MI,IQ).EQ.IE(MJ,JQ).AND.IE(MI,IQ1).EQ.IE(MJ,
     >             JQ1)) GO TO 30
                  IF (IE(MI,IQ).EQ.IE(MJ,JQ1).AND.IE(MI,IQ1).EQ.IE(MJ,
     >             JQ)) GO TO 30
   10             CONTINUE
   20          CONTINUE
C
            NI=IE(MI,IQ)
            NJ=IE(MI,IQ1)
            NBEL=NBEL+1
            NBE(NBEL)=MI
            ISB(NBEL,1)=NI
            ISB(NBEL,2)=NJ
            ISB(NBEL,3)=IQ
            ISB(NBEL,4)=IQ1
            IF(NBEL.GT.1) GO TO 25
            NBN=NBN+1
            NPB(NBN)=NI
```

Appendix C (continued)

```
            NBN=NBN+1
            NPB(NBN)=NJ
   25       DO 26 I=1,NBN
               IJ=NPB(I)
               IF(IJ.EQ.NI) GO TO 27
   26          CONTINUE
            NBN=NBN+1
            NPB(NBN)=NI
   27       DO 28 J=1,NBN
               IJ=NPB(J)
               IF(IJ.EQ.NJ) GO TO 29
   28          CONTINUE
            NBN=NBN+1
            NPB(NBN)=NJ
   29       CONTINUE
   30       CONTINUE
   40    CONTINUE
C
C  CALCULATE SIDE LENGTHS AND DIRECTION COSINES
C
      DO 70 MP=1,NBEL
         M=NBE(MP)
         NI=ISB(MP,1)
         NJ=ISB(MP,2)
C        DX=X(NI)-X(NJ)
C        DZ=Z(NI)-Z(NJ)
         DX=X(NJ)-X(NI)
         DZ=Z(NJ)-Z(NI)
         DLB(MP)=DSQRT(DX*DX+DZ*DZ)
C
         BETA=DATAN2(DZ,DX)
         DCOSXB(MP)=DSIN(BETA)
         DCOSZB(MP)=-DCOS(BETA)
   70    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE VELT(X.Z.IE, C.H.HT.VX.VZ.AKX.AKZ, MAXEL,MAXNP,MAXHBP)
C
C  FUNCTION OF SUBROUTINE TO COMPUTE DARCY VELOCITY VX AND VZ
C
      IMPLICIT REAL*8(A-H,O-Z)
C
      DIMENSION X(MAXNP),Z(MAXNP),IE(MAXEL,5)
      DIMENSION C(MAXNP,MAXHBP),H(MAXNP),HT(MAXNP),VX(MAXNP),VZ(MAXNP),
     > AKX(MAXEL,4),AKZ(MAXEL,4)
C
      DIMENSION QQ(4,4),RQ(4),XQ(4),ZQ(4),HTQ(4),AKXQ(4),AKZQ(4)
C
      COMMON /GEOM/ SNFE,CSFE,NNP,NEL,IBAND
C
      IHALFB=(IBAND-1)/2
      IHBP=IHALFB+1
C
C  INITIAZE THE DARCY VELOCITY VX(NP) AND VZ(NP)
C
      DO 100 NP=1,NNP
      VX(NP)=0.0
  100 VZ(NP)=0.0
C
C  CALCULATE THE TOTAL HEAD HT(NP)
C
      DO 105 NP=1,NNP
  105 HT(NP)=H(NP)-X(NP)*SNFE+Z(NP)*CSFE
C
C  COMPUTE DARCY VELOCITIES BY APPLYING FINITE ELEMENT METHOD TO DARCY
C  EQUATIONS.  IXZ=1 FOR COMPUTING VX, IXZ=2 FOR COMPUTING VZ.
C
C
      DO 300 IXZ=1,2
C
C  INITIALIZE MATRIX C(NP,IB)
C
      DO 110 NP=1,NNP
      DO 110 IB=1,IHBP
  110 C(NP,IB)=0.0
C
C  COMPUTE THE ELEMENT MATRIX QQ(IQ,JQ) AND RQ(IQ)
C
      DO 120 M=1,NEL
C
      DO 120 IQ=1,4
      NP=IE(M,IQ)
      XQ(IQ)=X(NP)
      ZQ(IQ)=Z(NP)
      HTQ(IQ)=HT(NP)
      AKXQ(IQ)=AKX(M,IQ)
```

```
  120 AKZQ(IQ)=AKZ(M,IQ)
C
      CALL Q4D(QQ,RQ,XQ,ZQ,AKXQ,AKZQ,HTQ,SNFE,CSFE,IXZ)
C
C
C  ASSEMBLE QQ(IQ,JQ) INTO THE GLOBAL MATRIX C(NP,IB) AND
C  FORM THE LOAD VECTOR VX(NP) OR VZ(NP)
C
      DO 140 IQ=1,4
      NI=IE(M,IQ)
      DO 130 JQ=1,4
      NJ=IE(M,JQ)
      IF(NJ.LT.NI) GO TO 130
      IB=NJ-NI+1
      C(NI,IB)=C(NI,IB)+QQ(IQ,JQ)
  130 CONTINUE
C
      IF(IXZ.EQ.2) GO TO 135
      VX(NI)=VX(NI)+RQ(IQ)
      GO TO 140
  135 VZ(NI)=VZ(NI)+RQ(IQ)
  140 CONTINUE
C
  180 CONTINUE
C
C  SOLVE THE MATRIX EQUATION CX=B
C
      IF(IXZ.EQ.2) GO TO 200
      CALL BANSOL(1,C,VX,NNP,IHBP,MAXNP,MAXHBP)
      CALL BANSOL(2,C,VX,NNP,IHBP,MAXNP,MAXHBP)
      GO TO 300
  200 CALL BANSOL(1,C,VZ,NNP,IHBP,MAXNP,MAXHBP)
      CALL BANSOL(2,C,VZ,NNP,IHBP,MAXNP,MAXHBP)
  300 CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE Q4D(QQ.RQ.XQ.ZQ.AKXQ.AKZQ.HTQ.SNFE.CSFE.IND)
C
C
C  FUNCTION OF SUBROUTINE-TO EVALUATE THE MATRIX QUADRATURE OVER THE
C  AREA OF ONE ELEMENT.  THESE INTEGRALS ARISE THROUGH THE
C  APPLICATION OF THE GALERKIN INTEGRATION SCHEME
C
C
      IMPLICIT REAL*8 (A-H.O-Z)
      REAL*8 N(4)
C
      DIMENSION QQ(4.4).RQ(4).XQ(4).ZQ(4).HTQ(4).AKXQ(4).AKZQ(4)
      DIMENSION S(4).T(4).DNX(4).DNZ(4)
      DIMENSION PJAB(2.2).DNSS(4).DNTT(4)
C
      DATA P / .577350269189626 /, S / -1.0D+00, 1.0D+00, 1.0D+00,-
     > 1.0D+00 /, T / -1.0D+00,-1.0D+00, 1.0D+00, 1.0D+00 /
C
C  INITIALIZE MATRICES QQ(IQ.JQ) AND RQ(IQ)
C
      DO 100 IQ=1.4
      RQ(IQ)=0.0
      DO 100 JQ=1.4
  100 QQ(IQ.JQ)=0.0
C
C
C  SUMMATION OF THE INTEGRAND OVER THE GAUSSIAN POINTS
C
C
      DO 400 KG=1.4
C
C  DETERMINE LOCAL COORDINATE (SS.TT) OF
C  GAUSS-INTEGRATION POINT KG
C
      SS=P*S(KG)
      TT=P*T(KG)
C
C  CALCULATE VALUES OF THE BASIS FUNCTIONS N(IQ) AND THEIR DERIVATIVES
C  DNX(IQ) AND DNZ(IQ) WITH RESPECT TO X AND Z. RESPECTIVELY. AT
C  THE GAUSS POINT KG
C
         CALL BASE(N.DNSS.DNTT.SS.TT)
C
         DO 11 I=1.2
            DO 11 J=1.2
   11          PJAB(I.J)=0.0
         DO 12 I=1.4
            PJAB(1.1)=PJAB(1.1)+ZQ(I)*DNTT(I)
            PJAB(1.2)=PJAB(1.2)-ZQ(I)*DNSS(I)
            PJAB(2.1)=PJAB(2.1)-XQ(I)*DNTT(I)
```

Appendix C (continued)

