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Training Course No. 1: The Implementation of FEMWATER (ORNL-5567) Computer Program

Final Report

Prepared by G. T. Yeh

Oak Ridge National Laboratory

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ABSTRACT

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This report documents a training course conducted for the U.S. Nuclear Regulatory Commission (NRC) on the implementation of a Finite Element Model of WATER flow through saturated-unsaturated porous media (FEMWATER) - ORNL-5567. In addition to present basic program operation (APPENDIX A-V), the course also covered the following topics: (1) Mathematical equations and physical principles that lead to the code development (APPENDIX A-I), (2) The finite element method (APPENDIX A-II), (3) Finite-element derivation of FEMWATER (APPENDIX A-III), (4) FEMWATER program structure (APPENDIX A-IV), (5) Uniqueness and limitations of FEMWATER (APPENDIX A-VI), and (6) Running of 4 sample problems (APPENDIX B) to demonstrate various options that FEMWATER can handle. The purpose of the training seminar is to enable the NRC staff to use the model (and to be able to modify the code if necessary) for checking information provided by a licensee, for evaluating alternative sites and designs for burial, and for comparing their results from other method of solution.

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INTRODUCTION

This report provides a summary and documentation of a training course conducted for the Low-Level Waste Licensing Branch of the U.S. Nuclear Regulatory Commission (NRC) by Oak Ridge National Laboratory (ORNL) on August 25-27, 1981. The course was designed to assist NRC scientists in using a Finite Element Model of WATER flow through saturated-unsaturated porous media (FEMWATER) - ORNL-5567. Use of this report should be in conjunction with the FEMWATER document for assistance in using the FEMWATER code.

COURSE OBJECTIVES AND SCOPES

The main objective of the course was to present the basic operational procedure of the FEMWATER program. The ultimate purpose is to enable the NRC staff to use the code for checking information provided by a licensee, for evaluating alternative sites and designs for burial, and for comparing their results with other methods of solution. To effectively achieve these objectives, a fundamental knowledge of mathematical and physical principles that form the basis of the program is required. Complete understanding of the function of all subroutines in the program is also required. Thus, in addition to basic program operation (mainly APPENDIX A-V), the course covered the following topics:

(1) Mathematical equations and physical principles that lead to the code development,

(2) Introduction to the finite element method in a simple way,

(3) Application of FEM to the governing equations,

(4) FEMWATER program structure,

(5) Uniqueness and limitations of the program, and

(6) Running of four sample problems.

COURSE MATERIALS

Materials that were distributed to the participants are included in the appendices of this report, except for the computer output of the four sample problems. The outputs of these four problems are given in the microfishe that is attached to the inside page of the back cover. Appendix A of this report includes the class notes used in the lecture presentation and some additional useful explanation. Appendix B contains complete input data of four sample problems given in the training seminar. Appendix C lists the FORTRAN source program that was converted to the CDC machine by Derek A. Widmayer of NRC.

CLASS EXERCISE

Following the course presentation, participants were given opportunities to actually code the input data for one of the sample problems. Enthusiastic discussion took place concerning the time-step size, computation of the number of time steps, interpreting soil properties from the curve to data digit, and automatic generation of data input. Interpretation of the output, which was executed on the IBM machine, was thoroughly discussed with the participants.

APPENDIX A: COURSE NOTES

A-I. FORMULATION OF GOVERNING EQUATIONS

A-I.1. Introduction

The derivation of the governing equations for groundwater flow is based on the following laws:

(1) Continuity of fluid,

(2) Continuity of solid,

(3) Motion of fluid,

(4) Consolidation of the medium, and

(5) Compressibility of water.

These aspects will be discussed in the next section and followed by a discussion on specification of initial and boundary conditions.

A-I.2. Derivation of Governing Equations

1. Continuity of fluid:

$$\frac{D}{Dt}\int_{\upsilon} (S\rho_f\, n_e)\, d\upsilon = -\int_{\Gamma} \vec{n} \cdot (\rho_f\, \vec{V}_{fs})\, d\Gamma \quad . \tag{1}$$

S = degree of saturation (dimensionless),

ρ_f = fluid density (M/L^3),

n_e = effective porosity (dimensionless),

$\vec{n}$ = outward unit vector to Γ,

$\vec{V}_{fs}$ = fluid velocity relative to solid matrix (L/T),

υ = volume of the region (L^3), and

Γ = surface enclosing the volume (L^2).

Equation (1) simply states that total rate of change of water mass within the volume υ is equal to the net mass flux through the enclosing surface Γ, which may expand or contract because of consolidation of bulk material.

Using the Reynold's transport theorem, one may rewrite Eq. (1) as

$$\int_{\upsilon} \frac{\partial(S\rho_f n_e)}{\partial t} d\upsilon + \int_{\Gamma} \vec{n} \cdot (S\rho_f n_e \vec{V}_s) d\Gamma + \int_{\Gamma} \vec{n} \cdot (\rho_f \vec{V}_{fs}) d\Gamma = 0 \quad , \tag{2}$$

where V_s = the velocity of the surface or the solid matrix. Because υ can be arbitrary, Eq. (2) can be written in differential form as

$$\frac{\partial(S\rho_f n_e)}{\partial t} + \nabla \cdot (\rho_f n_e S \vec{V}_s) + \nabla \cdot (\rho_f \vec{V}_{fs}) = 0 \quad , \tag{3}$$

where ∇ is the del operator.

2. Continuity of solid:

$$\frac{D}{Dt} \int_{\upsilon} \rho_b (1 - n_e) d\upsilon = 0 \quad , \tag{4}$$

where ρ_b is the bulk density of the medium. Equation (4) states that the total amount of solid material within the material volume υ (not the spatial volume) remains constant with time. By using Reynolds transport theorem, one can rewrite Eq. (4) into the following form:

$$\int_{\upsilon} \frac{\partial(1 - n_e)}{\partial t} d\upsilon + \int_{\Gamma} \vec{n} \cdot [(1 - n_e) \vec{V}_s] d\Gamma = 0 \quad . \tag{5}$$

Using the Gaussian divergence theorem and the fact that υ is arbitrary, we have

$$\frac{\partial(1 - n_e)}{\partial t} + \nabla \cdot [(1 - n_e) \vec{V}_s] = 0 \quad . \tag{6}$$

3. Motion of fluid (Darcy's law):

$$\vec{V}_{fs} = - \bar{\bar{K}} \cdot \nabla H = - \bar{\bar{K}} \cdot \nabla(h + z) \quad , \tag{7}$$

$$\bar{\bar{K}} = \frac{\rho_f g}{\mu_f} \bar{\bar{k}} \quad . \tag{8}$$

H = total head (L),

h = pressure head (L),

z = potential head (L),

$\bar{\bar{K}}$ = hydraulic conductivity tensor (L/T),

$\bar{\bar{k}}$ = permeability tensor (L^2),

μ_f = viscosity of fluid ($ML^{-1}\ T^{-1}$), and

g = gravitational acceleration (L/T^2).

4. Consolidation of the medium:

$$(\lambda_s + 2\mu_s)\nabla^2 e = \nabla^2 \sigma \quad , \tag{9}$$

where λ_s and μ_s = Lame constants, e = dilatation, and σ = normal stress = $\rho_f\, g\, h$.

5. Compressibility of water:

$$\rho_f = \rho_f^o \, e^{\beta(p - p_o)} = \rho_f^o \, e^{\beta' h} \, , \tag{10}$$

where $\beta' = \beta \, \rho_f \, g$ = modified compressibility of water and β = compressibility of water.

Expanding the continuity equation of fluid, Eq. (3):

$$S\rho_f \frac{\partial n_e}{\partial t} + n_e S \frac{\partial \rho_f}{\partial t} + n_e \rho_f \frac{\partial S}{\partial t} +$$

$$S\rho_f \, \nabla \cdot (n_e \, \vec{V}_s) + (n_e \, \vec{V}_s) \cdot \nabla \, (S\rho_f) + \nabla \cdot (\rho_f \, \vec{V}_{fs}) = 0 \quad . \tag{11}$$

The first and fourth terms can be combined to yield

$$S\rho_f \frac{\partial n_e}{\partial t} + S\rho_f \, \nabla \cdot (n_e \, \vec{V}_s) = S\rho_f \, [\frac{\partial n_e}{\partial t} + \nabla \cdot (n_e \, V_s)]$$

$$= S\rho_f \, \nabla \cdot \vec{V}_s \quad \text{, because of Eq. (6).} \tag{12}$$

Substitute Eq. (12) into Eq. (11):

$$n_e \, \rho_f \frac{\partial S}{\partial t} + n_e S \frac{\partial \rho_f}{\partial t} + S\rho_f \, \nabla \cdot \vec{V}_s +$$

$$\underbrace{(n_e \, \vec{V}_s) \cdot (\nabla \cdot S\rho_f)}_{0 \text{ second-order term}} + \nabla \cdot (\rho_f \, \vec{V}_{fs}) = 0 \quad . \tag{13}$$

Using the equation of fluid motion, Eq. (7), Eq. (13) becomes

$$n_e \rho_f \frac{\partial S}{\partial t} + n_e S \frac{\partial \rho_f}{\partial t} + S\rho_f \, \nabla \cdot \vec{V}_s = \nabla \cdot [\rho_f \, \bar{\bar{K}} \cdot (\nabla h + \nabla z)] \quad . \tag{14}$$

Note: up to this point, use has been made of the continuity of fluid, continuity of solid, and motion of fluid and of the assumption of neglecting second-order terms to yield Eq. (14).

Integration of the consolidation equation, Eq. (9), yields

$$(\lambda_s + 2\mu_s)e = \sigma + f \quad . \tag{15}$$

f = an integration function; it is zero if only vertical consolidation is considered. Taking the derivative of Eq. (15) with respect to time, we have

$$\frac{\partial e}{\partial t} = \frac{1}{(\lambda_s + 2\mu_s)} \frac{\partial \sigma}{\partial t} = \alpha \frac{\partial \sigma}{\partial t}, \tag{16}$$

$$\alpha = \frac{1}{(\lambda_s + 2\mu_s)} = \text{compressibility of consolidation.}$$

By definition:

$$e = \nabla \cdot \vec{U} \quad , \quad \vec{V}_s = \frac{\partial \vec{U}}{\partial t} \quad , \tag{17}$$

$\vec{U}$ = displacement vector.

Hence

$$\nabla \cdot \dot{V}_s = \frac{\partial(\nabla \cdot \vec{U})}{\partial t} = \frac{\partial e}{\partial t} = \alpha \frac{\partial \sigma}{\partial t} = \alpha \rho_f g \frac{\partial h}{\partial t} = \alpha' \frac{\partial h}{\partial t} \quad , \tag{18}$$

α' = modified compressibility of medium (= $\alpha \rho_f g$).

The moisture content, θ, is by definition given as

$$\theta = n_e S \quad . \tag{19}$$

The specific moisture capacity is defined as

$$\frac{d\theta}{dh} = n_e \frac{\partial S}{\partial h} \tag{20}$$

from which

$$\frac{d\theta}{dh}\frac{\partial h}{\partial t} = n_e \frac{\partial S}{\partial t} \quad . \tag{21}$$

From the equation of state for compressibility of water, Eq. (10), we have

$$\frac{\partial \rho_f}{\partial t} = \rho_f \, \beta' \, \frac{\partial h}{\partial t} \quad . \tag{22}$$

Substituting Eqs. (18), (19), (21), and (22) into Eq. (14), we have the governing equations, after neglecting the second-order term, $[K \cdot (\nabla h + \nabla z)] \cdot \nabla \rho_f$:

$$F \frac{\partial h}{\partial t} = \nabla \cdot [\bar{\bar{K}} \cdot (\nabla h + \nabla z)] \quad , \tag{23}$$

$$F = \frac{\theta}{n_e} \alpha' + \theta \beta' \frac{d\theta}{dh} \quad . \tag{24}$$

A-I.3. Specification of Initial and Boundary Conditions

* Dynamic point of view -- A boundary segment can be impervious or flow-through;
* Physical point of view -- A boundary segment can be a soil-soil interface, air-soil interface, or soil-water interface;

* Mathematical point of view -- A boundary segment can be a Dirichlet (prescribed head), a Neumann (prescribed derivative flux), a Cauchy (prescribed total flux), or a Variable (either Dirichlet or Cauchy).

These complex interrelationships are shown in Fig. A-1.

In summary:

Initial Conditions -

$$h = h_o\ (x,z) \text{ in } R \quad ; \tag{25}$$

Boundary Conditions -

$$h = h_1 \text{ on } B_1 \text{ (Dirichlet)} \quad , \tag{26}$$

$$-\vec{n} \cdot [\bar{\bar{K}} \cdot \nabla h] = q_2 \text{ on } B_2 \text{ (Neumann)} \quad , \tag{27}$$

$$-\vec{n} \cdot [\bar{\bar{K}} \cdot \nabla h + \bar{\bar{K}} \cdot \nabla z] = q_3 \text{ on } B_3 \text{ (Cauchy)} \quad , \tag{28}$$

$$h = h_4\ (x,z,t) \text{ on } B_4 \tag{29a}$$

or (Variable)

$$-\vec{n} \cdot [\bar{\bar{K}} \cdot (\nabla h + \nabla z] = q_4 \text{ on } B_4 \quad . \tag{29b}$$

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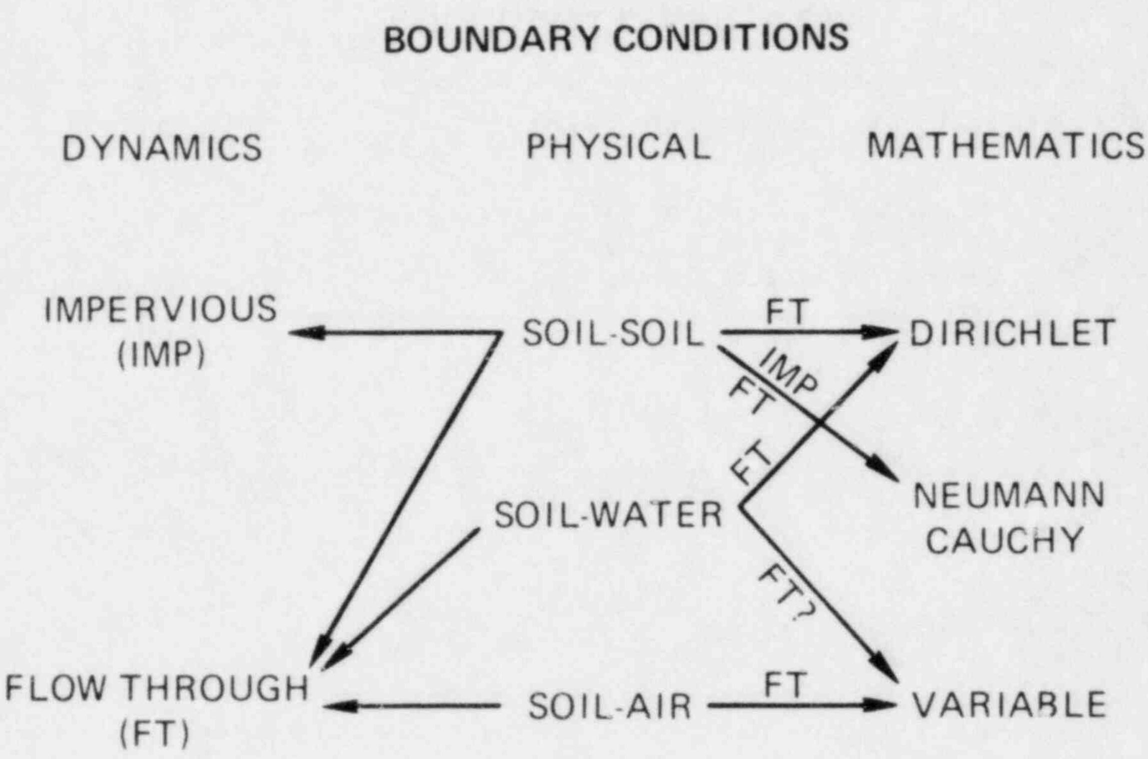


Fig. A-1. Boundary conditions from physical point of view, dynamic point of view, and mathematical point of view.

A-II. FINITE ELEMENT METHODS

A-II.1. Introduction

The following are the steps of applying the finite element method (FEM) to differential equations:

(1) Divide the region into elements and nodes,

(2) Define base functions for each node,

(3) Define weighting functions for each node,

(4) Approximate the function in terms of base functions and node values,

(5) Define the residual as the difference between true solution and approximate solution,

(6) Set weighted residual to zero,

(7) Derive the matrix equation,

(8) Incorporate boundary conditions to the matrix equation, and

(9) Use initial conditions to advance the solution through time.

A-II.2. A Simple Example

The steps of applying FEM to differential equations are best explained by showing how they are applied to a simple example. The governing equation of the simple example is

$$\frac{\partial f}{\partial t} - \frac{\partial^2 f}{\partial x^2} = 0 \quad . \tag{1}$$

The initial condition is

$$f = 0 \quad \text{at} \quad t = 0 \quad . \tag{2}$$

The boundary conditions are

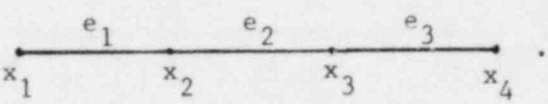
$$f = 1 \quad \text{at} \quad x = x_1 \tag{3}$$

and

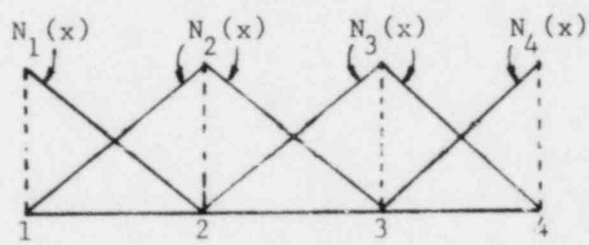
$$\frac{\partial f}{\partial x} = f \quad \text{at} \quad x = x_4 \quad . \tag{4}$$

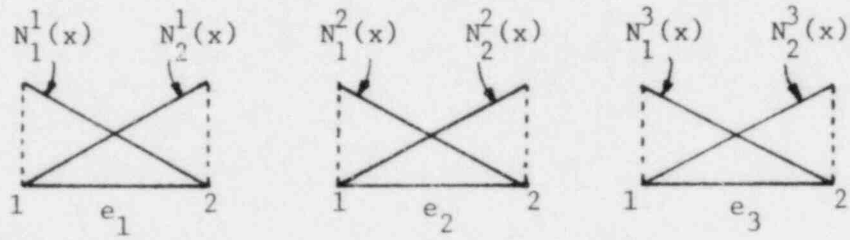
<u>Solution Procedure</u>

Step 1 - Divide region into 3 elements and four nodes:



Step 2 - Define base functions both globally and locally:





$N_1(x)$, $N_2(x)$, $N_3(x)$, $N_4(x)$ = base functions for nodes 1, 2, 3, and 4, respectively;

$N_1^1(x)$, $N_2^1(x)$ = the first- and second-node base function for element e_1;

$N_1^2(x)$, $N_2^2(x)$ = the first- and second-node base function for element e_2;

$N_1^3(x)$, $N_2^3(x)$ = the first- and second-node base function for element e_3.

It is seen that

* Over element e_1

$$N_1^1(x) = N_1(x),\ N_2^1(x) = N_2(x) \quad .$$

* Over element e_2

$$N_1^2(x) = N_2(x),\ N_2^2(x) = N_3(x) \quad .$$

* Over element e_3

$$N_1^3(x) = N_3(x),\ N_2^3(x) = N_4(x) \quad .$$

Step 3 - Define weighting functions:

$$\begin{aligned} W_1(x) &= N_1(x) \\ W_2(x) &= N_2(x) \\ W_3(x) &= N_3(x) \\ W_4(x) &= N_4(x) \end{aligned} \qquad \text{Galerkin Weighting} \qquad (5)$$

Step 4 - Approximate the solution by linear combination of base functions:

$$f \simeq \hat{f} = f_1(x)\,N_1(x) + f_2(x)\,N_2(x) + f_3(x)\,N_3(x) + f_4(x)\,N_4(x)$$

$$= \sum_{j=1}^{4} f_j(x)\,N_j(x) \quad . \tag{6}$$

Step 5 - Define residual:

$$R = \frac{\partial \hat{f}}{\partial t} - \frac{\partial^2 \hat{f}}{\partial x^2} \quad . \tag{7}$$

Step 6 - Set weighted residuals to zero:

$$\int_{x_1}^{x_4} W_i(x) \left\{ \frac{\partial \hat{f}}{\partial t} - \frac{\partial^2 \hat{f}}{\partial x^2} \right\} dx = 0 \quad , \tag{8}$$

$$i = 1,\ 2,\ 3,\ 4 \quad .$$

Step 7 - Derive matrix equation:

$$\int_{x_1}^{x_4} W_i(x) \frac{\partial \hat{f}}{\partial t}\, dx + \int_{x_1}^{x_4} \frac{dW_i(x)}{dx} \cdot \frac{\partial \hat{f}}{\partial x}\, dx = W_i(x) \frac{\partial \hat{f}}{\partial x} \Bigg|_{x=x_1}^{x=x_4} \quad , \tag{9}$$

$$\underbrace{\left(\int_{x_1}^{x_4} W_i\, N_j\, dx \right)}_{a_{ij}} \frac{df_j}{dt} + \underbrace{\left(\int_{x_1}^{x_4} \frac{dW_i}{dx} \frac{dN_j}{dx}\, dx \right)}_{b_{ij}} f_j = B_i \quad , \tag{10}$$

$$B_i = W_i(x) \frac{\partial \hat{f}}{\partial x} \Bigg|_{x=x_1}^{x=x_4} \qquad i = 1,\ 2,\ 3,\ 4 \quad , \tag{10a}$$

$$[a]\left\{\frac{df}{dt}\right\} + [b]\{f\} = \{B\} \quad , \tag{11}$$

where $[a]$ = mass matrix, $[b]$ = stiff matrix, and $\{B\}$ = boundary load vector,

$$a_{11}\frac{df_1}{dt} + a_{12}\frac{df_2}{dt} + a_{13}\frac{df_3}{dt} + a_{14}\frac{df_4}{dt} + b_{11}f_1 + b_{12}f_2 + b_{13}f_3 + b_{14}f_4 = B_1 \quad , \tag{12}$$

$$a_{21}\frac{df_1}{dt} + a_{22}\frac{df_2}{dt} + a_{23}\frac{df_3}{dt} + a_{24}\frac{df_4}{dt} + b_{21}f_1 + b_{22}f_2 + b_{23}f_3 + b_{24}f_4 = B_2 \quad , \tag{13}$$

$$a_{31}\frac{df_1}{dt} + a_{32}\frac{df_2}{dt} + a_{33}\frac{df_3}{dt} + a_{34}\frac{df_4}{dt} + b_{31}f_1 + b_{32}f_2 + b_{33}f_3 + b_{34}f_4 = B_3 \quad , \tag{14}$$

$$a_{41}\frac{df_1}{dt} + a_{42}\frac{df_2}{dt} + a_{43}\frac{df_3}{dt} + a_{44}\frac{df_4}{dt} + b_{41}f_1 + b_{42}f_2 + b_{43}f_3 + b_{44}f_4 = B_4 \quad , \tag{15}$$

$$\begin{aligned} a_{11} &= \int_{x_1}^{x_4} N_1N_1\,dx = \int_{x_1}^{x_2} N_1N_2\,dx + \int_{x_2}^{x_3} N_1N_2\,dx + \int_{x_3}^{x_4} N_1N_2\,dx \\ &= \underbrace{\int_{e_1} N_1^1N_1^1\,dx}_{a_{11}^1} + \int_{e_2} 0 \cdot 0\,dx + \int_{e_3} 0 \cdot 0\,dx \quad , \end{aligned} \tag{16}$$

$$\begin{aligned} a_{12} &= \int_{x_1}^{x_4} N_1N_2\,dx = \int_{x_1}^{x_2} N_1N_2\,dx + \int_{x_2}^{x_3} N_1N_2\,dx + \int_{x_3}^{x_4} N_1N_2\,dx \\ &= \underbrace{\int_{e_1} N_1^1N_1^1\,dx}_{a_{12}^1} + \int_{e_2} 0 \cdot N_1^2\,dx + \int_{e_3} 0 \cdot 0\,dx \quad , \end{aligned} \tag{17}$$

$$a_{13} = \int_{x_1}^{x_4} N_1N_3\ dx = \int_{x_1}^{x_2} N_1N_3\ dx + \int_{x_2}^{x_3} N_1N_3\ dx + \int_{x_3}^{x_4} N_1N_3\ dx$$

$$= \int_{e_1} N_1^1 \cdot 0\ dx + \int_{e_2} 0 \cdot N_2^2\ dx + \int_{e_3} 0 \cdot N_1^3 dx \quad , \tag{18}$$

$$a_{14} = \int_{x_1}^{x_4} N_1N_4\ dx = \int_{x_1}^{x_2} N_1N_4\ dx + \int_{x_2}^{x_3} N_1N_4\ dx + \int_{x_3}^{x_4} N_1N_4\ dx$$

$$= \int_{e_1} N_1^1 \cdot 0\ dx + \int_{e_2} 0 \cdot 0\ dx + \int_{e_3} 0 \cdot N_2^3 dx \quad , \tag{19}$$

$$a_{21} = \int_{x_1}^{x_4} N_2N_1\ dx = \int_{x_1}^{x_2} N_2N_1\ dx + \int_{x_2}^{x_3} N_2N_1\ dx + \int_{x_3}^{x_4} N_2N_1\ dx$$

$$= \underbrace{\int_{e_1} N_2^1N_1^1\ dx}_{a_{21}^1} + \int_{e_2} N_1^2 \cdot 0 dx + \int_{e_3} 0 \cdot 0\ dx \quad , \tag{20}$$

$$a_{22} = \int_{x_1}^{x_4} N_2N_2\ dx = \int_{x_1}^{x_2} N_2N_2\ dx + \int_{x_2}^{x_3} N_2N_2\ dx + \int_{x_3}^{x_4} N_2N_2\ dx$$

$$= \underbrace{\int_{e_1} N_2^1N_2^1\ dx}_{a_{22}^1} + \underbrace{\int_{e_2} N_1^2N_1^2\ dx}_{a_{11}^2} + \int_{e_3} 0 \cdot 0\ dx \quad , \tag{21}$$

$$a_{23} = \int_{x_1}^{x_4} N_2N_3\ dx = \int_{x_1}^{x_2} N_2N_3\ dx + \int_{x_2}^{x_3} N_2N_3\ dx + \int_{x_3}^{x_4} N_2N_3\ dx$$

$$= \int_{e_1} N_2^1 \cdot 0\ dx + \underbrace{\int_{e_2} N_1^2N_2^2 dx}_{a_{12}^2} + \int_{e_3} 0 \cdot N_1^3\ dx \quad , \tag{22}$$

$$a_{24} = \int_{x_1}^{x_4} N_2N_4\ dx = \int_{x_1}^{x_2} N_2N_4\ dx + \int_{x_2}^{x_3} N_2N_4\ dx + \int_{x_3}^{x_4} N_2N_4\ dx$$

$$= \int_{e_1} N_2^1 \cdot 0\ dx + \int_{e_2} N_1^2 \cdot 0\ dx + \int_{e_3} 0 \cdot N_2^3\ dx \quad , \tag{23}$$

$$a_{31} = \int_{x_1}^{x_4} N_3N_1\ dx = \int_{x_1}^{x_2} N_3N_1\ dx + \int_{x_2}^{x_3} N_3N_1\ dx + \int_{x_3}^{x_4} N_3N_1\ dx$$

$$= \int_{e_1} 0 \cdot N_1^1\ dx + \int_{e_2} N_2^2 \cdot 0\ dx + \int_{e_3} N_1^3 \cdot 0\ dx \quad , \tag{24}$$

$$a_{32} = \int_{x_1}^{x_4} N_3N_2\ dx = \int_{x_1}^{x_2} N_3N_2\ dx + \int_{x_2}^{x_3} N_3N_2\ dx + \int_{x_3}^{x_4} N_3N_2\ dx$$

$$= \int_{e_1} 0 \cdot N_2^1\ dx + \underbrace{\int_{e_2} N_2^2\ N_1^2\ dx}_{a_{21}^2} + \int_{e_3} N_1^3 \cdot 0\ dx \quad , \tag{25}$$

$$a_{33} = \int_{x_1}^{x_4} N_3N_3\ dx = \int_{x_1}^{x_2} N_3N_3\ dx + \int_{x_2}^{x_3} N_3N_3\ dx + \int_{x_3}^{x_4} N_3N_3\ dx$$

$$= \int_{e_1} 0 \cdot 0\ dx + \underbrace{\int_{e_2} N_2^2\ N_2^2\ dx}_{a_{21}^2} + \underbrace{\int_{e_3} N_1^3\ N_1^3\ dx}_{a_{11}^3} \quad , \tag{26}$$

$$a_{34} = \int_{x_1}^{x_4} N_3N_4\ dx = \int_{x_1}^{x_2} N_3N_4\ dx + \int_{x_2}^{x_3} N_3N_4\ dx + \int_{x_3}^{x_4} N_3N_4\ dx$$

$$= \int_{e_1} 0 \cdot 0\ dx + \int_{e_2} N_2^2 \cdot 0\ dx + \underbrace{\int_{e_3} N_1^3\ N_2^3\ dx}_{a_{12}^3} \quad , \tag{27}$$

$$a_{41} = \int_{x_1}^{x_4} N_4 N_1 \, dx = \int_{x_1}^{x_2} N_4 N_1 \, dx + \int_{x_2}^{x_3} N_4 N_1 \, dx + \int_{x_3}^{x_4} N_4 N_1 \, dx$$

$$= \int_{e_1} 0 \cdot N_1^1 \, dx + \int_{e_2} 0 \cdot 0 \, dx + \int_{e_3} N_2^3 \cdot 0 \, dx \quad , \tag{28}$$

$$a_{42} = \int_{x_1}^{x_4} N_4 N_2 \, dx = \int_{x_1}^{x_2} N_4 N_2 \, dx + \int_{x_2}^{x_3} N_4 N_2 \, dx + \int_{x_3}^{x_4} N_4 N_2 \, dx$$

$$= \int_{e_1} 0 \cdot N_2^1 \, dx + \int_{e_2} 0 \cdot N_1^2 \, dx + \int_{e_3} N_2^2 \cdot 0 \, dx \quad , \tag{29}$$

$$a_{43} = \int_{x_1}^{x_4} N_4 N_3 \, dx = \int_{x_1}^{x_2} N_4 N_3 \, dx + \int_{x_2}^{x_3} N_4 N_3 \, dx + \int_{x_3}^{x_4} N_4 N_3 \, dx$$

$$= \int_{e_1} 0 \cdot 0 \, dx + \int_{e_2} 0 \cdot N_2^2 \, dx + \underbrace{\int_{e_3} N_2^3 \, N_1^3 \, dx}_{a_{22}^3} \quad , \tag{30}$$

$$a_{44} = \int_{x_1}^{x_4} N_4 N_4 \, dx = \int_{x_1}^{x_2} N_4 N_4 \, dx + \int_{x_2}^{x_3} N_4 N_4 \, dx + \int_{x_3}^{x_4} N_4 N_4 \, dx$$

$$= \int_{e_1} 0 \cdot 0 \, dx + \int_{e_2} 0 \cdot 0 \, dx + \underbrace{\int_{e_3} N_2^3 \, N_2^3 \, dx}_{a_{22}^3} \quad , \tag{31}$$

$$[a] = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} , \tag{32}$$

$$[a] = \left[\begin{array}{c:c:c:c} a_{11}^{1} & a_{12}^{1} & 0 & 0 \\ \hdashline a_{21}^{1} & a_{22}^{1} + a_{11}^{2} & a_{12}^{2} & 0 \\ \hdashline 0 & a_{21}^{2} & a_{22}^{2} + a_{11}^{3} & a_{12}^{3} \\ \hdashline 0 & 0 & a_{21}^{3} & a_{22}^{3} \end{array}\right] , \tag{33}$$

Similarily,

$$[b] = \left[\begin{array}{c:c:c:c} b_{11}^{1} & b_{12}^{1} & 0 & 0 \\ \hdashline b_{21}^{1} & b_{22}^{1} + b_{11}^{2} & b_{12}^{2} & 0 \\ \hdashline 0 & b_{21}^{2} & b_{22}^{2} + b_{11}^{3} & b_{12}^{3} \\ \hdashline 0 & 0 & b_{21}^{3} & b_{22}^{3} \end{array}\right] , \tag{34}$$

$$B_1 = W_1 \frac{\partial \hat{f}}{\partial x} \bigg|_{x=x_1}^{x=x_4} = \cancelto{0}{N_1 \frac{dN_j}{dx}} f_j \bigg|_{x=x_4} - N_1 \frac{dN_j}{dx} f_j \bigg|_{x=x_1} = \Delta , \tag{35}$$

$$B_2 = W_2 \frac{\partial \hat{f}}{\partial x} \bigg|_{x=x_1}^{x=x_4} = \cancelto{0}{N_2 \frac{dN_j}{dx}} f_j \bigg|_{x=x_4} - \cancelto{0}{N_2 \frac{dN_j}{dx}} f_j \bigg|_{x=x_1} = 0 , \tag{36}$$

$$B_3 = W_3 \frac{\partial \hat{f}}{\partial x} \bigg|_{x=x_1}^{x=x_4} = \cancelto{0}{N_3 \frac{dN_j}{dx}} f_j \bigg|_{x=x_4} - \cancelto{0}{N_3 \frac{dN_j}{dx}} f_j \bigg|_{x=x_1} = 0 , \tag{37}$$

$$B_4 = W_4 \frac{\partial \hat{f}}{\partial x} \bigg|_{x=x_1}^{x=x_4} = N_4 f_j \bigg|_{x=x_4} - \cancelto{0}{N_4 \frac{dN_j}{dx}} f_j \bigg|_{x=x_1} = f_4 , \tag{38}$$

Thus,

$$\{B\} = \begin{Bmatrix} \triangle \\ 0 \\ 0 \\ f_4 \end{Bmatrix}, \tag{39}$$

$$\begin{bmatrix} a_{11} & a_{12} & 0 & 0 \\ a_{21} & a_{22} & a_{23} & 0 \\ 0 & a_{32} & a_{33} & a_{34} \\ 0 & 0 & a_{43} & a_{44} \end{bmatrix} \begin{Bmatrix} \frac{df_1}{dt} \\ \frac{df_2}{dt} \\ \frac{df_3}{dt} \\ \frac{df_4}{dt} \end{Bmatrix} +$$

$$\begin{bmatrix} b_{11} & b_{12} & 0 & 0 \\ b_{21} & b_{22} & b_{23} & 0 \\ 0 & b_{32} & b_{33} & b_{34} \\ 0 & 0 & b_{43} & b_{44} \end{bmatrix} \begin{Bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \end{Bmatrix} = \begin{Bmatrix} \triangle \\ 0 \\ 0 \\ f_4 \end{Bmatrix}. \tag{40}$$

Step 8 - Incorporate boundary conditions into the matrix equation:

$$a_{11} = 0,\ a_{12} = 0,\ b_{11} = 1,\ b_{12} = 0 \tag{41a}$$

and

$$\triangle = 1 \quad . \tag{41b}$$

The final matrix equation is

$$\begin{bmatrix} 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & a_{23} & 0 \\ 0 & a_{32} & a_{33} & a_{34} \\ 0 & 0 & a_{43} & a_{44} \end{bmatrix} \begin{Bmatrix} df_1/dt \\ df_2/dt \\ df_3/dt \\ df_4/dt \end{Bmatrix} + \begin{bmatrix} 1 & 0 & 0 & 0 \\ b_{21} & b_{22} & b_{23} & 0 \\ 0 & b_{32} & b_{33} & b_{34} \\ 0 & 0 & b_{43} & b_{44}-1 \end{bmatrix} \begin{Bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \end{Bmatrix} = \begin{Bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{Bmatrix}. \qquad (42)$$

Step 9 - Solve the initial value problem, Eq. (42). Matrix equation, Eq. (42), can be solved by any of the six numerical schemes as reported in FEMWATER - ORNL-5567.