```
   12         PJAB(2,2)=PJAB(2,2)+XQ(I)*DNSS(I)
           DJAC=PJAB(2,2)*PJAB(1,1)-PJAB(1,2)*PJAB(2,1)
           DJACI=1.0/DJAC
           DO 13 I=1,2
              DO 13 J=1,2
   13            PJAB(I,J)=PJAB(I,J)*DJACI
           DO 14 I=1,4
              DNX(I)=DNSS(I)*PJAB(1,1)+DNTT(I)*PJAB(1,2)
   14         DNZ(I)=DNSS(I)*PJAB(2,1)+DNTT(I)*PJAB(2,2)
C
        AKXK=0.0
        AKZK=0.0
C
C     ACCUMULATE THE SUMS TO OBTAIN THE MATRIX INTEGRALS QQ(IQ,JQ)
C     AND RQ(IQ)
C
        DO 150 IQ=1,4
        AKXK=AKXK+AKXQ(IQ)*N(IQ)
  150   AKZK=AKZK+AKZQ(IQ)*N(IQ)
        DO 300 IQ=1,4
        DO 300 JQ=1,4
        QQ(IQ,JQ)=QQ(IQ,JQ)+ N(IQ)*N(JQ)*DJAC
        IF(IND.EQ.2) GO TO 200
        RQ(IQ)=RQ(IQ)-AKXK*N(IQ)*(HTQ(JQ)*DNX(JQ))*DJAC
        GO TO 300
  200   RQ(IQ)=RQ(IQ)-AKZK*N(IQ)*(HTQ(JQ)*DNZ(JQ))*DJAC
  300   CONTINUE
  400   CONTINUE
        RETURN
        END
```

```
      SUBROUTINE SPRCP(IE, H,TH,DTH,AKX,AKZ,PROP,THPROP,AKPROP,HPROP,
     > CAPROP,  MAXEL,MAXNP, MAXMAT,MXMPPM,MXSPPM, NEL,KSP)
C
C
C  FUNCTION OF SUBROLTINE--TO CALCULATE SOIL PROPERTIES. I.E. THE
C  WATER CONTENTS TH(M.IQ), WATER CAPACITIES DTH(M,IQ), AND
C  PRINCIPAL VALUES CF THE CONDUCTIVITY TENSOR AKX(M,IQ) AND AKZ(M,IQ).
C
C
      IMPLICIT REAL*8(A-H.O-Z)
C
      DIMENSION IE(MAXEL.5).H(MAXNP).TH(MAXEL.4).DTH(MAXEL.4),
     > AKX(MAXEL.4).AKZ(MAXEL.4)
C
      DIMENSION PROP(MAXMAT.MXMPPM).THPROP(MAXMAT.MXSPPM),
     > AKPROP(MAXMAT.MXSPPM).HPROP(MAXMAT.MXSPPM),
     > CAPROP(MAXMAT.MXSPPM)
C
      COMMON /MTL/ NMAT.NMPPM.NSPPM
C
C
C
C ------- TH. DTH/DH. AKX. AND AKZ ARE OBTAINED BY TABLE
C
      IF(KSP.EQ.0) GO TC 80
      DO 70 M=1.NEL
         MTYP=IE(M.5)
         SATKX=PROP(NTYF.4)
         SATKZ=FROP(NTYF.5)
         DO 60 IQ=1.4
            NP=IE(M.IQ)
            HNP=H(NP)
            IF (HNP.GT.HPROP(MTYP.1)) GO TO 10
            JL=1
            JU=2
            A=0.
            GO TO 50
10          IF (HNP.LT.HPROP(MTYP.NSPPM)) GO TO 20
            JL=NSPPM
            JU=1
            A=C.
            GO TO 50
20          DO 30 J=2.NSPPM
               JU=J
               IF (HPRGP(MTYP.J).GT.HNP) GO TO 40
30             CONTINLE
40          JL=JU-1
            A=(HNP-HPROP(MTYP.JL))/(HPROP(MTYP.JU)-HPROP(MTYP.JL))
50          TH(M.IQ)=THFROP(MTYP.JL)+A*(THPROP(MTYP.JJ)-THPROP(MTYP.JL))
            DTH(M.IQ)=CAPROP(MTYP.JL)+A*(CAPROP(MTYP.JJ)-CAPROP(MTYP.JL)
```

Appendix C (continued)

```
     >         )
              USKFCT=AKPROP(MTYP.JL)+A*(AKPROP(MTYP.JJ)-AKPROP(MTYP.JL))
              AKX(M.IQ)=SATKX*USKFCT
              AKZ(M.IQ)=SATKZ*USKFCT
   60      CONTINUE
   70 CONTINUE
      RETURN
C
C ------- TH. DTH/DH. AKX. AND AKZ ARE OBTAINED BY ANALYTICAL FORM
C ------- THE READER MUST SUPPLY THE FUNCTIONAL FORM OF FKX. FKZ. AND
C ------- FTH BELOW
C
   80 DO 95 M=1.NEL
         MTYP=IE(M.5)
         SATKX=PROP(MTYP.4)
         SATKZ=PROP(MTYP.5)
C
C ------- WCR= THPROP(MTYP.1)=0.065. 0.050 FOR TWO SAMPLE MATERIALS
C ------- WCS=THPROP(MTYP.2)=0.364. 0.341 FOR TWO SAMPLE MATERIALS
C ------- RN=THPROP(MTYP.3)=1.092217. 1.546937 FOR TWO SAMPLE MATERIALS
C ------- ALPH=THPROP(MTYP.4)=0.109. 0.002166 FOR TWO SAMPLE MATERIALS
C
         WCR=THPROP(MTYP.1)
         WCS=THPROP(MTYP.2)
         RN=THPROP(MTYP.3)
         ALPH=THPROP(MTYP.4)
         RM=1.0D0-1.0D0/RN
         DO 90 IQ=1.4
            NP=IE(M.IQ)
            HNP=H(NP)
            HNP=-HNP
C
C
C ------- SATURATED CONDITION
C
            IF(HNP.GT.0.0) GO TO 85
            TH(M.IQ)=WCS
            DTH(M.IQ)=0.0D0
            AKX(M.IQ)=SATKX
            AKZ(M.IQ)=SATKZ
            GO TO 90
C
C ------- UNSATURATED CASE
C
   85       THMIQ=WCR+(WCS-WCR)/(1.0D0+(ALPH*HNP)**RN)**RM
            TH(M.IQ)=THMIQ
            RWC=(THMIQ-WCR)/(WCS-WCR)
            TERM=(1.0-RWC**(1.0/RM))**RM
            RK=DSQRT(RWC)*(1.0-TERM)*(1.-TERM)
            AKX(M.IQ)=SATKX*RK
```

Appendix C (continued)

```
            AKZ(M,IQ)=SATKZ*RK                                          SPRO 505
            DTH(M,IQ)=ALPH*(RN-1.0)*TERM*RWC**(1.0/RM)                  SPRO 510
C                                                                       SPRO 515
   50       CONTINUE                                                    SPRO 520
   55 CONTINUE                                                          SPRO 525
      RETURN                                                            SPRO 530
      END                                                               SPRO 535
```

```
      SUBROUTINE BCPREP(IE, H,VX,VZ, DL,DCOSX,DCOSZ,DCYFLX,FLX,RSFLX,
     > HCON,NRSE,IS,NPRS,NPCON,NPFLX,IRFTYP,TRF,RF,RFALL, MAXEL,MAXNP,
     > MXRSEL,MXRSNP,MXRFPR,MXRPAR, TIME,NCHG)
C
C
C    FUNCTION OF SUBROUTINE--TO PREPARE BOUNDARY CONDITIONS FOR THE
C    RAINFALL-SEEPAGE NODES.  IF THE PRESSURE H(NP) BECOMES GREATER THAN
C    THE PUDDLING DEPTH HCON(NP), THEN THE RAINFALL RATE IS GREATER
C    THAN THAT WHICH CAN BE ABSORBED BY THE SOIL AND EITHER INWARD FLUX
C    CONTINUES AT A REDUCED RATE OR SEEPAGE, OUTWARD FLUX, BEGINS.
C    IN EITHER EVENT THE BOUNDARY CONDITION IS CHANGED TO THE
C    CONSTANT PUDDLING DEPTH HCON(NP).  ON THE OTHER HAND, SHOULD THE
C    INTERIOR DARCY FLUX DCYFLX(NP) BECOME GREATER THAN CAN BE MAINTAINED
C    BY THE EXTERNAL FLUX, A CHANGE TO A FLUX BOUNDARY CONDITION IS
C    EFFECTED.
C
C
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
      DIMENSION IE(MAXEL,5),H(MAXNP),VX(MAXNP),VZ(MAXNP)
C
      DIMENSION DL(MXRSEL),DCOSX(MXRSEL),DCOSZ(MXRSEL),DCYFLX(MXRSNP),
     > FLX(MXRSNP),RSFLX(MXRSNP),HCON(MXRSNP),NRSE(MXRSEL),
     > IS(MXRSEL,4),NPRS(MXRSNP),NPCON(MXRSNP),NPFLX(MXRSNP),
     > IRFTYP(MXRSNP),TRF(MXRFPR,MXRPAR),RF(MXRFPR,MXRPAR),RFALL(MXRFPR)
C
      COMMON /GEOM/ SNFE,CSFE,NNP,NEL,IBAND
      COMMON /BRSND/ NBEL,NBN,NRSEL,NRSN,NRFPR,NRFPAR
C
C    CALCULATE THE RAINFALL RFALL(I) FROM EACH PROFILE
C
      IF (NRFPR.EQ.0) GO TO 40
      DO 30 I=1,NRFPR
         DO 20 J=2,NRFPAR
            IF (TRF(I,J-1).LE.TIME.AND.TIME.LE.TRF(I,J)) GO TO 10
            GO TO 20
   10       RFALL(I)=RF(I,J-1)+(TIME-TRF(I,J-1))*(RF(I,J)-RF(I,J-1))/
     >        (TRF(I,J)-TRF(I,J-1))
            GO TO 30
   20       CONTINUE
   30    CONTINUE
C
C    DETERMINE THE NORMAL RAINFALLS FLX(NP) AND DARCY FLUXES DCYFLX(NP)
C    FOR EACH RAINFALL-SEEPAGE NODAL POINT
C
   40 DO 50 NP=1,NRSN
         FLX(NP)=0.
   50    DCYFLX(NP)=0.
      DO 70 MP=1,NRSEL
```

Appendix C (continued)

```
      M=NRSE(MP)
      NI=IS(MP,1)
      NJ=IS(MP,2)
      DO 60 I=1,NRSN
         IJ=NPRS(I)
         IF(IJ.NE.NI) GO TO 60
         NII=I
         GO TO 62
60       CONTINUE
62    DO 65 J=1,NRSN
         IJ=NPRS(J)
         IF(IJ.NE.NJ) GO TO 65
         NJJ=J
         GO TO 67
65       CONTINUE
67    CONTINUE
      NITYP=IRFTYP(NII)
      NJTYP=IRFTYP(NJJ)
      RFNI=0.
      RFNJ=0.
      IF (NITYP.GT.0) RFNI=RFALL(NITYP)
      IF (NJTYP.GT.0) RFNJ=RFALL(NJTYP)
C
C  OBTAIN RAINFALL RATES RFNI AND RFNJ AT POINTS NI AND NJ NORMAL TO
C  THE SIDE SUBTENDED BY THESE POINTS
C
      MTYP=IE(M,5)
      PROJ=-DCOSX(MP)*SNFE+DCOSZ(MP)*CSFE
      RFNI=-RFNI*PROJ
      RFNJ=-RFNJ*PROJ
C
C  CALCULATE RAINFALL FLUX PASSING THROUGH SIDE (NI,NJ) AND DIVIDE IT
C  INTO TWO PARTS FLX(NI) AND FLX(NJ).  PERFORM A SIMILAR OPERATION TO
C  OBTAIN DARCY FLUXES DCYFLX(NI) AND DCYFLX(NJ)
C
      FLX(NII)=FLX(NII)+RFNI*DL(MP)/3.0+RFNJ*DL(MP)/6.0
      FLX(NJJ)=FLX(NJJ)+RFNI*DL(MP)/6.0+RFNJ*DL(MP)/3.0
C
C  COMPUTE THE FLUX THROUGH POINT NI USING THE WHOLE BOUNDARY LENGTH
C  AND THE FLUX THROUGH POINT NJ USING THE WHOLE BOUNDARY SIDE LENGTH
C
      FNI=(VX(NI)*DCOSX(MP)+VZ(NI)*DCOSZ(MP))*DL(MP)
      FNJ=(VX(NJ)*DCOSX(MP)+VZ(NJ)*DCOSZ(MP))*DL(MP)
C
C  DISTRIBUTE THE ABOVE FLUXES TO TWO END POINTS OF THE SIDE
C
C
      DCYFLX(NII)=DCYFLX(NII)+FNI/3.0+FNJ/6.0
      DCYFLX(NJJ)=DCYFLX(NJJ)+FNJ/3.0+FNI/6.0
C
```

```
   70    CONTINUE
C
C  CHANGE TO FLUX OR CONSTANT-HEAD CONDITIONS, AS NECESSARY, AND S)
C   INDICATE IN THE ARRAYS NPFLX(NPP) AND NPCON(NPP)
C
       IF (NCHG.NE.(-1)) GO TO 80
      NCHG=0
      RETURN
   80 NCHG=0
      DO 100 NPP=1,NRSN
C
C  CHECK IF THE CHANGING FROM RAINFALL-FLUX (NEUMANN) CONDITION TO
C  PONDING (DIRICHLET) CONDITION IS NECESSARY
C
         NP=NPFLX(NPP)
         IF (NP.EQ.0) GO TO 90
         IF(HCON(NPP).GE.H(NP)) GO TO 100
         NPCON(NPP)=NPFLX(NPP)
         NPFLX(NPP)=0
         NCHG=NCHG+1
         GO TO 100
C
C  CHECK IF THE CHANGING FROM PONDING (DIRICHLET) CONDITION TO
C  RAINFALL-FLUX (NEUMANN) CONDITION IS NECESSARY
C
   90    NP=NPCON(NPP)
         IF(FLX(NPP).LE.DCYFLX(NPP)) GO TO 100
         NPFLX(NPP)=NPCON(NPP)
         NPCON(NPP)=0
         NCHG=NCHG+1
  100    CONTINUE
      RETURN
      END
```

Appendix C (continued)

```
      SUBROUTINE ASEMBL(X,Z,IE, C,R,H,HP,TH,DTH,AKX,AKZ, PROP,
     > MAXNP,MAXEL,MAXHBP, MAXMAT,MXMPPM, KSS,W,DELT)
C
C
C   FUNCTION OF SUBROUTINE--TO ASSEMBLE THE TOTAL COEFFICIENT MATRIX
C   C(NP,IB) AND LOAD VECTOR R(NP) FROM THE ELEMENT MATRICES QA(IQ,JQ),
C   QB(IQ,JQ), AND RQ(IQ).
C
C
      IMPLICIT REAL*8(A-H,O-Z)
C
      DIMENSION X(MAXNP),Z(MAXNP),IE(MAXEL,5)
      DIMENSION C(MAXNP,MAXHBP),R(MAXNP),H(MAXNP),HP(MAXNP),
     > TH(MAXEL,4),DTH(MAXEL,4),AKX(MAXEL,4),AKZ(MAXEL,4)
      DIMENSION PROP(MAXMAT,MXMPPM)
C
      DIMENSION QA(4,4),QB(4,4),RQ(4),THQ(4),DTHQ(4),AKXQ(4),AKZQ(4),
     > XQ(4),ZQ(4),IEM(4)
C
      COMMON /GEOM/ SNFE,CSFE,NNP,NEL,IBAND
      COMMON /C4PAR/ ALF,BETAP,POR,SINFE,COSFE
      COMMON /OPT/ ILUMP,IMID
C
      SINFE=SNFE
      COSFE=CSFE
      IHALFB=(IBAND-1)/2
      IHBP=IHALFB+1
C
      DELTI=1./DELT
      W1=W
      W2=1.-W
      IF (KSS.GT.0) GO TO 10
      DELTI=0.
      W1=1.
      W2=0.
C
C   INITIALIZE MATRICES C(NP,IB) AND R(NP)
C
   10 DO 20 NP=1,NNP
        R(NP)=0.0
        DO 20 IB=1,IHBP
   20     C(NP,IB)=0.0
C
C   START TO ASSEMBLE OVER ALL ELEMENTS
C
      DO 60 M=1,NEL
C
C   COMPUTE MATRICES QA(IQ,JQ), QB(IQ,JQ), AND RQ(IQ) FOR ELEMENT M
C
        MTYP=IE(M,5)
```