A-III. APPLICATION OF FEM TO GOVERNING EQUATION

The application of FEM to the problem of flow-through saturated-unsaturated porous media is straight foward as that presented in Section A-II for the simple example.

The governing equation is

$$F \frac{\partial h}{\partial t} = \nabla \cdot [\bar{\bar{K}} \cdot (\nabla h + \nabla z)] \quad . \tag{1}$$

The initial conditions is

$$h = h_I \quad . \tag{2}$$

The boundary conditions are

$$h = h_D \quad \text{on the Dirichlet Boundary} \quad , \tag{3}$$

$$-\vec{n} \cdot [\bar{\bar{K}} \cdot (\nabla h + \nabla z)] = q_N \quad \text{on the Neumann Boundary} \quad , \tag{4}$$

$$h = h_V \quad \text{or} \tag{5a}$$

on the Variable Boundary .

$$-\vec{n} \cdot [\bar{\bar{K}} \cdot (\nabla h + \nabla z)] = q_V \tag{5b}$$

Equations (1) through (5) have mathematically defined the problem at hand. We may now proceed to apply the FEM to the governing equation and the boundary conditions following the same procedures as those in Section A-II.

Solution Procedure

Step 1 - Divide the region of interest into N nodes and M elements. Each node is specified by its spatial coordinate.

Step 2 - Define base functions both over the region of interest and over each element. Let N_j be the base function of node j. We will use a bilinear base function; i.e., N_j will have the value of 1.0 at the nodal point j and the values of 0.0 at all other nodal points, f, g, h, i, k, l, m, and n (Fig. A-2). Furthermore, N_j will vary bilinearly over those elements that have one nodal point coinciding with j and will have the value of 0.0 over all other elements (Fig. A-2). It is seen that

over element a,

$$N_1^a = N_f,\ N_2^a = N_i,\ N_3^a = N_j,\ N_4^a = N_g \quad ; \tag{6a}$$

over element b,

$$N_1^b = N_g,\ N_2^b = N_j,\ N_3^b = N_k,\ N_4^b = N_h \quad ; \tag{6b}$$

over element c,

$$N_1^c = N_i,\ N_2^c = N_l,\ N_3^c = N_m,\ N_4^c = N_j \quad ; \tag{6c}$$

over element d,

$$N_1^d = N_j,\ N_2^d = N_m,\ N_3^d = N_n,\ N_4^d = N_k \quad , \tag{6d}$$

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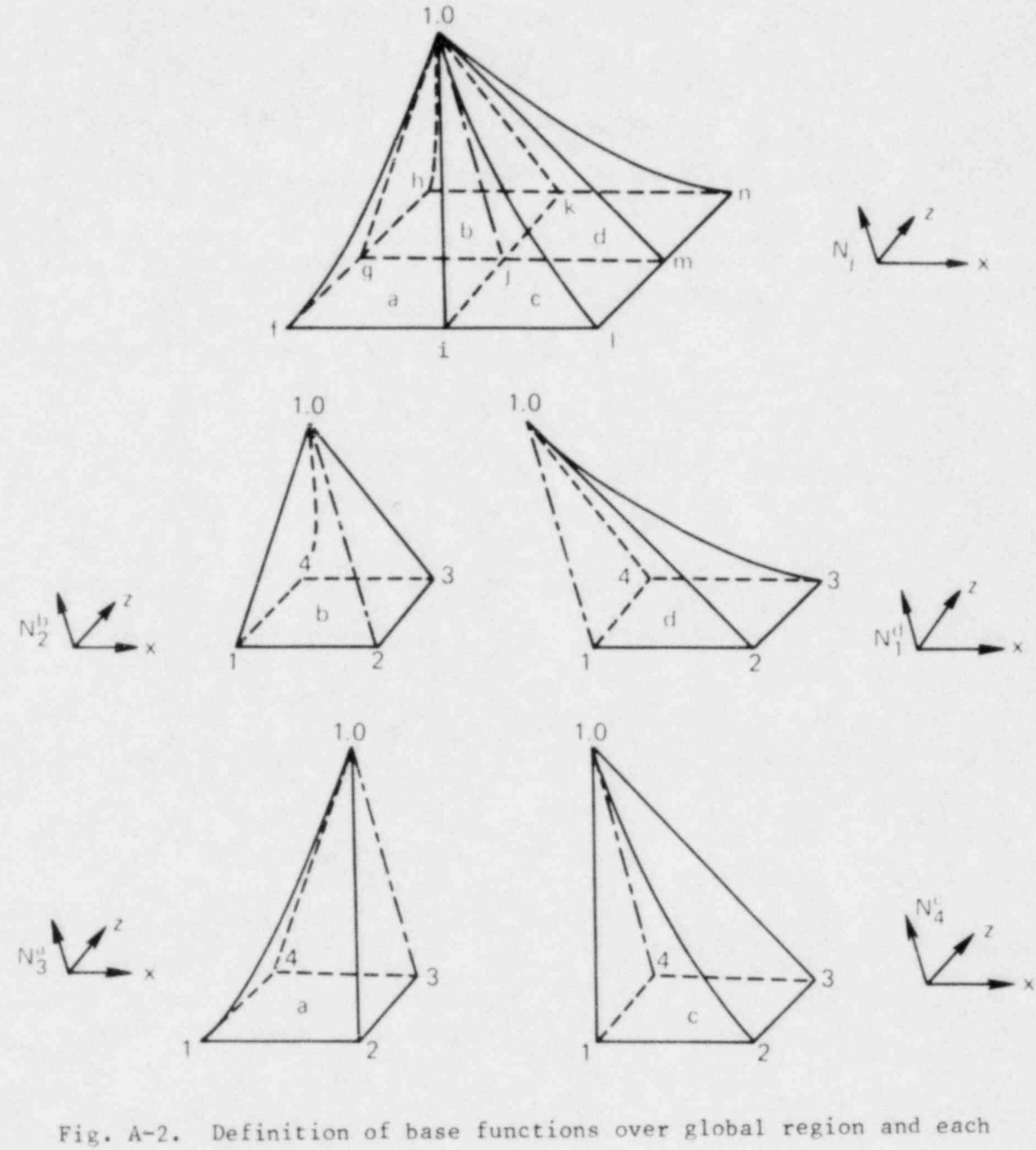


Fig. A-2. Definition of base functions over global region and each element where

N_f, N_g, N_h, N_i, N_j, N_k, N_l, N_m, N_n = base functions for nodes f, g, h, i, j, k, l, m, and n, respectively;

N_1^a, N_2^a, N_3^a, N_4^a = the first, second, third, and fourth-node base functions for element a;

N_1^b, N_2^b, N_3^b, N_4^b = the first, second, third, and fourth-node base functions for element b;

N_1^c, N_2^c, N_3^c, N_4^c = the first, second, third, and fourth-node base functions for element c; and

N_1^d, N_2^d, N_3^d, N_4^d = the first, second, third, and fourth-node base functions for element d.

In fact, the base function N_j is given by

$$N_j(x,z) = \frac{x - x_g}{x_j - x_g} \cdot \frac{z - z_i}{z_j - z_i} \quad \text{over element a} \quad , \tag{7a}$$

$$N_j(x,z) = \frac{x - x_g}{x_j - x_g} \cdot \frac{z_k - z}{z_k - z_j} \quad \text{over element b} \quad , \tag{7b}$$

$$N_j(x,z) = \frac{x_m - x}{x_m - x_j} \cdot \frac{z - z_i}{z_j - z_i} \quad \text{over element c} \quad , \tag{7c}$$

$$N_j(x,z) = \frac{x_m - x}{x_m - x_j} \cdot \frac{z_k - z}{z_k - z_j} \quad \text{over element d} \quad . \tag{7d}$$

Step 3 - Define weighting functions:

$$W_i(x,z) = N_i(x,z), \; i = 1,2,\ldots, N \quad . \tag{8}$$

Step 4 - Approximate the solution by linear combination of base functions:

$$h \simeq \hat{h} = \sum_{j=1}^{N} h_j(t) \; N_j(x,z) \quad . \tag{9}$$

Step 5 - Define residual R_r by

$$R_r = F \frac{\partial \hat{h}}{\partial t} - \nabla \cdot [\bar{\bar{K}} \cdot (\nabla \hat{h} + \nabla z)] \quad . \tag{10}$$

Step 6 - Set weighted residuals to zero:

$$\int_R W_i \; \left\{ F \frac{\partial \hat{h}}{\partial t} - \nabla \cdot [K \cdot (\nabla \hat{h} + \nabla z)] \right\} dR = 0 \quad ,$$

$$i = 1,2,\ldots, N \quad . \tag{11}$$

Step 7 - Derive matrix equation:

Substituting Eq. (9) into Eq. (11) and integrating by part, we obtain

$$[\int_R N_i \; F \; N_j] \frac{dh_j}{dt} + [\int_R (\nabla N_i) \cdot \bar{\bar{K}} \cdot (\nabla N_j) \; dR] \; h_j$$

$$= - \int_R (\nabla N_i) \cdot \bar{\bar{K}} \cdot (\nabla z) \; dR + \int_\Gamma \vec{n} \cdot \bar{\bar{K}} \cdot (\nabla h + \nabla z) N_i \; d\Gamma \quad ,$$

$$i = 1,2,\ldots, N \quad . \tag{12}$$

Equation (12) written in matrix form is

$$[a] \frac{dh}{dt} + [b] \{h\} = \{D\} + \{Q\} \quad , \tag{13}$$

where [a] = mass matrix,

[b] = stiff matrix,

{D} = known load vector, and

{Q} = boundary load vector.

$$a_{ij} = \int_R N_i F N_j \, dR = \sum_{e \in M} \int_{R_e} N_i F N_j \, dR$$

$$= \sum_{e \in M_e} \int_{R_e} N^e_\alpha F N^e_\beta \, dR \tag{14}$$

in which M_e is the set of elements that have a local side $\alpha - \beta$ coinciding with the global side $i - j$.

Similarly,

$$b_{ij} = \int_R (\nabla N_i) \cdot \bar{\bar{K}} \cdot (\nabla N_j) \, dR = \sum_{e \in M} \int_{R_e} (\nabla N_i) \cdot \bar{\bar{K}} \cdot (\nabla N_j) \, dR =$$

$$\sum_{e \in M_e} \int_{R_e} (\nabla N^e_\alpha) \cdot \bar{\bar{K}} \cdot (\nabla N^e_\beta) \, dR \quad , \tag{15}$$

$$D_i = - \int_R (\nabla N_i) \cdot \bar{\bar{K}} \cdot \nabla z \, dR = - \sum_{e \in M} \int_{R_e} (\nabla N_i) \cdot \bar{\bar{K}} \cdot \nabla z \, dR =$$

$$- \sum_{e \in M_e} \int_{R_e} (\nabla N^e_\alpha) \cdot \bar{\bar{K}} \cdot \nabla z \, dR \quad , \tag{16}$$

and

$$Q_i = \int_\Gamma \vec{n} \cdot \bar{\bar{K}} \cdot (\nabla h + \nabla z) N_i \, d\Gamma \quad . \tag{17}$$

Step 8 - Incorporate boundary conditions into the matrix equation. If Eq. (4) or (5b) is applied to a boundary node, then Eq. (17) is integrated over the boundary segments that have the boundary node and the results are used as boundary load vector. On the other hand, if Eq. (3) or (5a) is applied to a boundary node, the integration of Eq. (17) can be ignored because an identity equation will be created for such node.

Step 9 - Solve the initial value problem, Eqs. (13) and (2).

A-IV. FEMWATER PROGRAM STRUCTURE

A-IV.1. Purpose of FEMWATER

The source program of FEMWATER is designed mainly to solve for the following initial and boundary value problem:

Governing Equation

$$F \frac{\partial h}{\partial t} = \frac{\partial}{\partial x}[K_r \{K^s_{xx} \frac{\partial(h+z)}{\partial x} + K^s_{xz} \frac{\partial(h+z)}{\partial z}\}] + \frac{\partial}{\partial z}[K_r \{K^s_{zx} \frac{\partial(h+z)}{\partial x} + K^s_{zz} \frac{\partial(h+z)}{\partial z}\}] \quad , \qquad (1)$$

where h is the matric potential (pressure head); z is the gravitational head (potential head); x and z are the Cartesian coordinates on the vertical plane; t is the time; F is the generalized storage coefficient, a function of pressure h; K^s_{xx}, K^s_{xz}, K^s_{zx}, and K^s_{zz} are the four components of the saturated hydraulic conductivity tensor K^z; and K_r is the relative hydraulic conductivity, a function of pressure head h, resulting from expressing $\bar{\bar{K}} = \bar{\bar{K}}^s\ K_r$.

Initial Condition

$$h(x,z,0) = h_i(x,z,t) \text{ in } R \quad , \qquad (2)$$

where R is the region of interest and $h_i(x,z,t)$ is the prescribed initial value function, which may also be obtained by solving for h the steady-state version of Eq. (1) under time-invariant boundary conditions.

Boundary Conditions

$$h(x,z,t) = h_D(x_b,z_b,t) \quad \text{on} \quad B_D \quad , \tag{3}$$

$$- n_x[K_r\{K^s_{xx} \frac{\partial(h+z)}{\partial x} + K^s_{xz} \frac{\partial(h+z)}{\partial z}\}] - n_z[K_r\{K^s_{zx} \frac{\partial(h+z)}{\partial x} + K^s_{zz} \frac{\partial(h+z)}{\partial z}\}] =$$
$$= q_N(x_b,z_b,t) \quad \text{on} \quad B_N \quad , \tag{4}$$

and

$$h(x,z,t) = h_V(x_b,z_b,t) \quad \text{on} \quad B_V \tag{5a}$$

or

$$- n_x[K_r\{K^s_{xx} \frac{\partial(h+z)}{\partial x} + K^s_{xz} \frac{\partial(h+z)}{\partial z}\}] - n_z[K_r\{K^s_{zx} \frac{\partial(h+z)}{\partial x} +$$
$$K^s_{zz} \frac{\partial(h+z)}{\partial z}\}] = q_V(x_b,z_b,t) \quad \text{on} \quad B_V \quad , \tag{5b}$$

where $h_D(x_b,z_b,t)$ is the prescribed pressure head as a function of time t and spatial coordinate (x_b,z_b) on the Dirichlet boundary B_D; $q_N(x_b,z_b,t)$ is the prescribed water flux through the boundary, a function of the time t and spatial coordinate (x_b,z_b) on the Neumann boundary B_N; $h_V(x_b,z_b,t)$ and $q_V(x_b,z_b,t)$ are the prescribed pressure head and water flux through the boundary and both are functions of the time and spatial coordinate (x_b,z_b) on the Variable-type boundary B_V; and n_x and n_z are the x- and z-components, respectively, of a unit vector normal to the boundary outwardly. It should be noted that $q_N(x_b,z_b,t)$ and $q_V(x_b,z_b,t)$ are positive if they are directed out from the region of interest and negative if directed into the region. Only Eq. (5a) or (5b) can be applied to B_V at a time; they cannot be applied to B_V at the same time.

A-IV.2. Structure

The Finite Element Model of WATER flow through saturated-unsaturated porous media (FEMWATER) consists of a MAIN program and 16 subroutines. These subroutines are named according to their functions. The MAIN program is utilized to specify the dimension of arrays and to assign integer parameters of the array sizes. It also initializes the arrays. The control and coordinate activity are performed by the subroutine GW2DXZ. Figure A-3 shows the structure of the model.

Subroutine GW2DXZ

The subroutine GW2DXZ controls the entire sequence of operations, a function generally performed by the MAIN program. It is, however, preferable to keep a short MAIN and several subroutines with variable storage allocation. This makes it possible to place most of the FORTRAN deck on a permanent file and to deal with a site-specific problem without making changes in the array dimensions throughout all subroutines.

The subroutine will perform either the steady-state computation alone (KSS = 0 and NTI = 0), or a transient computation using the steady-state as the initial condition (KSS = 0 and NTI > 0), or the transient computation using user-supplied initial conditions (KSS = 1 and NTI > 0). GW2DXZ calls to subroutine DATAIN for reading data; subroutine SPROP for obtaining the hydraulic conductivity, water capacity, and moisture content from the pressure head; subroutine VELT to compute Darcy's velocity; subroutine BCPREP to determine if a change

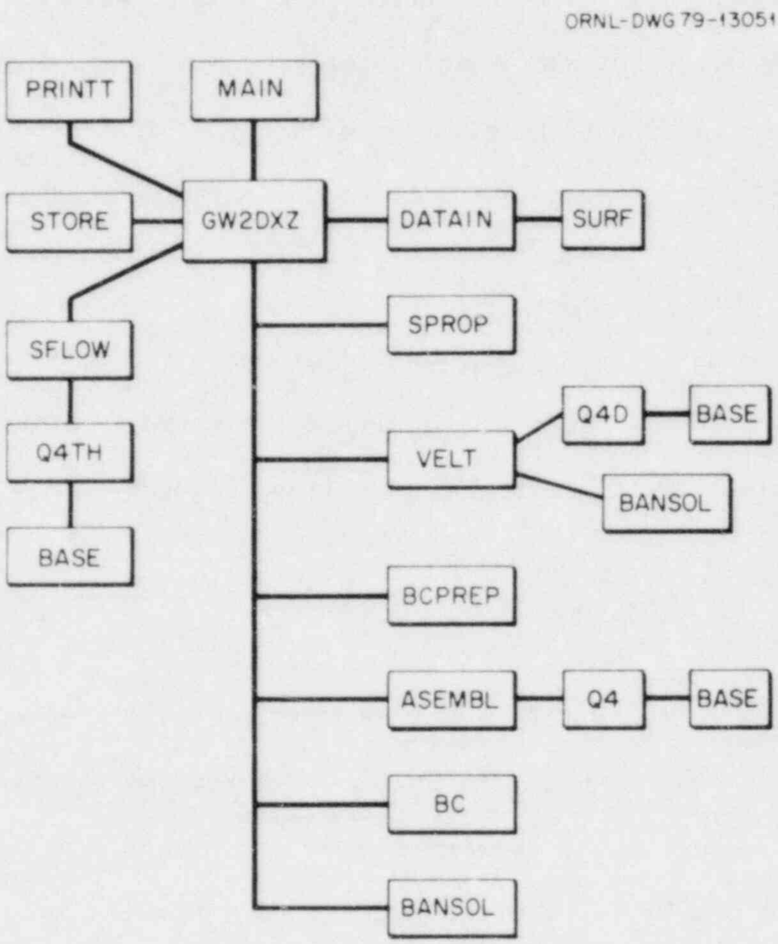


Fig. A-3. FEMWATER program structure

from Dirichlet to Neumann boundary condition is required or vice versa; subroutine ASEMBL to assemble the element matrix over all elements; subroutine BC to implement Dirichlet, Neumann, and rainfall-seepage boundary conditions; subroutine BANSOL to solve the resulting matrix equation; subroutine SFLOW to calculate flux through all types of boundaries and moisture-content accumulated in the media; subroutine PRINTT to print out the results; and subroutine STORE to store the flow variables for input to a waste-transport model or for plotting.