```
      ALP=PROP(MTYP.1)
      BETAP=PROP(MTYF.2)
      POR=PROP(MTYP.3)
      DO 30 IQ=1.4
         NP=IE(M.IQ)
         IEM(IQ)=NP
         XQ(IQ)=X(NP)
         ZQ(IQ)=Z(NP)
         THQ(IQ)=TH(M.IQ)
         DTHQ(IQ)=DTH(M.IQ)
         AKXQ(IQ)=AKX(M.IQ)
   30    AKZQ(IQ)=AKZ(M.IQ)
C
      CALL Q4(QA.QB.RQ.THQ.DTHQ.AKXQ.AKZQ.XQ.ZQ)
C
C
C  ASSEMBLE QA(IQ.JQ) AND QB(IQ.JQ) INTO THE TOTAL MATRIX
C  C(NP.IB) : B + A/DELT AND FORM THE LOAD VECTOR R(NP).
C  SINCE C IS SYMMETRIC. ONLY THE UPPER HALF BAND IS STORED
C
      IF(IMID.EQ.1) GO TO 51
   40 DO 50 IQ=1.4
         NI=IEM(IQ)
         R(NI)=R(NI)-RQ(IQ)
         DO 50 JQ=1.4
            NJ=IEM(JQ)
            QA(IQ.JQ)=QA(IC.JQ)*DELTI
            R(NI)=R(NI)+(QA(IQ.JQ)-W2*QB(IQ.JQ))*HP(NJ)
            IF (NJ.LT.NI) GO TO 50
            IB=NJ-NI+1
            C(NI.IB)=C(NI.IB)+QA(IQ.JQ)+W1*QB(IQ.JQ)
   50       CONTINUE
      GO TO 60
C
   51 DO 53 IQ=1.4
         NI=IEM(IQ)
         R(NI)=R(NI)-RQ(IQ)
         DO 52 JC=1.4
            NJ=IEM(JC)
            CA(IQ.JQ)=2.0D0*QA(IQ.JQ)*DELTI
            R(NI)=R(NI) + QA(IQ.JQ)*HP(NJ)
            IF(NJ.LT.NI) GO TC 52
            IB=NJ-NI+1
            C(NI.IB)=C(NI.IB)+QA(IQ.JQ)+QB(IQ.JQ)
   52       CONTINUE
   53    CONTINUE
   60 CONTINUE
    RETURN
    END
```

```
      SUBROUTINE Q4(QA,QB.RQ,THQ.DTHQ.AKXQ.AKZQ.XQ, ZQ)
C
C
C    FUNCTION OF SUBROUTINE--TO EVALUATE THE MATRIX QUADRATURES OVER THE
C    AREA OF ONE ELEMENT OF WATER CONTENT AND COMPRESSIBILITY QA(IQ,JQ)
C    AND OF CONDUCTIVITY QB(IQ,JQ) AND RQ(IQ), THE LATTER ARISING FROM THE
C    GRAVITY TERM IN THE MOISTURE-FLOW EQUATION. THESE INTEGRALS ARISE
C    THROUGH APPLICATION OF THE GALERKIN INTEGRATION SCHEME.
C
C
      IMPLICIT REAL*8 (A-H.O-Z)
      REAL*8 N(4)
C
      COMMON /Q4PAR/ ALF.BETAP.POR.SNFE.CSFE
      COMMON /OPT/ ILUNF.IMID
C
      DIMENSION QA(4.4).QB(4.4).RQ(4).THQ(4).DTHQ(4).AKXQ(4).AKZQ(4),
     > XQ(4).ZQ(4)
      DIMENSION S(4).T(4).DNX(4).DNZ(4)
      DIMENSION PJAB(2.2).DNSS(4).DNTT(4)
C
      DATA P / 0.577350269189626 /, S / -1.0D+00, 1.0D+00, 1.0D+00,-
     > 1.0D+00 /, T / -1.0D+00,-1.0D+00, 1.0D+00, 1.0D+00 /
C
C    INITIALIZE MATRICES QA, QB, AND RQ
C
      DO 10 IQ=1.4
         RQ(IQ)=0.
         DO 10 JQ=1.4
            QB(IQ.JQ)=0.0
 10         QA(IQ.JQ)=0.0
C
      DO 40 KG=1.4
C
C    DETERMINE LOCAL COORDINATES (SS,TT) OF GAUSS-INTEGRATION POINT KG
C
         SS = P*S(KG)
         TT = P*T(KG)
C
C    CALCULATE VALUES OF THE BASIS FUNCTIONS N(IQ) AND THEIR DERIVATIVES
C    DNX AND DNZ W.R.T X AND Z, RESPECTIVELY, AT THE GAUSS POINT KG
C
         CALL BASE(N.DNSS.DNTT.SS.TT)
C
C
         DO 11 I=1.2
            DO 11 J=1.2
 11            PJAB(I.J)=0.0
         DO 12 I=1.4
            PJAB(1.1)=PJAB(1.1)+ZQ(I)*DNTT(I)
```

```
            PJAB(1,2)=PJAB(1,2)-ZQ(I)*DNSS(I)
            PJAB(2,1)=PJAB(2,1)-XQ(I)*DNTT(I)
   12       PJAB(2,2)=FJAB(2,2)+XQ(I)*DNSS(I)
         DJAC=PJAB(2,2)*PJAB(1,1)-PJAB(1,2)*PJAB(2,1)
         DJACI=1.0/DJAC
         DO 13 I=1,2
            DO 13 J=1,2
   13          PJAB(I,J)=PJAB(I,J)*DJACI
         DO 14 I=1,4
            DNX(I)=DNSS(I)*PJAB(1,1)+DNTT(I)*PJAB(1,2)
   14       DNZ(I)=DNSS(I)*PJAB(2,1)+DNTT(I)*PJAB(2,2)
C
         AKXQP=0.
         AKZQP=0.
         THQP=C.
         DTHQP=0.
C
C  ACCUMULA TE THE SUMS TO EVALUATE THE MATRIX INTEGRALS QA(IQ,JQ),
C  QB(IQ,JQ), AND RG(IG)
C
         DO 20 IQ=1,4
            AKXQP=AKXQP+AKXQ(IQ)*N(IQ)
            AKZQP=AKZQF+AKZQ(IQ)*N(IQ)
            THQP=THQP+THQ(IQ)*N(IQ)
   20       D1;HQP=DTHQF+DTHQ(IQ)*N(IQ)
         FHP=ALP*THQP/PCR+BETAP*THQP+DTHQP
         AKXQP=AKXQP*DJAC
         AKZQP=AKZQP*DJAC
         FHP=FHP*DJAC
         DO 30 IQ=1,4
            RQ(IQ)=RQ(IQ)-DNX(IQ)*AKXQP*SNFE+DNZ(IQ)*AKZQP*CSFE
            DO 30 JQ=1,4
               QA(IQ,JQ)=QA(IG,JQ)+FHP*N(IQ)*N(JQ)
               QB(IQ,JQ)=QB(IG,JQ)+DNX(IQ)*AKXQP*DNX(JQ) +
     >                   DNZ(IQ)*AKZQP*DNZ(JQ)
   30          CONTINUE
   40    CONTINUE
      IF(ILUMP.NE.0) GG TG 50
C
      RETURN
   50 CONTINUE
      DO 52 I=1,4
         SUM=0.C
         DO 52 J=1,4
            SUM=SLM+CA(I,J)
   51       QA(I,J)=0.0
         QA(I,I)=SUN
   52    CONTINLE
      RETURN
      END
```

```
      SUBROUTINE BASE(N,DNSS,DNTT,SS,TT)                                BASE 005
C                                                                       BASE 010
C  FUNCTION OF THE SUBROUTINE-TO COMPUTE THE VALUES OF BASIS FUNCTIONS  BASE 015
C                                                                       BASE 020
C                                                                       BASE 025
      IMPLICIT REAL*8 (A-H,O-Z)                                         BASE 030
      REAL*8 N(4)                                                       BASE 035
C                                                                       BASE 040
      DIMENSION DNSS(4),DNTT(4)                                         BASE 045
C                                                                       BASE 050
      SM=1.0-SS                                                         BASE 055
      SP=1.0+SS                                                         BASE 060
      TM=1.0-TT                                                         BASE 065
      TP=1.0+TT                                                         BASE 070
      N( 1)=0.25*SM*TM                                                  BASE 075
      N( 2)=0.25*SP*TM                                                  BASE 080
      N( 3)=0.25*SP*TP                                                  BASE 085
      N( 4)=0.25*SM*TP                                                  BASE 090
      DNSS(1)=-0.25*TM                                                  BASE 095
      DNSS(2)=0.25*TM                                                   BASE 100
      DNSS(3)=0.25*TP                                                   BASE 105
      DNSS(4)=-0.25*TP                                                  BASE 110
      DNTT(1)=-0.25*SM                                                  BASE 115
      DNTT(2)=-0.25*SP                                                  BASE 120
      DNTT(3)=0.25*SP                                                   BASE 125
      DNTT(4)=0.25*SM                                                   BASE 130
      RETURN                                                            BASE 135
      END                                                               BASE 140
```

Appendix C (continued)

```
      SUBROUTINE BC(C,R, FLX,HCON,NPCON,NPFLX, RP,NPST, BB,NN,
     > MAXNP,MAXHBP, MXRSNP,MXSTNP,MAXBCN, KSS)
C
C
C  FUNCTION OF SUBROUTINE--TO APPLY BOTH CONSTANT AND TIME-VARYING
C  (RAINFALL-SEEPAGE) FLUX-TYPE NEUMANN AND PRESSURE-TYPE DIRICHLET
C  BOUNDARY CONDITIONS.
C
C
      IMPLICIT REAL*8(A-H,O-Z)
C
      DIMENSION C(MAXNP,MAXHBP),R(MAXNP)
      DIMENSION FLX(MXRSNP),HCON(MXRSNP),NPCON(MXRSNP),NPFLX(MXRSNP)
      DIMENSION RP(MXSTNP),NPST(MXSTNP),BB(MAXBCN),NN(MAXBCN)
C
      COMMON /GEOM/ SNFE,CSFE,NNP,NEL,IBAND
      COMMON /BRSND/ NBEL,NBN,NRSEL,NRSN,NRFPR,NRFPAR
      COMMON /BCST/ NBC,NST,NSTN
C
      IHALFB=(IBAND-1)/2
      IHBP=IHALFB+1
      IF (NBC.EQ.0) GO TO 90
C
C  APPLY CONSTANT DIRICHLET BOUNDARY CONDITIONS
C
      DO 80 NPP=1,NBC
C
C  MODIFY LOAD VECTOR FOR NON-ZERO BB
C
         NI=NN(NPP)
         IF (BB(NPP).EQ.0.0) GO TO 40
         DO 10 IB=1,IHALFB
              NJ=NI-IB
            IF (NJ.LT.1) GO TO 20
            JB=IB+1
   10       R(NJ)=R(NJ)-BB(NPP)*C(NJ,JB)
   20    DO 30 IB=1,IHALFB
            NJ=NI+IB
            IF (NJ.GT.NNP) GO TO 40
            JB=IB+1
   30       R(NJ)=R(NJ)-BB(NPP)*C(NI,JB)
   40    R(NI)=BB(NPP)
C
C  ZERO COLUMN NN
C
         DO 50 IB=1,IHALFB
            NJ=NI-IB
            IF (NJ.LT.1) GO TO 60
            JB=IB+1
   50       C(NJ,JB)=0.0
```

Appendix C (continued)

```
C
C   MODIFY ROW NN
C
  60     DO 70 KB=1,IHBP
  70        C(NI,KB)=0.0
         C(NI,1)=1.0
  80     CONTINUE
C
C   MODIFY LOAD VECTOR FOR CONSTANT SURFACE TERMS OF THE FORM DR/DT=C
C
  90 IF (NST.EQ.0) GO TO 110
        DO 100 NPP=1,NSTN
         NP=NPST(NPP)
 100     R(NP)=R(NP)-RF(NPP)
 110 IF (NRSN.EQ.0) GO TO 210
C
C   APPLY DIRICHLET TIME-VARIABLE (RAINFALL-SEEPAGE) CONDITIONS
C
        DO 190 NPP=1,NRSN
C
C   MODIFY LOAD VECTOR FOR NON-ZERO HCON
C
         NI=NPCON(NPP)
         IF (NI.EQ.0) GO TO 190
         IF (HCON(NI).EQ.0.0) GO TO 150
         DO 120 IB=1,IHALFB
            NJ=NI-IB
            IF (NJ.LT.1) GO TO 130
            JB=IB+1
 120        R(NJ)=R(NJ)-HCON(NPP)*C(NJ,JB)
 130     DO 140 IB=1,IHALFB
            NJ=NI+IB
            IF (NJ.GT.NNP) GO TO 150
            JB=IB+1
 140        R(NJ)=R(NJ)-HCON(NPP)*C(NI,JB)
 150     R(NI)=HCON(NPP)
C
C   ZERO COLUMN NPCON
C
         DO 160 IB=1,IHALFB
            NJ=NI-IB
            IF (NJ.LT.1) GO TO 170
            JB=IB+1
 160        C(NJ,JB)=0.0
C
C   MODIFY ROW NPCON
C
 170     DO 180 KB=1,IHBP
 180        C(NI,KB)=0.0
         C(NI,1)=1.0
```

Appendix C (continued)

```
  190     CONTINUE                                                          BC   505
C                                                                           BC   510
C  APPLY NEUMANN TIME-VARIABLE (RAINFALL-SEEPAGE) CONDITIONS                BC   515
C                                                                           BC   520
      DO 200 NPP=1.NRSN                                                     BC   525
          NP=NPFLX(NPP)                                                     BC   530
          IF (NP.EQ.0) GO TO 200                                            BC   535
          R(NP)=R(NP)-FLX(NPP)                                              BC   540
  200     CONTINUE                                                          BC   545
  210 RETURN                                                                BC   550
      END                                                                   BC   555
```

```
      SUBROUTINE BANSCL(KKK,C,R,NNP,IHBP,MAXNP,MAXHBP)
C
C     FUNCTION OF SUBROUTINE--TO SOLVE THE MATRIX EQUATION CX = R,
C     RETURNING THE SOLUTION X IN R.  IT IS ASSUMED THAT THE ARRAY
C     C(NP,IB) CONTAINS ONLY THE UPPER HALF BAND OF A SYMMETRIC MATRIX.
C
C
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION C(MAXNP,MAXHBP),R(MAXNP)
C
      IHALFB=IHBP-1
      NNP1=NNP-1
C
C     IF KKK = 1, THEN TRIANGULARIZE THE BAND MATRIX C(NP,IB), BUT
C     IF KKK = 2, THEN SIMPLY SOLVE WITH THE NEW RIGHT-HAND SIDE R(NP)
C
      IF (KKK.EQ.2) GO TO 50
C
C     TRIANGULARIZE MATRIX C
C
      NU=NNP-IHALFB
      DO 20 NI=1,NU
          NJ=NI-1
          PIVOTI=1./C(NI,1)
          DO 20 LB=2,IHBP
              A=C(NI,LB)*PIVOTI
              NK=NJ+LB
              JB=0
              DO 10 KB=LB,IHBP
                  JB=JB+1
   10             C(NK,JB)=C(NK,JB)-A*C(NI,KB)
   20         C(NI,LB)=A
      NL=NU+1
      DO 40 NI=NL,NNP1
          NJ=NI-1
          MB=NNP-NJ
          PIVOTI=1./C(NI,1)
          DO 40 LB=2,MB
              A=C(NI,LB)*PIVOTI
              NK=NJ+LB
              JB=0
              DO 30 KB=LB,MB
                  JB=JB+1
   30             C(NK,JB)=C(NK,JB)-A*C(NI,KB)
   40         C(NI,LB)=A
      RETURN
C
C     MODIFY LOAD VECTOR R
C
   50 NU=NNP-IHALFB
```