Subroutine DATAIN

Subroutine DATAIN reads all data input described in Section A-IV.3 except the card group 1. It also prints all the input information and calls subroutine SURF to identify the surface elements and boundary nodes.

Subroutine SURF

Subroutine SURF identifies the boundary sides, sequences the boundary nodes, and computes the length and directional cosines of each side. The element numbers associated with the boundary sides are stored in NBE; the boundary nodes are stored in NPB. The length and directional cosines for each side are stored in DLB and DCOSXB and DCOSZB, respectively. The local and global nodal numbers of two nodes of each side are in ISB. The information is returned to the subroutine DATAIN for other users.

Subroutine SPROP

This subroutine calculates the values of moisture content, TH(M,IQ), the hydraulic conductivity components, AKX(M,IQ) and AKZ(M,IQ), and the water capacity, DTH(M,IQ) as functions of the pressure head, H(NP). Two options are available. One is to interpolate the values from the tabular input. The other is to compute the value with an analytical function characterized by a certain number of parameters. The maximum number of the parameters one can input is given by MXSPPM. When the analytical option is used, the user must supply the functional form. An example in the present code is given by cards SPRO 315 to SPRO 525. Any analytical function other than the example should be coded in lieu of the above FORTRAN statements.

Subroutine VELT

This subroutine calls to Q4D to evaluate the element matrix. It then sums over all element matrices to form a matrix equation governing the velocity components at all nodal points. Subsequently, it calls Subroutine BANSOL to yield the solution. The computed velocity field is then returned to GW2DXZ through the argument. The velocity field is then passed to Subroutine BCPREP to evaluate the Darcy flux across the seepage-rainfall surfaces.

Subroutine Q4D

Subroutine Q4D is called by the Subroutine VELT to compute the element matrix given by

$$QQ(I,J) = \int_{R_e} N_i N_j \, dR \quad ,$$

where N_i and N_j are the base functions for nodal points i and j, respectively. It also evaluates the element load vector given by

$$RQ(I) = - \int_{R_e} N_i [K_{xx} \frac{\partial N_j}{\partial x} h_j + K_{xz} \frac{\partial N_j}{\partial z} h_j + K_{xz}] \, dR$$

or

$$RQ(I) = - \int_{R_e} N_i [K_{zx} \frac{\partial N_j}{\partial x} h_j + K_{zz} \frac{\partial N_j}{\partial z} h_j + K_{zz}] \, dR \quad ,$$

where h_j is the pressure head at nodal point j and K_{xx}, K_{xz}, K_{zx}, and K_{zz} are hydraulic conductivity tensor components. The computation of these quantities is straightforward.

Subroutine BASE

This subroutine is called by Q4D, Q4TH, and Q4 to evaluate the value of the base function at a Gaussian point. The computation is straightforward.

Subroutine BANSOL

This subroutine is called by VELT and GW2DXZ to solve for the matrix equation of the type

$$[C] \{x\} = \{y\} \quad ,$$

where [C] is a matrix and {x} and {y} are two vectors. {x} is the unknown to be solved and {y} is the known load vector. The computer returns the solution {x} and stores it in {y}. The computation is a standard procedure.

Subroutine BCPREP

This subroutine is called by GW2DXZ to prepare the rainfall-seepage boundary conditions. It decides the number of nodal points on the rainfall-seepage boundaries to be considered as Dirichlet points and Neumann points. It also computes the number of points that change boundary conditions from Dirichlet to Neumann types or from Neumann to Dirichlet types. Upon completion, this subroutine returns the Darcy flux--DCYFLX, rainfall flux--FLX, the ponding depth nodal index--NPCON, the flux-type nodal index--NPFLX, and the number of nodal points--NCHG that have changed boundary conditions.

Subroutine ASEMBL

This subroutine calls Q4 to evaluate the element matrix. It then sums over the entire element matrix to form a matrix equation governing the pressure head at all nodal points.

Subroutine Q4

Subroutine Q4 is called by ASEMBL to compute the element matrix given by

$$QA(I,J) = \int_{R_e} N_i F N_j \, dR$$

and

$$QB(I,J) = \int_{R_e} \left[\frac{\partial N_i}{\partial x}\left(K_{xx}\frac{\partial N_j}{\partial x} + K_{xz}\frac{\partial N_j}{\partial z}\right) + \frac{\partial N_i}{\partial z}\left(K_{zx}\frac{\partial N_j}{\partial x} + K_{zz}\frac{\partial N_j}{\partial z}\right)\right] dR$$

where F is the soil property function and K_{xx}, K_{xz}, and K_{zz} are the tensor components of the hydraulic conductivity. It also evaluates the load vector given by

$$RQ(I) = \int_{R_e} \left(K_{xz}\frac{\partial N_i}{\partial x} + K_{zz}\frac{\partial N_i}{\partial z}\right) dR \quad ,$$

Subroutine BC

This subroutine evaluates both Dirichlet and Neumann boundary conditions. For a Dirichlet boundary condition, an identity algebraic equation is generated for each Dirichlet nodal point. Any other equation having this nodal variable is modified accordingly to simplify the computation. For the Neumann boundary-side, the integration of the surface source is added to the load vector. The subroutine BC also implements the variable boundary conditions. First, it checks over all rainfall-seepage points, identifying any of them that are Dirichlet points. If any are Dirichlet points, the method of incorporating Dirichlet boundary conditions mentioned above is used. If a given point is not, the point is bypassed. Second, it checks over all rainfall-seepage points again to see if any of them are Neumann points. If any are, the computed flux by the rainfall is added to the load vector. If a given point is not a Neumann point, it is bypassed. Because the rainfall-seepage points are either Dirichlet or Neumann points, all points are taken care of in this manner.

Subroutine PRINTT

This subroutine is used to line-print the flow variables. These include the fluxes through variable boundary segments, the pressure head, total head, moisture head, and Darcy's velocity components.

Subroutine STORE

This subroutine is used to store the flow variables on logical unit 1. It is intended for use with a subsequent computer model, FEMWASTE. The information stored includes TITLE, NPROB, NNP, NEL, NBN,

NBEL, NTI, NRSN, X, Z, IE, DCOSXB, DCOSZB, NBE, ISB, and TIME, H, HT, TH, VX, VZ, NPCON, NPFLX for each desired time step.

Subroutine SFLOW

This subroutine is used to compute the fluxes through various types of boundaries and the increasing rate of moisture content in the region of interest. FLOW(6) is to store the flux through the whole boundary enclosing the region of interest. It is given by

$$FLOW(6) = \int_B (V_x n_x + V_z n_z)\, dB \quad ,$$

where B is the global boundary of the region of interest, V_x and V_z are the Darcian velocity components on the boundary in the x- and z-direction, respectively, and n_x and n_z are the directional cosines of the outward unit vector normal to the boundary B. FLOW(1) through FLOW(4) store the flux through Dirichlet boundary B_D, Neumann boundary B_N, the seepage boundary B_S, and the rainfall infiltration boundary B_R, respectively, and are given by

$$FLOW(1) = \int_{B_D} (V_x n_x + V_z n_z)\, dB \quad ,$$

$$FLOW(2) = \int_{B_N} (V_x n_x + V_z n_z)\, dB \quad ,$$

$$FLOW(3) = \int_{B_S} (V_x n_x + V_z n_z)\, dB \quad ,$$

$$FLOW(4) = \int_{B_R} (V_x n_x + V_z n_z)\, dB \quad .$$

FLOW(5), which is related to the numerical loss, is given by

$$\text{FLOW}(5) = \text{FLOW}(6) - [\text{FLOW}(1) + \text{FLOW}(2) + \text{FLOW}(3) + \text{FLOW}(4)] \quad .$$

If there is no numerical error in the computation, FLOW(6) should be equal to FLOW(7) to be defined below and FLOW(5) should be equal to zero. FLOW(7) is used to store the moisture-content increasing rate within the porous media; that is,

$$\text{FLOW}(7) = \int_R F \frac{\partial h}{\partial t} \, dR \quad ,$$

where F is the soil property function and h is the pressure head.

Subroutine Q4TH

This subroutine is used to compute the contribution of moisture-content increasing rate from an element:

$$\text{QTHP} = \int_{R_e} \left(\frac{d\theta}{dh} + \theta\alpha'/n_e + \beta'\right)\frac{\partial h}{\partial t} \, dR$$

where α' and β' are the modified compressibility of the soil matrix and liquid fluid, respectively, n_e is the effective porosity, and θ is the moisture-content. The computation of the above integration is straight-forward.

A-V. FEMWATER PROGRAM REQUIREMENTS AND INPUT DATA GUIDE

The following describes the requirements for each site-specific application and the input data guide.

A-V.1. Variable Array Dimension Specification

The subscripted variable arrays have to be dimensioned for each site-specific problem in the main program. Fourteen (14) cards containing the following variables should be dimensioned according to the subscript in each of the arrays:

X(MAXNP),Z(MAXNP),IE(MAXEL,5)	1 card
C(MAXNP,MAXHBP),R(MAXNP),H(MAXNP), HP(MAXNP),HW(MAXNP),HT(MAXNP), TH(MAXZL,4),DTH(MAXZL,4),VX(MAXNP), VZ(MAXNP),AKX(MAXEL,4)AKZ(MAXEL,4), NPCNV(MAXNP)	3 cards
DLB(MAXBEL),DCOSXB(MAXBEL),DCOSZ(MAXBEL), BFLX(MAXBNP),BFLXP(MAXBNP),NBE(MAXBEL), ISB(MAXBEL,4),NPB(MAXBNP)	2 cards
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)	3 cards
RP(MXSTNP),NPST(MXSTNP),BB(MAXBCN),NN(MAXBCN)	1 card
PROP(MAXMAT,MXMPPM),THPROP(MAXMAT,MXSPPM), AKPROP(MAXMAT,MXSPPM),HPROP(MAXMAT,MXSPPM), CAPROP(MAXMAT,MXSPPM)	2 cards
PMAT(3,MXMPPM),AKPAR(3,NAKPPM),THPAR(3,NTHPPM)	1 card
KPR(MAXNTI),KDSK(MAXNTI)	1 card

where MAXNP is the maximum number of nodal points; MAXEL, the maximum number of elements; MAXBEL, the maximum number of boundary element-sides; MAXBNP, the maximum number of boundary nodal points; MXRSEL, the maximum number of rainfall seepage element-sides; MXRSNP, the maximum number of rainfall-seepage nodal points; MXRFPR, the maximum number of rainfall profiles; MXRPAR, the maximum number of rainfall parameters; MXSTNP, the maximum number of surface-term nodal points (the maximum number of Neumann boundary points); MAXBCN, the maximum number of Dirichlet boundary condition nodal points; MAXMAT, the maximum number of material types; MXMPPM, the maximum number of material properties per material type; MXSPPM, the maximum number of soil property points per material; MAXNTI, the maximum number of time integration steps; NAKPPM, the number of parameters per material to describe the conductivity parameter names; NTHPPM, the number of parameter per material to describe the moisture content parameter names; and MAXHBP, the maximum number of half band width plus 1 of the global matrix. For example, the seepage pond problem is dimensioned as follows:

```
 DIMENSION X(595),Z(595),IE(528,5)                                      MAIN 170

 DIMENSION C(595,16),R(595),H(595),HP(595),HW(595),HT(595),             MAIN 180
>TH(528,4),DTH(528,4),VX(595),VZ(595),                                  MAIN 185
>AKX(528,4),AKZ(528,4),NPCNV(595)                                       MAIN 190

 DIMENSION DLB(199),DCOSXB(199),DCOSZB(199),BFLX(200),BFLXP(200),       MAIN 200
>NBE(199),ISB(199,4),NPB(200)                                           MAIN 205

 DIMENSION DL(99),DCOSX(99),DCOSZ(99),DCYFLX(100),FLX(100),             MAIN 215
>RSFLX(100),HCON(100),NRSE(99),IS(99,4),NPRS(100),NPCON(100),           MAIN 220
>NPFLX(100),IRFTYP(100),TRF(3,20),RF(3,20),RFALL(3)                     MAIN 225

 DIMENSION RP(30),NPST(30),BB(40),NN(40)                                MAIN 235
```

```
      DIMENSION PROP(3,5),THPROP(3,52),AKPROP(3,52),HPROP(3,52)         MAIN 245
     >CAPROP(3,52)                                                      MAIN 250
      DIMENSION PMAT(3,5),AKPAR(3,8),THPAR(3,8)                         MAIN 255
      DIMENSION KPR(250),KDSK(250)                                      MAIN 265
```

Corresponding to the above dimension specification cards, six data specification cards must be used to assign the control number; for example:

```
      DATA MAXEL,MAXNP,MAXHBP/528,595,16/                           MAIN 335
      DATA MAXBEL,MAXBNP/199,200/                                   MAIN 340
      DATA MXRSEL,MXRSNP,MXRFPR,MXRPAR/99,100,3,20/                 MAIN 345
      DATA MXSTEL,MXSTNP,MAXBCN/29,30,40/                           MAIN 350
      DATA MAXMAT,MXSPPM,MXMPPM,NTHPPM,NAKPPM/3,52,5,8,8/           MAIN 355
      DATA MAXNTI/250/                                              MAIN 360
```

where MAXHBP is the maximum number of half band width of matrix C.

A-V.2. Soil Property Function Specifications

The code provides two options to handle the functional relationships of moisture-content, water-capacity, and hydraulic conductivity with the pressure head. One is the tabular input while the other is the analytic function specification. If the former option is used, the user may ignore this subsection. If the latter is used, the user must supply three functions to compute the moisture-content, hydraulic conductivity, and water capacity based on the current value of pressure head. The parameters needed to specify these functional forms are read and stored in AKPROP and THPROP arrays. One example is shown in the subroutine SPROP (Appendix A) when KSP = 0.

A-V.3. Input Data Guide

The input format for each data card is specified in the following. The number under the drawing is the last column of each field. In general, an integer has a field length of 5 and should be right-justified. On the other hand, a real number has a field length of 10 and can be placed anywhere within the field.

1. Title

Format (I5,9A8,IX,2I1). One card per problem:

NPROB	TITLE		IBUG	ICHNG
5	77	78	79	80

NPROB = Problem number.

TITLE(9) = Array for the title of the problem.

IBUG = Integer control number indicating if the diagnostic output is desired: = 0, no; = 1, yes.

ICHNG = Integer control number indicating if the cyclic change of rainfall-seepage nodes is to be printed: = 0, no; = 1, yes.

2. Basic Integer Parameters

Two cards per problem are required.

Card 1: Format (16I5):

NNP	NEL	NMAT	NCM	NTI	KSS	KSP	NSPPM
5	10	15	20	25	30	35	40

KSTR	KCP	KGRAV	NSTRT	MAXIT	MAXCY	NMPPM	X
45	50	55	60	65	70	75	80

NNP = Number of nodal points.

NEL = Number of elements.

NMAT = Number of materials.

NCM = Number of elements with material property correction.

NTI = Number of time increments.

KSS = Steady state control; 0 = steady solution, 1 = transient.

KSP = Soil property control; 0 = analytical, 1 = tabular data.

NSPPM = Number of points in tabular soil property functions or number of parameters to specify analytical soil functions per material.

KSTR = Auxiliary storage output control; 0 = no storage, 1 = output stored in logical unit 1 (disk or tape).

KCP = Permeability input control; 0 = input conductivity, 1 = input permeability.

KGRAV = Gravity term control; 0 = no gravity, 1 = include gravity.

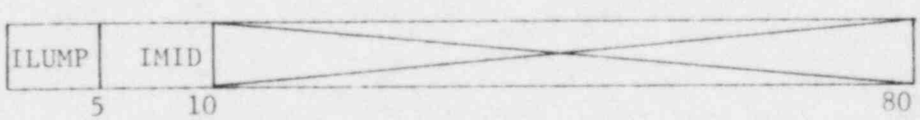
NSTRT = Number of logical records to be read from auxiliary storage for restarting calculations; 0 = no restart.

MAXIT = Maximum number of iterations per cycle.

MAXCY = Maximum number of cycles permitted for iterating rainfall-seepage boundary conditions per time step.

NMPPM = Number of material properties per material, = 5 for the present.

Card 2: Format (16I5):



ILUMP = Mass matrix lumping control; 0 = no lumping, 1 = lumping.

IMID = Mid-difference integration control; 0 = no,

1 = mid-difference.

3. Basic Real Parameters

Two cards per problem. Use of an E-, D-, or another F-type field specification in the input card overrides any of the F10.0 specifications of the format.

Card 1: Format (8F10.0):

DELT	CHNG	DELMAX	TMAX	FE	TOLA	TOLB	RHO
10	20	30	40	50	60	70	80

DELT = Time increment (T).

CHNG = Multiplier for increasing time increment.

DELMAX = Maximum value of DELT (T).

TMAX = Value of maximum simulation time (T).

FE = Angle between coordinate axes and principal directions of conductivity tensor in degrees.