```
      DO 60 NI=1,NL                                                     BANS 255
         NJ=NI-1                                                        BANS 260
         A=R(NI)                                                        BANS 265
         R(NI)=A/C(NI,1)                                                BANS 270
         DO 60 LB=2,IHBP                                                BANS 275
            NK=NJ+LB                                                    BANS 280
   60       R(NK)=R(NK)-C(NI,LB)*A                                      BANS 285
      NL=NL+1                                                           BANS 290
      DO 70 NI=NL,NNP1                                                  BANS 295
         NJ=NI-1                                                        BANS 300
         MB=NNP-NJ                                                      BANS 305
         A=R(NI)                                                        BANS 310
         R(NI)=A/C(NI,1)                                                BANS 315
         DO 70 LB=2,MB                                                  BANS 320
            NK=NJ+LB                                                    BANS 325
   70       R(NK)=R(NK)-C(NI,LB)*A                                      BANS 330
C                                                                       BANS 335
C  BACK-SOLVE                                                           BANS 340
C                                                                       BANS 345
      R(NNP)=R(NNP)/C(NNP,1)                                            BANS 350
      DO 80 IB=1,IHALFB                                                 BANS 355
         NI=NNP-IB                                                      BANS 360
         NJ=NI-1                                                        BANS 365
         MB=IB+1                                                        BANS 370
         DO 80 KB=2,MB                                                  BANS 375
            NK=NJ+KB                                                    BANS 380
   80       R(NI)=R(NI)-C(NI,KB)*R(NK)                                  BANS 385
      DO 90 IB=IHBP,NNF1                                                BANS 390
         NI=NNP-IB                                                      BANS 395
         NJ=NI-1                                                        BANS 400
         DO 90 KB=2,IHBP                                                BANS 405
            NK=NJ+KB                                                    BANS 410
   90       R(NI)=R(NI)-C(NI,KB)*R(NK)                                  BANS 415
      RETURN                                                            BANS 420
      END                                                               BANS 425
```

```
      SUBROUTINE SFLOW(X,Z,IE, TH,VX,VZ, DLB,DCOSXB,DCOSZB,BFLX,BFLXP,
     > ISB,NBE,NPB, NPRS,      NPST,NN, FRATE,FLOW,TFLOW, MAXNP,MAXEL,
     > MAXBEL,MAXBNP, MXRSNP,          MXSTNP,MAXBCN,KFLOW,DELT,DTH,H,HP,
     > PROP,MAXMAT,MXNPPM)
C
C
C    FUNCTION OF SUBROUTINE--TO COMPUTE BOUNDARY FLUXES, FLOW RATES,
C    INCREMENTAL FLOWS OCCURRING DURING TIME DELT, TOTAL FLOWS SINCE
C    TIME ZERO, AND THE CHANGE IN MOISTURE CONTENT FOR THE ENTIRE
C    SYSTEM DURING TIME DELT.
C
C
      IMPLICIT REAL*8(A-H,O-Z)
C
      DIMENSION X(MAXNP),Z(MAXNP),IE(MAXEL,5)
      DIMENSION TH(MAXEL,4),VX(MAXNP),VZ(MAXNP)
      DIMENSION DTH(MAXEL,4),H(MAXNP),HP(MAXNP)
      DIMENSION DLB(MAXBEL),DCOSXB(MAXBEL),DCOSZB(MAXBEL),BFLX(MAXBNP),
     > BFLXP(MAXBNP),NBE(MAXBEL),ISB(MAXBEL,4),NPB(MAXBNP)
      DIMENSION NPRS(MXRSNP),                NPST(MXSTNP),NN(MAXBCN)
      DIMENSION PROP(MAXMAT,MXMPPM)
      DIMENSION FRATE(10),FLOW(10),TFLOW(10)
C
      DIMENSION XQ(4),ZQ(4),THQ(4)
C
      COMMON /GEOM/ SNFE,CSFE,NNP,NEL,IBAND
      COMMON /BRSND/ NBEL,NBN,NRSEL,NRSN,NRFPR,NRFPAR
      COMMON /BCST/ NBC,NST,NSTN
C
C
      KKFLOW=0
C
C    CALCULATE NODAL FLOW RATES
C
      DO 10 NP=1,NBN
         BFLXP(NP)=BFLX(NP)
   10    BFLX(NP)=0.
C
      DO 30 MP=1,NBEL
         M=NBE(MP)
         NI=ISB(MP,1)
         NJ=ISB(MP,2)
         DO 20 I=1,NBN
            IJ=NPB(I)
            IF(IJ.NE.NI) GO TO 20
            NII=I
            GO TO 22
   20       CONTINUE
   22    DO 25 J=1,NBN
            IJ=NPB(J)
```

```
            IF(IJ.NE.NJ) GO TO 25
            NJJ=J
            GO TO 27
   25       CONTINUE
   27    CONTINUE
C
C  COMPUTE THE FLUX THROUGH POINT NI USING THE WHOLE BOUNDARY LENGTH
C  AND THE FLUX THROUGH POINT NJ USING THE WHOLE BOUNDARY SIDE LENGTH
C
         FNI=(VX(NI)*DCOSXB(MP)+VZ(NI)*DCOSZB(MP))*DLB(MP)
         FNJ=(VX(NJ)*DCOSXB(MP)+VZ(NJ)*DCOSZB(MP))*DLB(MP)
C
C  DISTRIBUTE THE ABOVE FLUXES TO TWO END POINTS OF THE SIDE
C
         BFLX(NII)=BFLX(NII)+FNI/3.0+FNJ/6.0
         BFLX(NJJ)=BFLX(NJJ)+FNJ/3.0+FNI/6.0
C
   30    CONTINUE
      IF (KFLOW.EQ.0) GO TO 60
      DO 40 NP=1,NBN
   40    BFLXP(NP)=BFLX(NP)
      DO 50 I=1,6
   50    TFLOW(I)=0.
      IF (KFLOW.EQ.(-1)) TFLOW(7)=0.
      IF (KFLOW.EQ.(-1)) QTH=0.
      IF(KFLOW.EQ.(-1)) KKFLOW=-1
      KFLOW=0
C
C  DETERMINE FLOWS AND FLOW RATES THROUGH THE VARIOUS
C  TYPES OF BOUNDARY NODES, STARTING WITH THE
C  NET FLOWS THROUGH ALL BOUNDARY NODES.
C
   60 SUM=0.
      SUMP=0.
      DO 70 NP=1,NBN
         SUM=SUM+BFLX(NP)
   70    SUMP=SUMP+BFLXP(NP)
      FRATE(6)=SUM
      FLOW(6)=.5*(SUM+SUMP)*DELT
C
C  CONSTANT DIRICHLET BOUNDARY NODES
C
      FRATE(1)=0.
      FLOW(1)=0.
      IF (NBC.LE.0) GO TO 90
      SUM=0.
      SUMP=0.
      DO 80 NPP=1,NBC
         NP=NN(NPP)
         DO 75 I=1,NBN
```

```
            IJ=NPB(I)
            IF(IJ.NE.NP) GO TO 75
            NII=I
            GO TO 76
   75       CONTINUE
   76    CONTINUE
         SUM=SUM+BFLX(NII)
   80    SUMP=SUMP+BFLXP(NII)
      FRATE(1)=SUM
      FLOW(1)=.5*(SUM+SUMP)*DELT
C
C  CONSTANT NEUMANN BOUNDARY NODES
C
   90 FRATE(2)=0.
      FLOW(2)=0.
      IF (NST.LE.0) GO TO 110
      SUM=0.
      SUMP=0.
      DO 100 NPP=1,NSTN
         NP=NPST(NPP)
         DO 95 I=1,NBN
            IJ=NPB(I)
            IF(IJ.NE.NP) GO TO 95
            NII=I
            GO TO 96
   95       CONTINUE
   96    CONTINUE
         SUM=SUM+BFLX(NII)
  100    SUMP=SUMP+BFLXP(NII)
      FRATE(2)=SUM
      FLOW(2)=.5*(SUM+SUMP)*DELT
C
C  RAINFALL-SEEPAGE BOUNDARY NODES
C
  110 FRATE(3)=0.
      FLOW(3)=0.
      FRATE(4)=0.
      FLOW(4)=0.
      SUMS=0.
      SUMSP=0.
      SUMR=0.
      SUMRP=0.
      IF (NRSN.LE.0) GO TO 140
      DO 130 NPP=1,NRSN
         NP=NPRS(NPP)
         DO 115 I=1,NBN
            IJ=NPB(I)
            IF(IJ.NE.NP) GO TO 115
            NII=I
            GO TO 116
```