TOLA = Steady-state convergence criteria (L).

TOLB = Transient-state convergence criteria (L).

RHO = Density of water (ML^{-3}).

Card 2: Format (8F10.0):

GRAV	VISC	W	
10	20	30	

GRAV = Acceleration of gravity (LT^{-2}).

VISC = Dynamic viscosity of water ($ML^{-1}\ T^{-1}$).

W = Time derivative weighting; 0.5 = Crank-Nicolson,

1.0 = backward.

4. <u>Printer Output and Disk Store Control</u>: FORMAT(80I1).

The number of cards here depends on the number of time increments, NTI. The number of cards is (NTI/80 + 1)*2. (NTI/80 + 1) cards for printer output control and (NTI/80 + 1) cards for store control:

KPRO	KPR(1)	KPR(2)	. . .	KPR(NTI)
1	2	3		

KDSKO	KDSK(1)	KDSK(2)	. . .	KDSK(NTI)
1	2	3		

KPRO = Printer control for steady state and initial conditions;) = print nothing, 1 = print FLOW, FRATE, TFLOW only, 2 = print above (1) plus H, 3 = print above (2) plus HT, 4 = print above (3) plus TH, 5 = print above (4) plus VX and VZ.

KPR(ITM) = Printer control for transient solution similar to KPRO as function of time index ITM.

KDSKO = Disk storage control for steady-state and initial control; 0 = no storage, 1 = store on logical unit 1.

KDSK(ITM) = Disk storage control for transient solution similar to KDSKO as a function of time index ITM.

5. <u>Material Properties</u>: FORMAT(8F10.0).

A total of NMAT groups of cards, one for each of the materials:

PROP(1,1)	PROP(1,2)	. . .	PROP(1,NMPPM)
.	.	.	.
PROP(NMAT,1)	PROP(NMAT,2)	. . .	PROP(NMAT,NMPPM)
10	20		

PROP(J,1) = Modified coefficient of compressibility of media J (L^{-1}).

PROP(J,2) = Modified coefficient of compressibility of water J (L^{-1}).

PROP(J,3) = Effective porosity of media J.

PORO(J,4) = xx-component of the saturated hydraulic conductivity tensor (L/T) or saturated permeability tensor (L^2).

PROP(J,5) = zz-component of the saturated hydraulic conductivity tensor (L/T) or saturated permeability tensor (L^2).

6. Analytic Soil Parameters: FORMAT(8F10.0).

These cards are input, if and only if KSP = 0. Two sets of cards per material--one for moisture-content parameters and the other for conductivity (permeability) parameters. The number of cards per set is determined both by the number of parameters used to specify the soil property per material, NSPPM, and by the number of materials, NMAT:

THPROP(1,1)	THPROP(1,2)	. . .	THPROP(1,NSPPM)
⋮			
THPROP(NMAT,1)	THPROP(NMAT,2)	. . .	THPROP(NMAT,NSPPM)
AKPROP(1,1)	KAPROP(1,2)	. . .	AKPROP(1,NSPPM)
⋮			
AKPROP(NMAT,1)	AKPROP(NMAT,2)	. . .	AKPROP(NMAT,NSPPM)
10	20		

THPROP(J,I) = Analytical moisture-content parameter I of material J.

AKPROP(J,I) = Analytical relative conductivity parameter I of material J.

7. Soil Properties in Tabular Form: FORMAT(8F10.0).

These cards are input if and only if KSP ≠ 0. Four sets of cards per material--one each for pressure, water-content, relative conductivity (or relative permeability), and water capacity, respectively. The number of cards per set is determined by input parameters, NSPPM and NMAT:

HPROP(1,1)	HPROP(1,2)	. . .	HPROP(1,NSPPM)
⋮			
HPROP(NMAT,1)	HPROP(NMAT,2)	. . .	HPROP(NMAT,NSPPM)
10	20		

THPROP(1,1)	THPROP(1,2)	. . .	THPROP(1,NSPPM)
⋮			
THPROP(NMAT,1)	THPROP(NMAT,2)	. . .	THPROP(NMAT,NSPPM)
AKPROP(1,1)	AKPROP(1,2)	. . .	AKPROP(1,NSPPM)
⋮			
AKPROP(NMAT,1)	AKPROP(NMAT,2)	. . .	AKPROP(NMAT,NSPPM)
CAPROP(1,1)	CAPROP(1,2)	. . .	CAPROP(1,NSPPM)
⋮			
CAPROP(NMAT,1)	CAPROP(NMAT,2)	. . .	CAPROP(NMAT,NSPPM)
10	20		

HPROP(J,K) = Tabular values of pressure head of K-th point for material J (L).

THPROP(J,K) = Tabular values of moisture-content of K-th point for material J (L^3/L^3).

AKPROP(J,K) = Tabular values of relative conductivity (or relative permeability) of K-th point for material J.

CAPROP(J,K) = Tabular values of specific moisture-content capacity of K-th point for material J (L^{-1}).

8. Nodal-Point Positions: FORMAT(I5,2F10.3).

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 group are needed. Intermediate nodal positions are automatically generated by linear interpolation:

NJ	X(NJ)	Z(NJ)	╳
5	15	25	80

⋮

NJ = Node number.

X(NJ) = X-coordinate of node NJ (L).

Z(NJ) = Z-coordinate of node NJ (L).

9. Element Definitions: FORMAT(16I5).

Usually one card per element is needed, i.e., a total of NEL cards:

MI	IE(MI,1)	. . .	IE(MI,5)	MODL	NLAY	╳
5	10	25	30	35	40	80

⋮

MI = Element number.

IE(MI,1) = Global nodal number of the first node of element MI.

IE(MI,2) = Global nodal number of the second node of element MI.

IE(MI,3) = Global nodal number of the third node of element MI.

IE(MI,4) = Global nodal number of the fourth node of element MI.

IE(MI,5) = Material type of element MI.

MODL = Number of elements in width.

NLAY = Number of elements in length.

IE(MI,1) to IE(MI,4) are the nodal numbers of element MI (beginning with the lower left and progressing around the element in a counterclockwise direction), and IE(MI,5) is the material type MTYP. For rectangular blocks of elements--the same material having sequentially numbered nodes--it is necessary to specify only the first element, the width MODL, and the length NLAY, where MODL and NLAY are measured in elements. Element numbering proceeds most rapidly along the MODL dimension and least rapidly along the NLAY dimension (Fig. A-4 provides an example). The object is considered to be rectangular because it has width MODL = 3 on two opposite sides and length NLAY = 5 on the other two sides. To generate definitions of elements 2 through 15 automatically, including both corner node identification and material type, only one card is necessary:

1	1	5	6	2	1	3	5	
5	10	15	20	25	30	35	40	80

Although all elements of this example will be assumed to contain the same material, MTYP = 1, this situation can easily be changed by using the material-correction facility.

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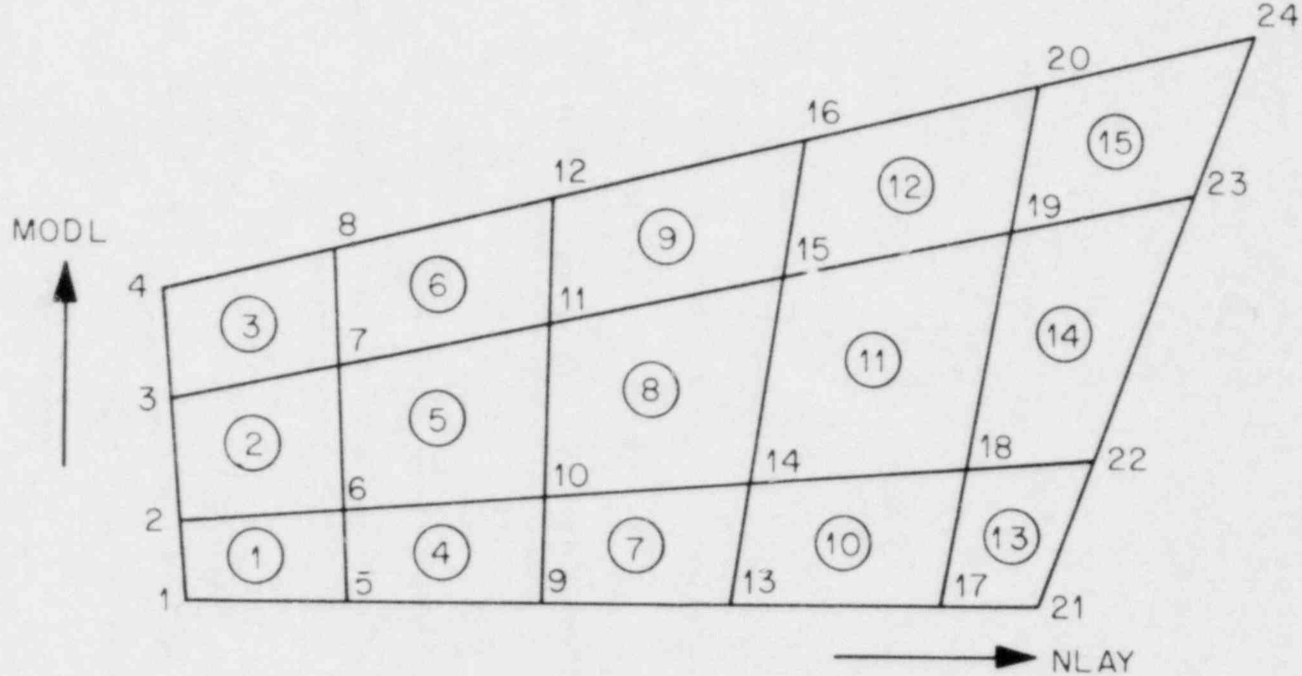


Fig. A-4. Example of the automatic generation of elements

10. Material Correction: FORMAT(16I5).

In many cases 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 limt 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:

MI	MTYP	MK	MINC	╳
5	10	15	20	80

⋮

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 and MINC = 0 for no automatically generated correction).

11. Card Input for Initial or Pre-initial Conditions: FORMAT(I5,5X,F10.0).

These cards are necessary only if NSTRT = 0. In the most general case there is one card per node, i.e., a total of NNP cards:

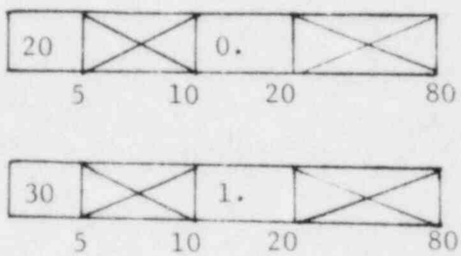
NJ	╳	H(NJ)	╳
5	10	20	80

⋮

NJ = Nodal number.

H(NJ) = Initial or pre-initial pressure head of node NJ, (L).

Frequently, however, groups of neighboring nodal points NJ have identical values H(NJ). If a gap is recognized in the input sequence of nodal numbers, the intial pressures are assumed to be identical to the pressure at the lower boundary of the gap. For example, if two neighboring cards of the form



where encountered, nodes 21 to 29 would be assigned values of H = 0.0.

Note on initial conditions and restarting: The initial condition for a transient calculation may be obtained in three different ways: from card input, auxiliary storage input (referred to as tape input in discussion to follow), or steady-state calculation using a different set of boundary conditions than that used for transient calculation. In the latter case a card input of, shall we say, the pre-initial condition is required as the zero-th order iterate of the steady-state solution. Tape input is necessary whenever the restarting facility is being used. That is, pressure distributions for NSTRT different times have been generated and written on a magnetic tape. If NSTRT > 0, these distributions will be read from the tape, and the NSTRT-th distribution will be used as the initial condition for the current calculation. (If KSTR > 0, the pressure values will be written on a different magnetic tape as they are being read so that a complete record of the calculations may be kept on one tape.) If either the first (card-input) or the last (steady-state) option is desired, then NSTRT = 0.

<u>Note on auxiliary storage units</u>: Logical unit 1 is used for output if KSTR = Ø, and logical unit 2 is used for input if NSTRT > 0. Proper identification of these units must be made in the job control language if either of these two options is used.

<u>Note on steady-state input</u>: The steady-state option may be used to provide either the final state of a system under study or the initial condition for a transient calculation. In the former case KSS = 0 and NTI = 0, whereas in the latter KSS = 0 and NTI > 0. If KSS = Ø, there will be no steady-state calculation. Use of a steady-state as an initial condition requires a different set of boundary conditions than is used for the transient calculations. (A transient calculation using the same set of boundary conditions would not be meaningful because no changes in the pressure distributions could occur.) Input Data Sets 12 to 17, described below, define the steady-state boundary conditions. They are, of course, necessary if and only if KSS = 0.

12. <u>Integer Parameters for Steady-state (KSS = 0, NTI = 0) or Transient (KSS = 1)</u>: FORMAT(16I5).

One card per problem is required:

NBC	NST	NRFPR	NRFPAR	NRSEL	NRSN	
5	10	15	20	25	30	80

NBC = Number of constant Dirichlet nodes.

NST = Number of elements with Neumann conditions.

NRFPR = Number of rainfall profiles.

NRFPAR = Number of parameters in each rainfall profile.

NRSEL = Number of rainfall-seepage element sides.

NRSN = Number of rainfall-seepage nodes.

13. <u>Rainfall Profiles</u>: FORMAT(8F10.0).

These cards are necessary if and only if the number of rainfall-seepage nodes NRSN > 0 and the number of rainfall profiles NRFRP > 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:

TRF(1,1)	TRF(1,2)	. . .	TRF(1,NRFPAR)
RF(1,1)	RF(1,2)	. . .	RF(1,NRFPAR)
⋮			
TRF(NRFPR,1)	TRF(NRFPR,2)	. . .	TRF(NRFPR,NRFPAR)
RF(NRFPR,1)	RF(NRFPR,2)	. . .	RF(NRFPR,NRFPAR)

Only the linearly interpolated value of the rainfall rate RF at time TRF = 0 will be used in the steady-state calculation. (See Data Set 19, below.)

TRF(I,J) = J-th interpolation time for rainfall profile I (T).

RF(I.J) = J-th interpolation value of rainfall for rainfall profile I (L).

14. Rainfall Type and Ponding Depth: FORMAT(3I5,5X,2F10.0).

Card input is required here if and only if NRSN > 0. Typically one card is required per rainfall-seepage node as follows:

NI	IRFTYP(NI)	NPINC		HCON(NI)	
5	10	15	20	30	80

⋮

However, if NPINC ≠ 0, this information is automatically generated. If the card immediately preceding is for node NJ, then nodes NJ + NPINC, NJ + 2*NPINC, ..., NK will be given rainfall type IRFTYP(NJ) and puddling depth HCON(NJ), where NK is the largest integer in the above sequence that is less than the current nodal value NI. Rainfall type values IRFTYP(NI) > 0 are permitted. If the value is zero, then a rainfall rate of zero is assumed for node NI. If the value is greater than zero, then IRFTYP(NI) serves as a pointer to a rainfall profile input under Data Set 13, which is to be used to obtain the rainfall rate at node NI.

NI = Node number of rainfall type and ponding depth.

IRFTYP(NI) = Rainfall-type parameter used to identify the rainfall profile to be used at node NI.

NPINC = Automatic generation increment.

HCON(NI) = Ponding depth at node NP (L).

15. <u>Rainfall-Seepage Surface Element Sides</u>: FORMAT(16I5).

As in the two previous input sets, input is necessary here if and only if rain falls on surfaces or seepage flows through surfaces, or both, i.e., NRSN > 0. Typically, one card is required for each side of each element on which such a boundary is to be applied:

NRSE(MP)	IS(MP,1)	IS(MP,2)	KINC	X
5	10	15	20	80

⋮

NRSE(MP) = Element number of MP--the rainfall-seepage element-side.

IS(MP,1) = Global node number of the first nodal point of MP--the rainfall-seepage element-side.

IS(MP,2) = Global node number of the second nodal point of MP--the rainfall-seepage element-side.

KINC = Automatic generation indicator for NRSE and IS.

However, if KINC > 0, automatic generation is employed in the following manner. Nodal-point and element number increments are formed from information on the input card immediately preceding the current one:

$$NPINC = IS(MP,2) - IS(MP,1)$$

and

$$MINC = |NPINC| - 1 \quad ,$$

where the vertical bars denote absolute value. A sequence of element numbers is then obtained:

```
M = NRSE(MP) (previous card)
NRSE(MP+1) = M + MINC
NRSE(MP+2) = M + 2*MINC
    ⋮
```

The sequence is continued until the largest element number is encountered that has a value less than NRSE of the current card. Corresponding nodal point sequences are also generated:

```
NI = IS(MP,1) (previous card)
IS(MP+1,1) = NI + NPINC
IS(MP+2,1) = NI + 2*NPINC
    ⋮
```

and

```
NJ = IS(MP,2)
IS(MP+1,2) = NJ + NPINC
IS(MP+2,2) = NJ + 2*NPINC
    ⋮
```

16. Dirichlet Boundary Conditions: FORMAT(2I5,F10.0).

These cards are necessary if and only if NBC > 0 (and KSS = 0, a condition either stated or implied for the last four sets of cards). If automatic generation is not used (NPINC = 0), NBC cards are required of the form

NN(NPP)	NPINC	BB(NPP)	
5	10	20	80

⋮

NN(NPP) = Dirichlet node number.

NPINC = Automatic generation increment for NN.

BB(NPP) = Dirichlet pressure at node NN (L).

If NPINC > 0, automatic generation proceeds in the same manner as described for Data Set 14. That is, an algebraic sequence is built on the nodal number NN of the card immediately preceeding, and each such node is given boundary condition BB of that card.

17. Neumann Boundary Conditions: FORMAT(3I5,5X,2F10.0).

Cards of this type must be used if and only if NST > 0. Usually a number of cards equal to NST must be used. However, if some of the KINC are greater than zero, some of the NST boundary conditions will be generated internally, and NST cards will not be necessary.

NI	NJ	KINC		EI	EJ	
5	10	15	20	30	40	8-

⋮

NI = Neumann flux node number.

NJ = Neumann flux node number.

KINC = Automatic gneration indicator for NI and NJ.

EI = Dot product of flux at NI with outwardly directed unit vector normal to element-side (NI,NJ).