```
  115           CONTINUE                                                 SFLO 755
  116        CONTINUE                                                    SFLO 760
             BFLXA=.5*(BFLX(NII)+BFLXP(NII))                             SFLO 765
             IF (BFLXA.LT.0.D0) GO TO 120                                SFLO 770
             SUMS=SUMS+BFLX(NII)                                         SFLO 775
             SUMSP=SUMSP+BFLXA                                           SFLO 780
             GO TO 130                                                   SFLO 785
  120        SUMR=SUMR+BFLX(NII)                                         SFLO 790
             SUMRP=SUMRP+BFLXA                                           SFLO 795
  130        CONTINUE                                                    SFLO 800
          FRATE(3)=SUMS                                                  SFLO 805
          FLOW(3)=SUMSP*DELT                                             SFLO 810
          FRATE(4)=SUMR                                                  SFLO 815
          FLOW(4)=SUMRP*DELT                                             SFLO 820
C                                                                        SFLO 825
C  NUMERICAL FLOW THROUGH UNSPECIFIED BOUNDARY NODES                     SFLO 830
C                                                                        SFLO 835
  140     SUM=0.                                                         SFLO 840
          SUMP=0.                                                        SFLO 845
          DO 150 I=1,4                                                   SFLO 850
             SUM=SUM+FRATE(I)                                            SFLO 855
  150        SUMP=SUMP+FLOW(I)                                           SFLO 860
          FRATE(5)=FRATE(6)-SUM                                          SFLO 865
          FLOW(5)=FLOW(6)-SUMP                                           SFLO 870
C                                                                        SFLO 875
C  FINALLY, CALCULATE THE INCREASE IN THE INTEGRATED WATER CONTENT       SFLO 880
C                                                                        SFLO 885
          QTHP=QTH                                                       SFLO 890
          QTH=0.                                                         SFLO 895
          DO 170 M=1,NEL                                                 SFLO 900
             MTYP=IE(M,5)                                                SFLO 905
             ALP=PROP(MTYP,1)                                            SFLO 910
             BETAP=PROP(MTYP,2)                                          SFLO 915
             POR=PROP(MTYP,3)                                            SFLO 920
C                                                                        SFLO 925
             DO 160 IQ=1,4                                               SFLO 930
                NP=IE(M,IQ)                                              SFLO 935
                XQ(IQ)=X(NP)                                             SFLO 940
                ZQ(IQ)=Z(NP)                                             SFLO 945
                THQ(IQ)=TH(M,IQ)                                         SFLO 950
                IF(KKFLOW.GE.0) THQ(IQ)=(DTH(M,IQ)+THQ(IQ)*ALP/POR+BETAP)*SFLO 955
     >           (H(NP)-HP(NP))                                          SFLO 960
  160        CONTINUE                                                    SFLO 965
C                                                                        SFLO 970
             CALL Q4TH(QTHM,THQ,XQ,ZQ)                                   SFLO 975
C                                                                        SFLO 980
             QTH=QTH+QTHM                                                SFLO 985
  170        CONTINUE                                                    SFLO 990
          FLOW(7)=QTH                                                    SFLO 995
          IF(KKFLOW.LT.0)  FLOW(7)=0.0                                   SFLO1000
```

Appendix C (continued)

```
      FRATE(7)=FLOW(7)/DELT                                             SFL01005
      DO 180 I=1,7                                                      SFL01010
  180    TFLOW(I)=TFLOW(I)+FLOW(I)                                      SFL01015
      RETURN                                                            SFL01020
      END                                                               SFL01025
```

```
      SUBROUTINE Q4TH(QTHM.THQ.XQ.ZQ)
C
C  FUNCTION OF SUBROUTINE--TO EVALUATE THE WATER-CONTENT INTEGRAL
C  OVER THE AREA OF ONE ELEMENT.
C
      IMPLICIT REAL*8 (A-H.O-Z)
      REAL*8 N(4)
C
      DIMENSION THQ(4).S(4).T(4).XQ(4).ZQ(4)
      DIMENSION PJAB(2.2).DNSS(4).DNTT(4)
C
      DATA P / 0.577350269189626 /. S / -1.0D+00, 1.0D+00, 1.0D+00.-
     > 1.0D+00 /. T / -1.0D+00.-1.0D+00, 1.0D+00, 1.0D+00 /
C
      QTHM=0.
      DO 20 KG=1.4
C
C  DETERMINE LOCAL COORDINATES (SS.TT) OF GAUSS-INTEGRATION POINT KG
C
         SS = P*S(KG)
         TT = P*T(KG)
C
C  CALCULATE VALUES OF THE BASIS-INTERPOLATION FUNCTIONS N(IQ)
C
         CALL BASE(N.DNSS.DNTT.SS.TT)
C
         DO 11 I=1.2
            DO 11 J=1.2
 11            PJAB(I.J)=0.0
         DO 12 I=1.4
            PJAB(1.1)=PJAB(1.1)+ZQ(I)*DNTT(I)
            PJAB(1.2)=PJAB(1.2)-ZQ(I)*DNSS(I)
            PJAB(2.1)=PJAB(2.1)-XQ(I)*DNTT(I)
 12         PJAB(2.2)=PJAB(2.2)+XQ(I)*DNSS(I)
         DJAC=PJAB(2.2)*PJAB(1.1)-PJAB(1.2)*PJAB(2.1)
C
C  INTERPOLATE TO OBTAIN THE WATER CONTENT THQP AT THE GAUSS POINT KG
C
         THQP=0.
         DO 10 IQ=1.4
 10         THQP=THQP+THQ(IQ)*N(IQ)
C
C  ACCUMULATE THE SUM TO EVALUATE THE INTEGRAL
C
         QTHM=QTHM+THQP*DJAC
 20      CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PRINTT(VX,VZ,H,HT,TH, NPB,BFLX, NPRS,RSFLX,NPCON,NPFLX,
     > FRATE,FLOW,TFLOW, MAXNP,MAXEL, MAXBNP,MXRSNP, NNP,NEL, NBN,NRSN,
     > TIME,DELT,SUBHD,IBAND, KPR,KOUT,KDIAG,ITIM)
C
C
C    FUNCTION OF SUBROUTINE--TO OUTPUT FLOWS, PRESSURE HEADS, TOTAL
C    HEADS, WATER CONTENTS, AND DARCY VELOCITIES AS SPECIFIED BY
C    PARAMETER KPR.
C
C
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*4 SUBHD
C
      DIMENSION VX(MAXNP),VZ(MAXNP),H(MAXNP),HT(MAXNP),TH(MAXEL,4)
      DIMENSION NPB(MAXBNP),BFLX(MAXBNP),NPRS(MXRSNP),RSFLX(MXRSNP),
     > NPCON(MXRSNP),NPFLX(MXRSNP)
      DIMENSION FRATE(10),FLOW(10),TFLOW(10)
      DIMENSION SUBHD(8)
C
C
C
      IF (KDIAG.NE.0) GO TO 10
      KDIAG=1
      GO TO 30
C
C    PRINT DIAGNOSTIC FLOW INFORMATION
C
   10 KDIAG=KDIAG+1
      KDIA=KDIAG-1
      IF(KPR.EQ.0) RETURN
      PRINT 10600, KDIA, TIME,DELT, (FRATE(I),FLOW(I),TFLOW(I),I=1,7)
      IF (NRSN.EQ.0) GO TO 30
      DO 20 NPP=1,NRSN
         NP=NPRS(NPP)
         DO 15 I=1,NBN
            IJ=NPB(I)
            IF(IJ.NE.NP) GO TO 15
            NKK=I
            GO TO 20
   15       CONTINUE
   20    RSFLX(NPP)=BFLX(NKK)
      PRINT 10700
      PRINT 10100,(RSFLX(NPP),NPP=1,NRSN)
      PRINT 10101,(NPCON(NPP),NPP=1,NRSN)
      PRINT 10102, (NPFLX(NPP),NPP=1,NRSN)
   30 IF (KPR.EQ.1) RETURN
C
C    PRINT PRESSURE HEADS
C
      KOUT=KOUT+1
```

```
      KLINE=-1
      PRINT 10200,KOUT,TIME,DELT,IBAND,ITIM,(SUBHD(I),I=1,8)
      DO 40 NI=1,NNP,8
         NJMN=NI
         NJMX=MINO(NI+7,NNP)
         KLINE=KLINE+1
         IF(MOD(KLINE,50).EQ.0 .AND. KLINE.GE.1) PRINT 10200,KOUT,TIME,
     >      DELT,IBAND,ITIM,(SUBHD(I),I=1,8)
   40    PRINT 10000,NI,(H(NJ),NJ=NJMN,NJMX)
      IF (KPR.EQ.2) RETURN
C
C   PRINT TOTAL HEADS
C
      KOUT=KOUT+1
      KLINE=-1
      PRINT 10300,KOUT,TIME,DELT,IBAND,ITIM,(SUBHD(I),I=1,8)
      DO 50 NI=1,NNP,8
         NJMN=NI
         NJMX=MINO(NI+7,NNP)
         KLINE=KLINE+1
         IF(MOD(KLINE,50).EQ.0 .AND. KLINE.GE.1) PRINT 10300,KOUT,TIME,
     >      DELT,IBAND,ITIM,(SUBHD(I),I=1,8)
   50    PRINT 10000,NI,(HT(NJ),NJ=NJMN,NJMX)
      IF(KPR.EQ.3) RETURN
C
C   PRINT WATER CONTENTS
C
      KOUT=KOUT+1
      KLINE=-1
      PRINT 10400,KOUT,TIME,DELT,IBAND,ITIM,(SUBHD(I),I=1,8)
      DO 60 M=1,NEL,2
         KLINE=KLINE+1
         IF(MOD(KLINE,50).EQ.0 .AND. KLINE.GE.1) PRINT 10400,KOUT,TIME,
     >      DELT,IBAND,ITIM,(SUBHD(I),I=1,8)
         NJMN=M
         NJMX=MINO(M+1,NEL)
   60    PRINT 10103, (MJ,(TH(MJ,IQ),IQ=1,4),MJ=NJMN,NJMX)
      IF (KPR.EQ.4) RETURN
C
C   PRINT DARCY VELOCITIES
C
      KOUT=KOUT+1
      KLINE=-1
      PRINT 10500,KOUT,TIME,DELT,IBAND,ITIM,(SUBHD(I),I=1,8)
      DO 70 NP=1,NNP,4
         KLINE=KLINE+1
         IF(MOD(KLINE,50).EQ.0 .AND. KLINE.GE.1) PRINT 10500,KOUT,TIME,
     >      DELT,IBAND,ITIM,(SUBHD(I),I=1,8)
         NJMN=NP
         NJMX=MINO(NP+3,NNP)
```

Appendix C (continued)

```
   70    PRINT 11000, (NJ,VX(NJ),VZ(NJ),NJ=NJMN,NJMX)
      RETURN
C
10000 FORMAT(I7.8(1PD15.4))
10100 FORMAT(8D15.4)
10101 FORMAT(1H0,'VALUES OF NFCON'/(8I15))
10102 FORMAT(1H0,'VALUES OF NPFLX'/(8I15))
10103 FORMAT(1H .2(1X.I7.2X.1PD12.4.1PD12.4.1PD12.4.1PD12.4.2X, ))
10200 FORMAT(13H1OUTPUT TABLE.I4.27H.. PRESSURE HEADS AT TIME =,
     > 1PD12.4.5H .(DELT =.1PD12.4.15H).(BAND WIDTH =.I4.1H).6H  IT =.
     > I5//1X.8A4/1X.7H NODE I.5X.36HPRESSURE HEAD OF NODES I.I+1....I+7
     > /)
10300 FORMAT(13H1OUTPUT TABLE.I4.24H.. TOTAL HEADS AT TIME =, 1PD12.4.
     > 9H .(DELT =.1PD12.4.15H).(BAND WIDTH =.I4.1H).6H  IT =.I5//1X.8A4
     > /1X.7H NODE I.5X.33HTOTAL HEAD OF NODES I.I+1....I+7/)
10400 FORMAT(13H1OUTPUT TABLE.I4.27H.. WATER CONTENTS AT TIME =,
     > 1PD12.4.5H .(DELT =.1PD12.4.15H).(BAND WIDTH =.I4.1H).6H  IT =.
     > I5//1X.8A4/30X.5HNODES/2(17X.1H1.11X.1H2.11X.1H3.11X.1H4.6X)/
     > 2(3X.7HELEMENT.2X.
     > 46H**********************************************.2X)/)
10500 FORMAT(13H1OUTPUT TABLE.I4.29H.. DARCY VELOCITIES AT TIME =.
     > 1PD12.4.5H .(DELT =.1PD12.4.15H).(BAND WIDTH =.I4.1H).6H  IT =.
     > I5//1X.8A4/2X.4HNODE.9X.2HVX.9X.2HVZ.4X.4HNODE.9X.2HVX.9X.2HVZ.
     > 4X.4HNODE.9X.2HVX.9X.2HVZ.4X.4HNODE.9X.2HVX.9X.2HVZ/
     > 27H***************************.3X.27H***************************.
     >3X.27H***************************.3X.27H**************************
     >*/)
10600 FORMAT(1H1.32H TABLE OF SYSTEM-FLOW PARAMETERS.2X.7HTABLE: .I4.
     > 12H.. AT TIME =.1PD12.4.9H .(DELT = 1PD12.4.1H)//5X..
     > 13H TYPE OF FLOW.35X.4HRATE.8X.9HINC. FLOW.7X.10HTOTAL FLOW/5X
     > 40H CONSTANT-PRESSURE-NODE FLOW . . . . . . ..3(E12.4.5X)/5X
     > 40H CONSTANT-FLUX-NODE FLOW . . . . . . . . ..3(E12.4.5X)/5X
     > 40H SEEPAGE . . . . . . . . . . . . . . . . ..3(E12.4.5X)/5X
     > 40H RAINFALL. . . . . . . . . . . . . . . . ..3(E12.4.5X)/5X
     > 40H NUMERICAL LOSSES. . . . . . . . . . . . ..3(E12.4.5X)/5X
     > 40H NET FLOW. . . . . . . . . . . . . . . . ..3(E12.4.5X)/5X
     > 40H INCREASE IN VOLUMETRIC WATER CONTENT. ..3(E12.4.5X))
10700 FORMAT(/29H RAINFALL-SEEPAGE NODAL FLOWS)
11000 FORMAT(1H .I5.2D11.3.3X.I5.2D11.3.3X.I5.2D11.3.3X.I5.2D11.3)
      END
```

```
      SUBROUTINE STORE(X,Z,IE,H,HT,TH,VX,VZ,DLB,DCOSXB,DCOSZB,NBE,ISB,
     > NPB,TITLE,TIME,MAXNP,MAXEL,MAXBNP,MAXBEL,NPROB,NNP,NEL,NBN,NBEL,
     > NTI, NPCON,NPFLX,MXRSNP,NRSN, NSTRT)
C
C
C   FUNCTION OF SUBROUTINE--TO STORE PERTINENT QUANTITIES ON AUXILIARY
C   DEVICE FOR FUTURE USE BY EITHER PLOTTING OR MATERIAL-TRANSPORT
C   CODES.  WHAT DEVICE IS TO BE USED MUST BE SPECIFIED BY APPROPRIATE
C   JOB-CONTROL CARDS.
C
      IMPLICIT REAL*8(A-H,O-Z)
C
      DIMENSION TITLE(9)
      DIMENSION X(MAXNP),Z(MAXNP),IE(MAXEL,5)
      DIMENSION H(MAXNP),HT(MAXNP),VX(MAXNP),VZ(MAXNP),TH(MAXEL,4)
      DIMENSION DLB(MAXBEL),DCOSXB(MAXBEL),DCOSZB(MAXBEL),NBE(MAXBEL),
     > ISB(MAXBEL,4),NPB(MAXBNP)
      DIMENSION NPCON(MXRSNP),NPFLX(MXRSNP)
C
      DATA NPPROB/-1/
C
      IF (NSTRT.GT.0) GO TO 10
      IF (NPPROB.EQ.(-1)) REWIND 1
      IF (NPPROB.EQ.NPROB) GO TO 10
      WRITE(1) (TITLE(I),I=1,9),NPROB,NNP,NEL,NBN,NBEL,NTI,NRSN
      WRITE(1) (X(NP),NP=1,NNP),(Z(NP),NP=1,NNP),((IE(M,IQ),M=1,NEL),IQ=
     >  1,4), (DLB(M),M=1,NBEL),(DCOSXB(M),M=1,NBEL),(DCOSZB(M),M=1,
     > NBEL),(NBE(M),M=1,NBEL),((ISB(M,IQ),M=1,NBEL),IQ=1,4),
     > (NPB(NP),NP=1,NBN)
      NPPROB=NPROB
C
C
C   DUE TO CHANGES IN THE MATERIAL-TRANSPORT CODE, DARCY VELOCITIES MAY
C   BE USED DIRECTLY, AND IT IS UNNECESSARY TO COMPUTE PORE QUANTITIES
C
   10 WRITE(1) TIME,(H(NP),NP=1,NNP),(HT(NP),NP=1,NNP),((TH(M,IQ),M=1,
     > NEL),IQ=1,4),(VX(NP),NP=1,NNP),(VZ(NP),NP=1,NNP),
     > (NPCON(NP),NP=1,NRSN),(NPFLX(NP),NP=1,NRSN)
      RETURN
      END
```