EJ = Similar to EI.

If KINC > 0, then the nodal-point increment is formed from NI and NJ of the immediately preceding card:

$$NPINC = |NJ - NI| \quad .$$

Two sequences are formed:

NI + NPINC, NI + 2*NPINC . . .

NJ + NPINC, NJ + 2*NPINC . . .

Both are terminated when the largest integer is reached that is less than both current values of NI and NJ. Corresponding nodal points for these two sequences define a surface. Quantity EI is the dot product of the flux of NI with an outwardly directed unit vector normal to the element side (NI,NJ). A similar definition holds for EJ.

Note on transient-state input: Data Sets 18 to 23 which follow are identical to Sets 12 to 17 used to define the boundary conditions for the steady-state calculation. Most of the remarks regarding automatic generation, sign conventions, and other input restrictions that are pertinent there are pertinent here as well. Cards, whose descriptions follow, are necessary only if NTI > 0. If NTI = 0, there will be no transient calculation, and transient-state boundary conditions are unnecessary. All variable definitions in card groups 19 through 25 below are the same as those in card groups 12 through 18.

18. Transient-State Integer Parameters (KSS=Ø,NTI=0): FORMAT(16I5). One card per problem.

NBC	NST	NRFPR	NRFPAR	NRSEL	NRSN	
5	10	15	20	25	30	80

19. Rainfall Profiles: FORMAT(8F10.0).

These cards are necessary if and only if the number of rainfall seepage nodes NRSN > 0 and the number of rainfall profiles NRFPR > 0.

TRF(1,1)	TRF(1,2)	. . .	TRF(1,NRFPAR)
RF(1,1)	RF(1,2)	. . .	RF(1,NRFPAR)
⋮			
TRF(NRFPR,1)	TRF(NRFPR,2)	. . .	TRF(NRFPR,NRFPAR)
RF(NRFPR,1)	RF(NRFPR,2)	. . .	RF(NRFPR,NRFPAR)

This input provides the basic data for a linear interpolation from which the rainfall rate RF may be obtained at any time TRF and at any boundary node, as specified by pointer indices IRFTYP.

20. Rainfall Types and Ponding Depth: FORMAT(3I5,5X,2F10.0).

Card input is required here if and only if NRSN > 0.

NI	IRFTYP(NI)	NPINC	X	HCON(NI)	X
5	10	15	20	30	80

⋮

21. Rainfall-seepage Surface Element-sides: FORMAT(16I5).

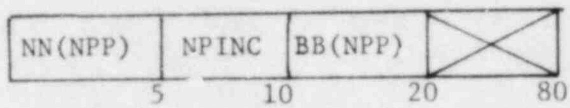
Input is required if and only if NRSN > 0.

NRSE(MP)	IS(MP,1)	IS(MP,2)	KINC	X
5	10	15	20	80

⋮

22. Dirichlet Boundary Conditions: FORMAT(2I5,2F10.0).

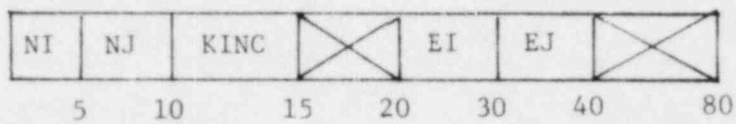
These cards are necessary if and only if NBC > 0.



⋮

23. Neumann Boundary Conditions: FORMAT(3I5,2F10.0).

Cards of this type must be used if and only if NST > 0.



⋮

A-VI. UNIQUENESS AND LIMITATIONS OF FEMWATER

The uniqueness of the FEMWATER code is given below:

* Treatment of Variable Boundary Conditions
* Three Options of Obtaining Initial Conditions
* Six Options of Solution Strategies listed in Table A.1

The limitations of FEMWATER lie in the availability of soil property function and computer storage:

* Need Two Curves for Each Material Type
* Need Large Amount of Computer Storage

Table A.1. Listing of Alternative Numerical Schemes*

	Time-marching			Mass matrix	
Numerical schemes	Central difference	Backward difference	Mid-difference	Without lumping	With lumping
1	X			X	
2		X		X	
3	X				X
4		X			X
5			X	X	
6			X		X

*In general, numerical scheme 1 is prefered because it has the second-order accuracy in time. However, if oscilation occurs, numerical scheme 2 is preferred. If both numerical schemes 1 and 2 fail, one should try all other alternative schemes. As a rule of thumb, a mass lumping scheme (numerical scheme 3, 4, or 6) yields more stable but less accurate results.

APPENDIX B: COURSE PROBLEMS

B-I. A SIMPLE ONE-DIMENSIONAL PROBLEM

B-II. A SEEPAGE DRAINAGE PROBLEM

B-III. A SOLID WASTE DISPOSAL AREA PROBLEM

B-IV. A SHALLOW TRENCH BURIAL PROBLEM

APPENDIX B: COURSE PROBLEMS

In this class note, four example problems are used to illustrate the application of the FEMWATER code to low-level waste disposals in the shallow land system. The first example (B-I) is the study of vertical infiltration. It is typical of column tests, lysimetric experiments, or infiltrations by precipitation over flat horizontal ground surface. The second example is the study of water moving from a seepage pond into groundwater and to the stream. This typifies a class of problems involving leaching of wastes such as uranium mill tailings. The third (B-III) and fourth (B-IV) examples are the investigation of near-surface disposal of solid wastes and shallow trench burials, respectively. They are representative of dry or wet burials above the groundwater table with surface sealing.

In addition, these four examples also show various options and complete use of FEMWATER. Both one-dimensional (B-I) and two-dimensional (B-II, B-III, and B-IV) problems are included. Three options of providing initial conditions are demonstrated: transient simulation with prescribed initial condition (B-I), transient state computation with intial conditions obtained by steady-state solution (B-III), and steady-state solution only (B-II and B-IV). Both homogeneous and complex media can be handled. Examples B-I, B-II, and B-IV treat the media as a single homogeneous formation while example B-III considers the media as composed of two different formations.

The set up of these various options will be explained in the input data.

B-I. A SIMPLE ONE-DIMENSIONAL PROBLEM

B-I.1. Problem Description

A one-dimensional infiltration experiment was used to illustrate the operation procedure of FEMWATER. The soil column is assumed to be 160 cm long and 5 x 5 cm in cross section. The column is filled with loam soil having an initial moisture content of 0.2 cm^3/cm^3. The column is assumed to be infiltrated and maintained at a constant head on its top with a slug of water. The total infiltration occurs in 17.5 h. The problem being addressed is to find out the distributions of the pressure, moisture content, and flow velocity along the column with the passage of time. The soil properties of the loam soil are given in Figs. B-1 and B-2. For this demonstration, a total of 8.5 h simulation time was made. The initial condition was assumed to be the input rather than obtained by steady-state solution. The boundary conditions are: (1) a prescribed head of -14.49 cm is imposed on the top and (2) a zero flux is applied to the bottom.

For FEMWATER execution, the column is discretized by 25 elements and 52 nodes as shown in Fig. B-3. To minimize the bandwidth of the coefficient matrix, the nodes are numbered to proceed most rapidly along the direction that contains the least number of nodes. A constant time step of 0.1 h was used resulting in a total number of 85 time steps.

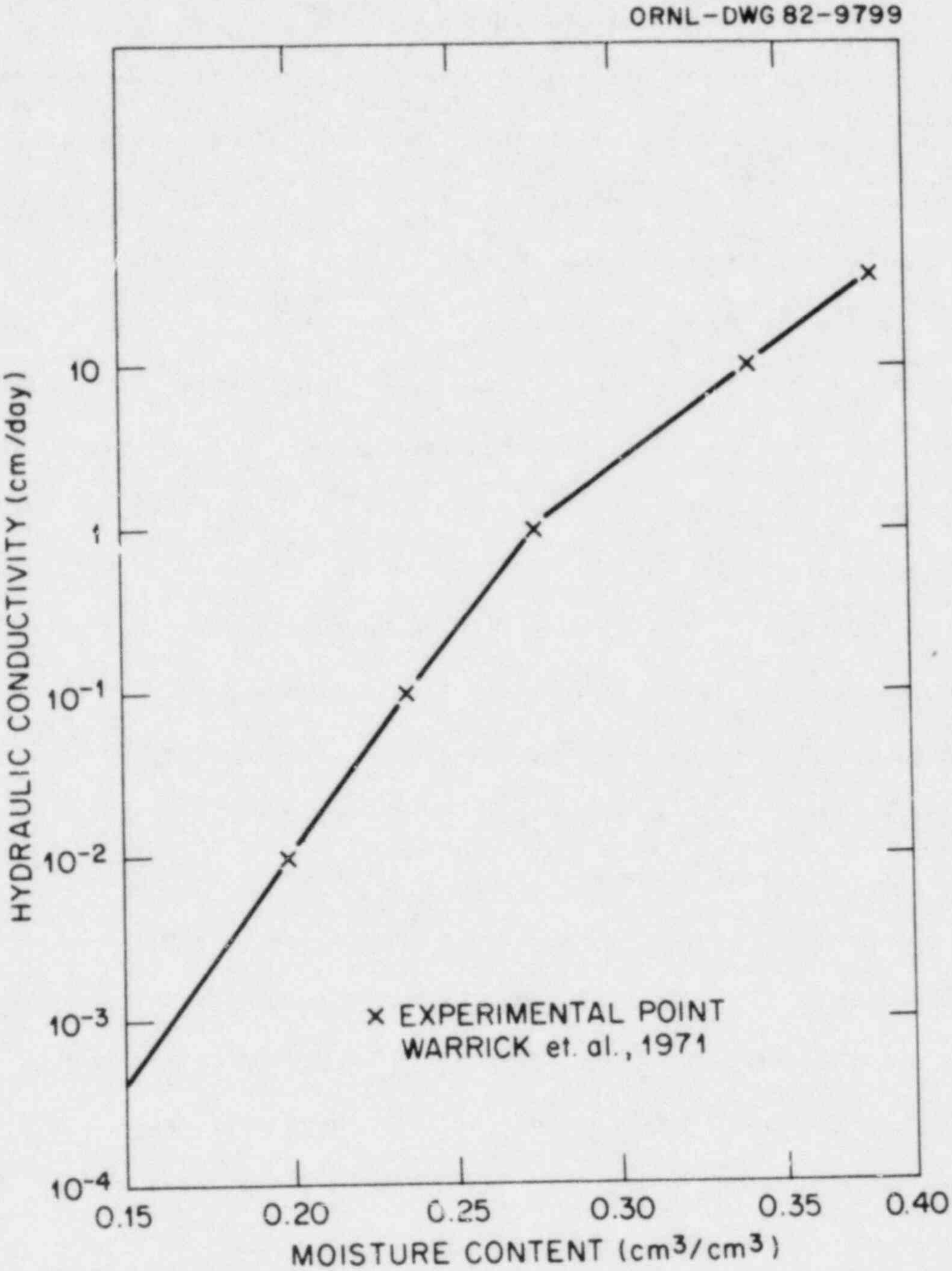


Fig. B-1. Hydraulic conductivity vs moisture content used for the simple one-dimensional problem

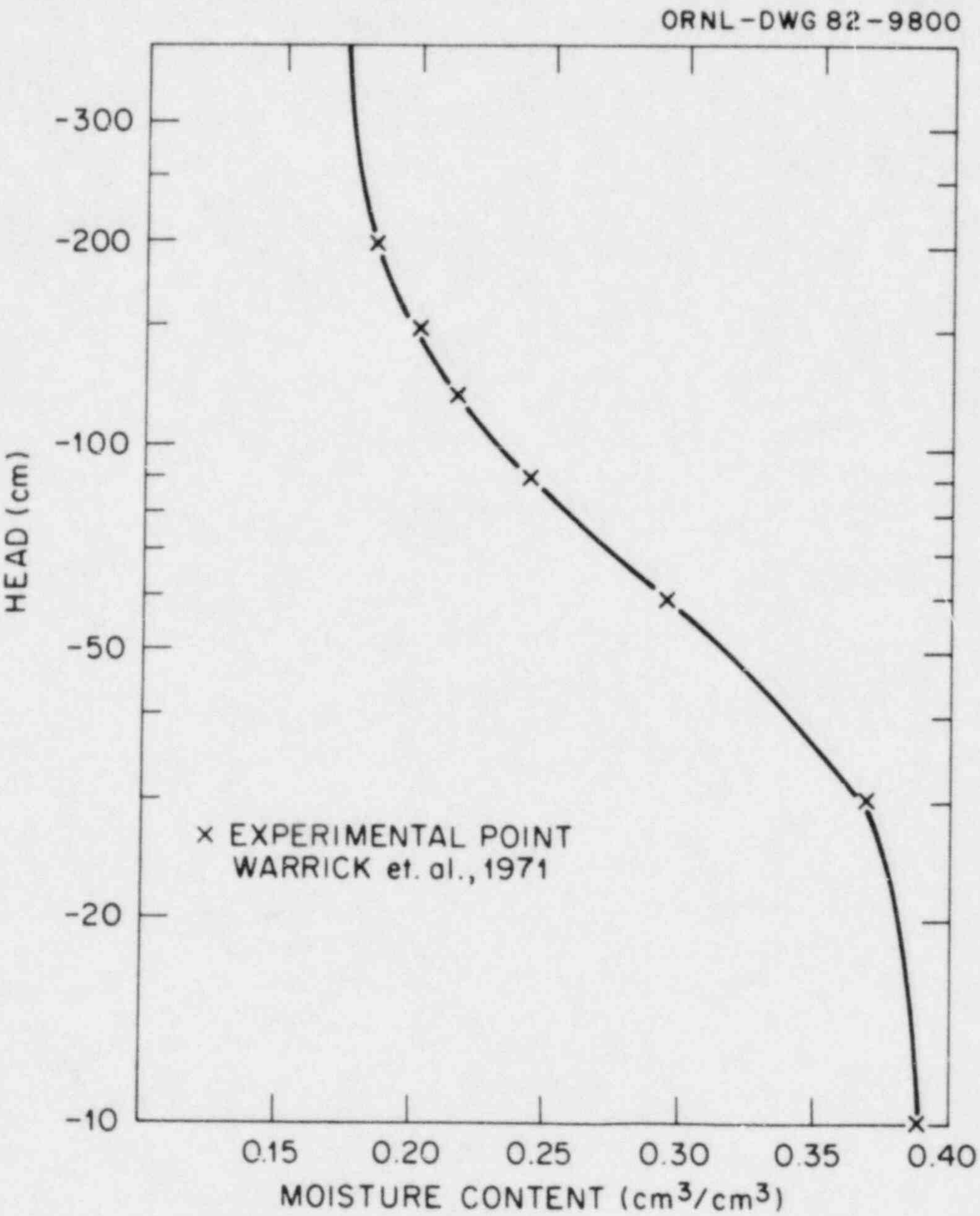


Fig. B-2. Pressure head vs moisture content used for the simple one-dimensional problem

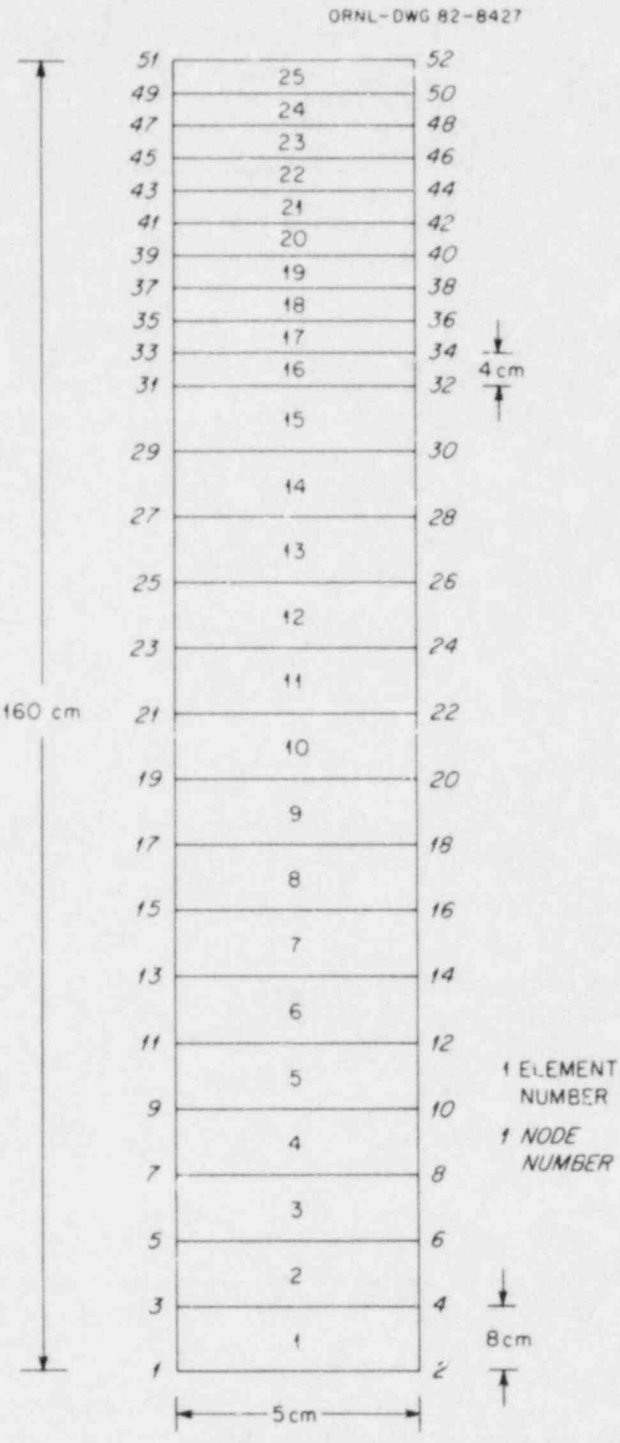


Fig. B-3. Finite element discretization for the simple one-dimensional problem

B-I.2. Input Deck

Input data and set for this simple one-dimensional problem is given in Table B.1, coded according to the instruction given in Section A-V.3. Cards with a "C" on the first column are used to explain the data immediately following. They must be removed for execution of the program. Because the initial condition is prescribed, KSS is set equal to 1. Eighty-five (85) time steps are desired to yield a total simulation of 8.5 h, NTI = 85. The media is a single homogeneous formation, thus NMAT = 1, and NCM = 0.

B-II. A SEEPAGE POND PROBLEM

B-II-1. Problem Description

A seepage pond near a stream is assumed to be situated entirely in the unsaturated zone above the water table. This pond provides the source of water which drains into the aquifer. Although the rainfall on the soil surface also provides water sources in the form of infiltration, it is on the average very small compared to the continuous drainage from the pond. After the water reaches the water table, it flows toward a nearby stream as depicted in Fig. B-4 which also outlines the surface topography and the extent of the aquifer system. This example typifies a class of problems involving leaching of wastes from storage lagoons. The soil properties are given in Fig. B-5. The problem being addressed is to find the spatial distribution of pressure head, total head, moisture content, and Darcy's velocity under the steady state condition achieved by a constant drainage rate of 1.44 cm/h. To use the FEMWATER program for

Table B.1. Input data for a simple one-dimensional problem

```
C
C ------- DATA SET 1: TITLE
   1  ONE-DIMENSIONAL SIMULATION OF WARICK'S EXPERIMENT WITH FEMWATER
C
C  ------ DATA SET 2: BASIC INTEGER PARAMETERS
   52   25     1     0    85     1     1    24     1     0     1     0    10     2     5
    0    0
C
C ------- DATA SET 3: BASIC REAL PARAMETERS
 160.0      1.0         360.0      32400.0    0.0         0.01        0.01        1.0
 980.0      0.012       1.0
C
C ------- DATA SET 4: PRINTER OUTPUT AND DISK STORE CONTROL
151       151       151       151       151       151       151       151       1
51  15
11111111111111111111111111111111111111111111111111111111111111111111111111111111
111111
C
C ------- DATA SET 5: MATERIAL PROPERTIES
 0.0        0.0         0.38        0.00E00    4.37E-4
C
C ------- DATA SET 6 ANALYTIC SOIL PARAMETERS ARE NOT NEEDED SINCE KSP.NE.0
C
C ------- DATA SET 7: SOIL PROPERTIES IN TABULAR FORM
C ------- PRESSURE HEAD
 -269.11    -242.29    -219.14    -196.39    -176.92    -159.18    -143.33    -128.00
 -116.18    -104.60    -94.17     -84.79     -76.33     -68.73     -61.88     -55.71
 -50.15     -45.16     -41.13     -36.56     -32.95     -29.67     -20.90     -14.49
C ------- MOISTURE CONTENT
 0.15       0.16       0.17       0.18       0.19       0.20       0.21       0.22
 0.23       0.24       0.25       0.26       0.27       0.28       0.29       0.30
 0.31       0.32       0.33       0.34       0.35       0.36       0.37       0.38
C ------- RELATIVE HYDRAULIC CONDUCTIVITY
   1.06E-5    2.01E-5    3.81E-5    7.28E-5    1.38E-4    2.65E-4    5.08E-4    9.73E-4
   1.88E-3    3.58E-3    6.22E-3    1.08E-2    1.89E-2    3.29E-2    4.65E-2    6.60E-2
   5.35E-2    1.32E-1    1.87E-1    2.65E-1    3.71E-1    5.20E-1    7.15E-1    1.00E00
 0.0          3.93E-4    4.36E-4    4.85E-4    5.39E-4    5.98E-4    6.61E-4    7.44E-4
   8.20E-4    9.10E-4    1.01E-3    1.12E-3    1.25E-3    1.39E-3    1.54E-3    1.54E-3
   1.90E-3    2.11E-3    2.32E-3    2.60E-3    2.90E-3    1.46E-3    1.34E-3    0.00E00
C
C ------- DATA SET 8: NODAL-POINT POSITIONS
     1 0.0          0.0
     2 5.0          0.0
     3 0.0          8.0
     4 5.0          8.0
     5 0.0          16.0
     6 5.0          16.0
     7 0.0          24.0
     8 5.0          24.0
     9 0.0          32.0
    10 5.0          32.0
    11 0.0          40.0
    12 5.0          40.0
    13 0.0          48.0
    14 5.0          48.0
    15 0.0          56.0
    16 5.0          56.0
    17 0.0          64.0
    18 5.0          64.0
    19 0.0          72.0
    20 5.0          72.0
    21 0.0          80.0
    22 5.0          80.0
    23 0.0          88.0
    24 5.0          88.0
    25 0.0          96.0
    26 5.0          96.0
    27 0.0          104.0
    28 5.0          104.0
    29 0.0          112.0
    30 5.0          112.0
    31 0.0          120.0
    32 5.0          120.0
    33 0.0          124.0
    34 5.0          124.0
    35 0.0          128.0
    36 5.0          128.0
    37 0.0          132.0
    38 5.0          132.0
    39 0.0          136.0
    40 5.0          136.0
    41 0.0          140.0
    42 5.0          140.0
    43 0.0          144.0
    44 5.0          144.0
    45 0.0          148.0
```

Table B.1. (continued)

```
   46  5.0        148.0
   47  0.0        152.0
   48  5.0        152.0
   49  0.0        156.0
   50  5.0        156.0
   51  0.0        160.0
   52  5.0        160.0
C
C ------- DATA SET 9: ELEMENT DEFINITIONS
    1     1     2     4     3     1     1    25
C
C ------- DATA SET 10 MATERIAL CORRECTION IS NOT REQUIRED SINCE NCM=0
C ------- DATA SET 11: CARD INPUT FOR INITIAL OR PRE-INITIAL CONDITIONS
    1        -15[illegible].2
   27        -1[illegible].9
   29        -17[illegible].8
   31        -189.6
   33        -196.4
   35        -203.4
   37        -210.6
   39        -218.1
   41        -225.9
   43        -230.0
   45        -242.3
   47        -250.9
   49        -259.9
   51        -14.9
   52        -14.9
C
C ------- DATA SET 12: INTEGER PARAMETERS FOR STEADY-STATE OR TRANSIENT
    2     0     0     0     0     0
C
C ------- DATA SET 13 RAINFALL PROFILES, DATA SET 14 RAINFALL TYPE AND PONDING
C ------- DEPTH, AND DATA SET 15 RAINFALL-SEEPAGE SURFACE ELEMENT SIDES ARE NOT
C ------- NEEDED SINCE NRSN=0
C
C ------- DATA SET 16: DIRICHLET BOUNDARY CONDITIONS
   51     0 -14.49
   52     0 -14.49
C
C ------- DATA SET 17 NEUMANN BOUNDARY CONDITIONS ARE NOT NEEDED SINCE NST=0
C
C ------- DATA SET 18 THROUGH DATA SET 23 ARE NOT NEEDED SINCE KSS=1 AND NTI>0
C
C ------- FINIALLY A BLANK CARD TO END THE JOB
```

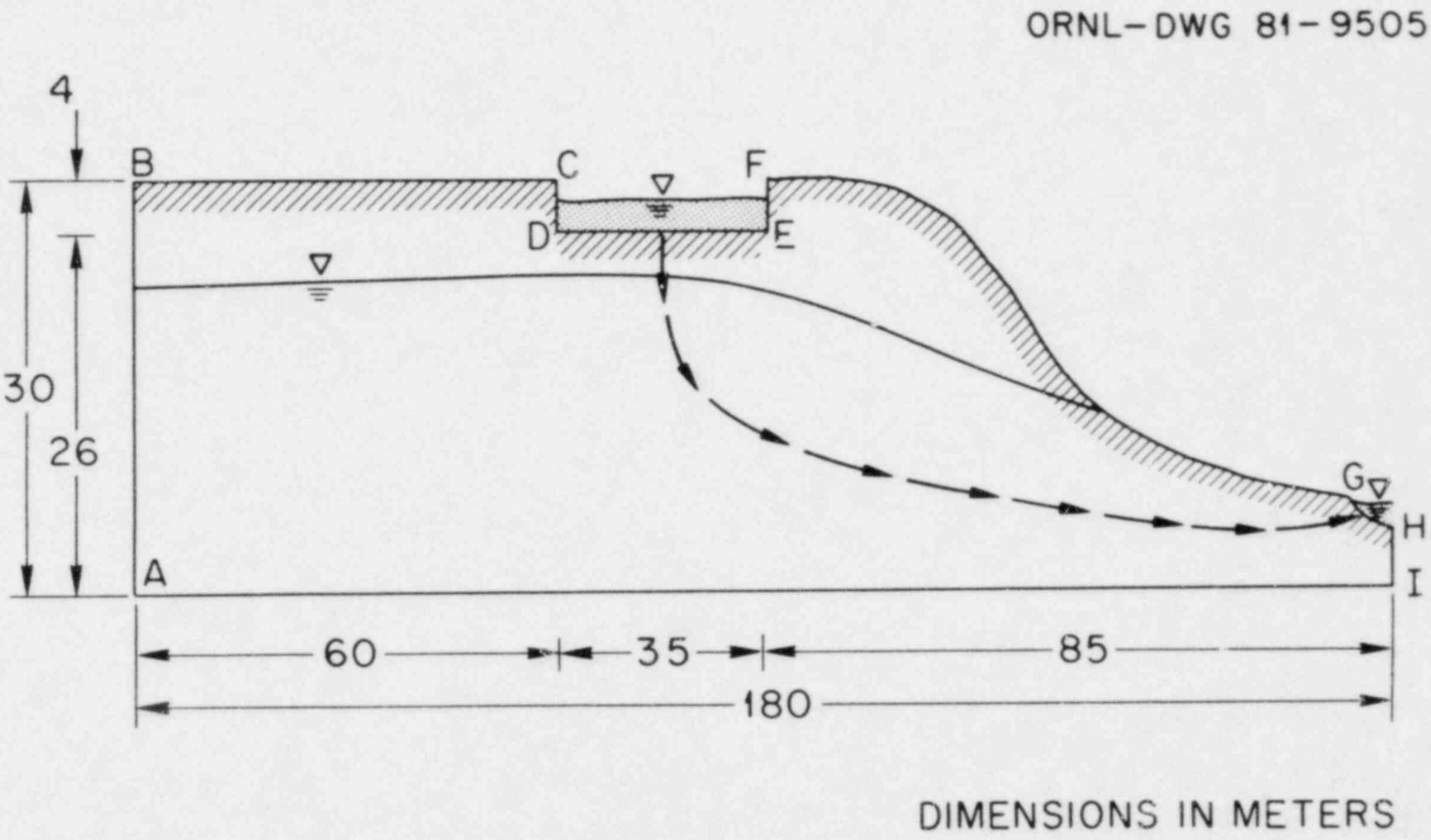


Fig. B-4. Sketch of the region of interest for the seepage pond problem

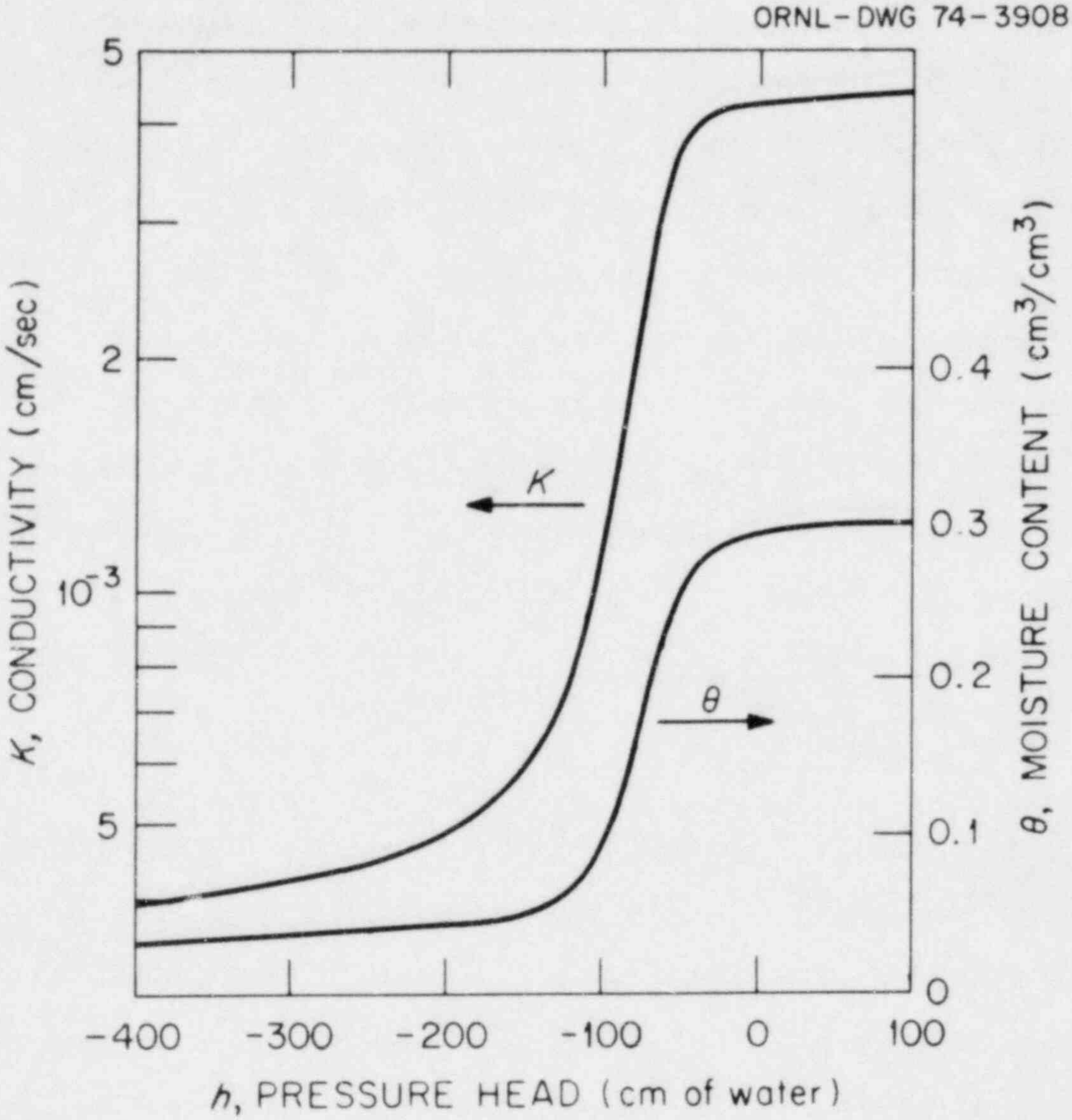


Fig. B-5. Hydraulic property functions used for the seepage pond problem answering this question, the region in Fig. B-4 is discretized by 595 nodes and 528 elements as shown in Fig. B-6. For the finite element computation, the seven nodal points on the stream-soil interface are designated as Dirichlet nodes (Fig. B-6). Seven nodal points on the bottom of the seepage pond, namely nodal point nos. 152, 164, 172, 180, 188, 196, and 204, are considered as constant Neumann flux points and are assigned a constant infiltration rate of 4.0×10^{-4} cm/s. 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 on this surface are either Dirichlet or Neumann points with the infiltration rate equal to the through rainfall rate, which is assumed zero in this case. All other boundaries are treated as impervious.

B-II.2. Input Deck

With the above problem description, the input data for FEMWATER can be coded according to section A-V.3 of APPENDIX A. The complete data set is given in Table B.2. Again, cards with a "C" in column one are used for description only and must be removed for execution. The steady-state solution only is desired; thus KSS = 0 and NTI = 0. A single homogeneous media is considered, hence NMAT = 1 and NCM = 0. Also, the first three numbers on data set 3 are not used in the computation; thus they can be anything.

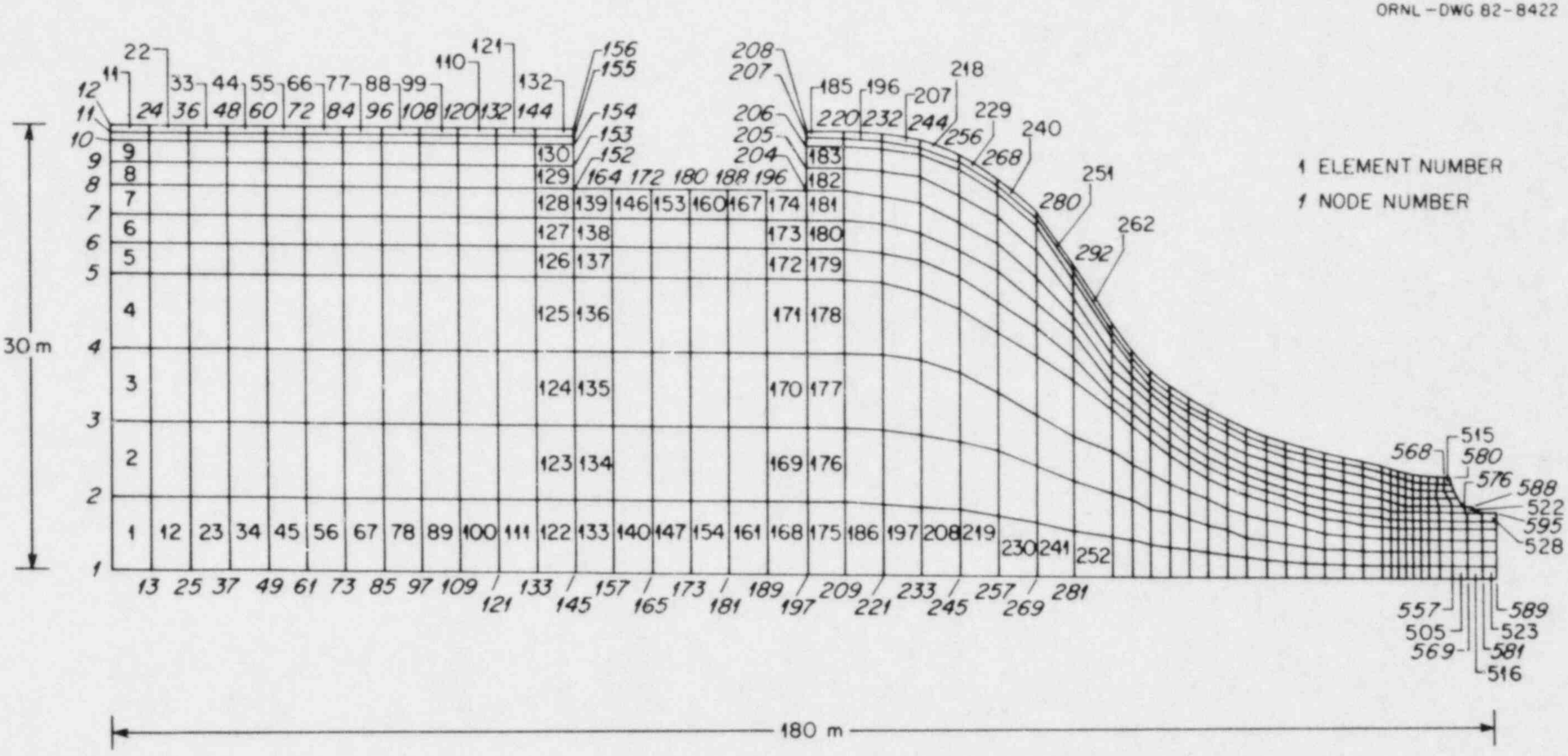


Fig. B-6. Finite element discretization for the seepage pond problem

Table B.2. Input data for a seepage pond problem

```
C
C ------- DATA SET 1: TITLE
   3    SEEPAGE POND, STEADY STATE SIMULATION, WITH FEMWATER CODE
C
C ------- DATA SET 2: BASIC INTEGER PARAMETERS
  595  528    1    0    0    0    1   16    1    1    1    0   20   15    5
    0    0
C
C ------- DATA SET 3: BASIC REAL PARAMETERS
300.       .5          86400.     0.          0.          .01         .1          1.
980.6      .013        1.
C
C ------- DATA SET 4: PRINTER OUTPUT AND DISK STORE CONTROL
55
11
C
C ------- DATA SET 5: MATERIAL PROPERTIES
0.         0.          .3                    .58E-7      .58E-7
C
C ------- DATA SET 6 ANALYTIC SOIL PARAMETERS ARE NOT NEEDED SINCE KSP.NE.0
C
C ------- DATA SET 7: SOIL PROPERTIES IN TABULAR FORM
C ------- PRESSURE HEAD
 -800.0    -400.       -200.       -175.       -150.       -125.       -100.       -62.5
 -50.0     -37.5       -25.        -12.5       0.          50.         100.        2000.
C ------- MOISTURE CONTENT
.024       .032        .0425       .045        .050        .0625       .09         .21
.25        .275        .285        .290        .2925       .2975       .2995       .3
C ------- RELATIVE PERMEABILITY*VISCOSITY/(DENSITY*GRAVITY)
 .10057E-5 .11886E-5 .14857E-5 .16000E-5 .18286E-5 .21715E-5 .36565E-5 .91430E-5
 .10972E-4 .12114E-4 .12572E-4 .12800E-4 .12800E-4 .13029E-4 .13257E-4 .13257E-4
C ------- MOISTURE CONTENT CAPACITY
    0.          .52E-4      .10E-3      .20E-3      .50E-3      .11E-2      .32E-2      .32E-2
    .20E-2      .80E-3      .40E-3      .20E-3      .10E-3      .40E-4      .26E-6      0.
C
C ------- DATA SET 8: NODAL-POINT POSITIONS
    1       0.0         0.0
    2       0.0       500.000
    3       0.0      1000.000
    4       0.0      1500.000
    5       0.0      2000.000
    6       0.0      2200.000
    7       0.0      2400.000
    8       0.0      2600.000
    9       0.0      2750.000
   10       0.0      2900.000
   11       0.0      2950.000
   12       0.0      3000.000
   13     500.000       0.0
   14     500.000     500.000
   15     500.000    1000.000
   16     500.000    1500.000
   17     500.000    2000.000
   18     500.000    2200.000
   19     500.000    2400.000
   20     500.000    2600.000
   21     500.000    2750.000
   22     500.000    2900.000
   23     500.000    2950.000
   24     500.000    3000.000
   25    1000.000       0.0
   26    1000.000     500.000
   27    1000.000    1000.000
   28    1000.000    1500.000
   29    1000.000    2000.000
   30    1000.000    2200.000
   31    1000.000    2400.000
   32    1000.000    2600.000
   33    1000.000    2750.000
   34    1000.000    2900.000
   35    1000.000    2950.000
   36    1000.000    3000.000
   37    1500.000       0.0
   38    1500.000     500.000
   39    1500.000    1000.000
   40    1500.000    1500.000
   41    1500.000    2000.000
   42    1500.000    2200.000
   43    1500.000    2400.000
   44    1500.000    2600.000
   45    1500.000    2750.000
   46    1500.000    2900.000
   47    1500.000    2950.000
   48    1500.000    3000.000
   49    2000.000       0.0
   50    2000.000     500.000
```

Table B.2. (continued)

51	2000.000	1000.000
52	2000.000	1500.000
53	2000.000	2000.000
54	2000.000	2200.000
55	2000.000	2400.000
56	2000.000	2600.000
57	2000.000	2750.000
58	2000.000	2900.000
59	2000.000	2950.000
60	2000.000	3000.000
61	2500.000	0.0
62	2500.000	500.000
63	2500.000	1000.00
64	2500.000	1500.000
65	2500.000	2000.000
66	2500.000	2200.000
67	2500.000	2400.000
68	2500.000	2600.000
69	2500.000	2750.000
70	2500.000	2900.000
71	2500.000	2950.000
72	2500.000	3000.000
73	3000.000	0.0
74	3000.000	500.000
75	3000.000	1000.000
76	3000.000	1500.000
77	3000.000	2000.000
78	3000.000	2200.000
79	3000.000	2400.000
80	3000.000	2600.000
81	3000.000	2750.000
82	3000.000	2900.000
83	3000.000	2950.000
84	3000.000	3000.000
85	3500.000	0.0
86	3500.000	500.000
87	3500.000	1000.000
88	3500.000	1500.000
89	3500.000	2000.000
90	3500.000	2200.000
91	3500.000	2400.000
92	3500.000	2600.000
93	3500.000	2750.000
94	3500.000	2900.000
95	3500.000	2950.000
96	3500.000	3000.000
97	4000.000	0.0
98	4000.000	500.000
99	4000.000	1000.000
100	4000.000	1500.000
101	4000.000	2000.000
102	4000.000	2200.000
103	4000.000	2400.000
104	4000.000	2600.000
105	4000.000	2750.000
106	4000.000	2900.000
107	4000.000	2950.000
108	4000.000	3000.000
109	4500.000	0.0
110	4500.000	500.000
111	4500.000	1000.000
112	4500.000	1500.000
113	4500.000	2000.000
114	4500.000	2200.000
115	4500.000	2400.000
116	4500.000	2600.000
117	4500.000	2750.000
118	4500.000	2900.000
119	4500.000	2950.000
120	4500.000	3000.000
121	5000.000	0.0
122	5000.000	500.000
123	5000.000	1000.000
124	5000.000	1500.000
125	5000.000	2000.000
126	5000.000	2200.000
127	5000.000	2400.000
128	5000.000	2600.000
129	5000.000	2750.000
130	5000.000	2900.000
131	5000.000	2950.000
132	5000.000	3000.000
133	5500.000	0.0
134	5500.000	500.000
135	5500.000	1000.000
136	5500.000	1500.000

Table B.2. (continued)

137	5500.000	2000.000
138	5500.000	2200.000
139	5500.000	2400.000
140	5500.000	2600.000
141	5500.000	2750.000
142	5500.000	2900.000
143	5500.000	2950.000
144	5500.000	3000.000
145	6000.000	0.0
146	6000.000	500.000
147	6000.000	1000.000
148	6000.000	1500.000
149	6000.000	2000.000
150	6000.000	2200.000
151	6000.000	2400.000
152	6000.000	2600.000
153	6000.000	2750.000
154	6000.000	2900.000
155	6000.000	2950.000
156	6000.000	3000.000
157	6500.000	0.0
158	6500.000	500.000
159	6500.000	1000.000
160	6500.000	1500.000
161	6500.000	2000.000
162	6500.000	2200.000
163	6500.000	2400.000
164	6500.000	2600.000
165	7000.000	0.0
166	7000.000	500.000
167	7000.000	1000.000
168	7000.000	1500.000
169	7000.000	2000.000
170	7000.000	2200.000
171	7000.000	2400.000
172	7000.000	2600.000
173	7500.000	0.0
174	7500.000	500.000
175	7500.000	1000.000
176	7500.000	1500.000
177	7500.000	2000.000
178	7500.000	2200.000
179	7500.000	2400.000
180	7500.000	2600.000
181	8000.000	0.0
182	8000.000	500.000
183	8000.000	1000.000
184	8000.000	1500.000
185	8000.000	2000.000
186	8000.000	2200.000
187	8000.000	2400.000
188	8000.000	2600.000
189	8500.000	0.0
190	8500.000	500.000
191	8500.000	1000.000
192	8500.000	1500.000
193	8500.000	2000.000
194	8500.000	2200.000
195	8500.000	2400.000
196	8500.000	2600.000
197	9000.000	0.0
198	9000.000	500.000
199	9000.000	1000.000
200	9000.000	1500.000
201	9000.000	2000.000
202	9000.000	2200.000
203	9000.000	2400.000
204	9000.000	2600.000
205	9000.000	2750.000
206	9000.000	2900.000
207	9000.000	2950.000
208	9000.000	3000.000
209	9500.000	0.0
210	9500.000	500.000
211	9500.000	1000.000
212	9500.000	1500.000
213	9500.000	2000.000
214	9500.000	2200.000
215	9500.000	2400.000
216	9500.000	2600.000
217	9500.000	2750.000
218	9500.000	2900.000
219	9500.000	2950.000
220	9500.000	3000.000
221	10000.000	0.0
222	10000.000	480.000

Table B.2. (continued)

223	10000.000	990.000
224	10000.000	1500.000
225	10000.000	1979.999
226	10000.000	2179.999
227	10000.000	2379.999
228	10000.000	2559.999
229	10000.000	2739.999
230	10000.000	2889.999
231	10000.000	2939.999
232	10000.000	2989.999
233	10500.000	0.0
234	10500.000	450.000
235	10500.000	960.000
236	10500.000	1460.000
237	10500.000	1920.000
238	10500.000	2129.999
239	10500.000	2320.000
240	10500.000	2520.000
241	10500.000	2700.000
242	10500.000	2850.000
243	10500.000	2900.000
244	10500.000	2950.000
245	11000.000	0.0
246	11000.000	450.000
247	11000.000	910.000
248	11000.000	1380.000
249	11000.000	1809.999
250	11000.000	2020.000
251	11000.000	2200.000
252	11000.000	2389.999
253	11000.000	2570.000
254	11000.000	2750.000
255	11000.000	2800.000
256	11000.000	2850.000
257	11500.000	0.0
258	11500.000	400.000
259	11500.000	850.000
260	11500.000	1250.000
261	11500.000	1659.999
262	11500.000	1859.999
263	11500.000	2059.999
264	11500.000	2250.000
265	11500.000	2439.999
266	11500.000	2599.999
267	11500.000	2679.999
268	11500.000	2689.999
269	12000.000	0.0
270	12000.000	360.000
271	12000.000	750.000
272	12000.000	1100.000
273	12000.000	1500.000
274	12000.000	1700.000
275	12000.000	1859.999
276	12000.000	2020.000
277	12000.000	2200.000
278	12000.000	2370.000
279	12000.000	2420.000
280	12000.000	2470.000
281	12500.000	0.0
282	12500.000	300.000
283	12500.000	650.000
284	12500.000	950.000
285	12500.000	1330.000
286	12500.000	1490.000
287	12500.000	1639.999
288	12500.000	1759.999
289	12500.000	1879.999
290	12500.000	2000.000
291	12500.000	2050.000
292	12500.000	2100.000
293	13000.000	0.0
294	13000.000	270.000
295	13000.000	570.000
296	13000.000	850.000
297	13000.000	1140.000
298	13000.000	1210.000
299	13000.000	1300.000
300	13000.000	1400.000
301	13000.000	1510.000
302	13000.000	1620.000
303	13000.000	1670.000
304	13000.000	1720.000
305	13250.000	0.0
306	13250.000	250.000
307	13250.000	530.000
308	13250.000	770.000

Table B.2. (continued)

309	13250.000	1030.000
310	13250.000	1120.000
311	13250.000	1200.000
312	13250.000	1300.000
313	13250.000	1370.000
314	13250.000	1450.000
315	13250.000	1500.000
316	13250.000	1550.000
317	13500.000	0.0
318	13500.000	220.000
319	13500.000	460.000
320	13500.000	700.000
321	13500.000	920.000
322	13500.000	1010.000
323	13500.000	1100.000
324	13500.000	1180.000
325	13500.000	1250.000
326	13500.000	1300.000
327	13500.000	1350.000
328	13500.000	1400.000
329	13750.000	0.0
330	13750.000	200.000
331	13750.000	440.000
332	13750.000	650.000
333	13750.000	830.000
334	13750.000	910.000
335	13750.000	1000.000
336	13750.000	1080.000
337	13750.000	1140.000
338	13750.000	1200.000
339	13750.000	1250.000
340	13750.000	1300.000
341	14000.000	0.0
342	14000.000	190.000
343	14000.000	400.000
344	14000.000	590.000
345	14000.000	750.000
346	14000.000	830.000
347	14000.000	900.000
348	14000.000	980.000
349	14000.000	1050.000
350	14000.000	1120.000
351	14000.000	1170.000
352	14000.000	1220.000
353	14250.000	0.0
354	14250.000	170.000
355	14250.000	350.000
356	14250.000	540.000
357	14250.000	670.000
358	14250.000	750.000
359	14250.000	820.000
360	14250.000	900.000
361	14250.000	960.000
362	14250.000	1050.000
363	14250.000	1100.000
364	14250.000	1150.000
365	14500.000	0.0
366	14500.000	150.000
367	14500.000	320.000
368	14500.000	470.000
369	14500.000	610.000
370	14500.000	690.000
371	14500.000	760.000
372	14500.000	830.000
373	14500.000	900.000
374	14500.000	980.000
375	14500.000	1030.000
376	14500.000	1080.000
377	14750.000	0.0
378	14750.000	140.000
379	14750.000	270.000
380	14750.000	430.000
381	14750.000	560.000
382	14750.000	630.000
383	14750.000	700.000
384	14750.000	760.000
385	14750.000	840.000
386	14750.000	910.000
387	14750.000	960.000
388	14750.000	1010.000
389	15000.000	0.0
390	15000.000	120.000
391	15000.000	250.000
392	15000.000	390.000
393	15000.000	520.000
394	15000.000	590.000

Table B.2. (continued)

395	15000.000	650.000
396	15000.000	720.000
397	15000.000	800.000
398	15000.000	860.000
399	15000.000	910.000
400	15000.000	960.000
401	15250.000	0.0
402	15250.000	110.000
403	15250.000	230.000
404	15250.000	370.000
405	15250.000	480.000
406	15250.000	550.000
407	15250.000	610.000
408	15250.000	680.000
409	15250.000	750.000
410	15250.000	820.000
411	15250.000	870.000
412	15250.000	920.000
413	15500.000	0.0
414	15500.000	100.000
415	15500.000	210.000
416	15500.000	330.000
417	15500.000	440.000
418	15500.000	500.000
419	15500.000	560.000
420	15500.000	640.000
421	15500.000	710.000
422	15500.000	790.000
423	15500.000	840.000
424	15500.000	890.000
425	15750.000	0.0
426	15750.000	100.000
427	15750.000	200.000
428	15750.000	300.000
429	15750.000	400.000
430	15750.000	470.000
431	15750.000	510.000
432	15750.000	610.000
433	15750.000	690.000
434	15750.000	750.000
435	15750.000	800.000
436	15750.000	850.000
437	16000.000	0.0
438	16000.000	100.000
439	16000.000	200.000
440	16000.000	290.000
4[illegible]	16000.000	390.000
442	16000.000	450.000
443	16000.000	510.000
444	16000.000	590.000
445	16000.000	650.000
446	16000.000	730.000
447	16000.000	780.000
448	16000.000	830.000
449	16250.000	0.0
450	16250.000	90.000
451	16250.000	190.000
452	16250.000	280.000
453	16250.000	360.000
454	16250.000	440.000
455	16250.000	490.000
456	16250.000	560.000
457	16250.000	630.000
458	16250.000	700.000
459	16250.000	750.000
460	16250.000	800.000
461	16500.000	0.0
462	16500.000	90.000
463	16500.000	180.000
464	16500.000	270.000
465	16500.000	350.000
466	16500.000	410.000
467	16500.000	480.000
468	16500.000	540.000
469	16500.000	600.000
470	16500.000	660.000
471	16500.000	710.000
472	16500.000	760.000
473	16600.000	0.0
474	16600.000	90.000
475	16600.000	180.000
476	16600.000	270.000
477	16600.000	350.000
478	16600.000	400.000
479	16600.000	460.000
480	16600.000	520.000

Table B.2. (continued)

481	16600.000	590.000
482	16600.000	650.000
483	16600.000	700.000
484	16600.000	750.000
485	16700.000	0.0
486	16700.000	90.000
487	16700.000	180.000
488	16700.000	260.000
489	16700.000	340.000
490	16700.000	400.000
491	16700.000	460.000
492	16700.000	510.000
493	16700.000	570.000
494	16700.000	640.000
495	16700.000	690.000
496	16700.000	740.000
497	16800.000	0.0
498	16800.000	90.000
499	16800.000	180.000
500	16800.000	260.000
501	16800.000	340.000
502	16800.000	400.000
503	16800.000	450.000
504	16800.000	500.000
505	16800.000	560.000
506	16800.000	620.000
507	16800.000	670.000
508	16800.000	720.000
509	16900.000	0.0
510	16900.000	90.000
511	16900.000	180.000
512	16900.000	260.000
513	16900.000	340.000
514	16900.000	390.000
515	16900.000	450.000
516	16900.000	500.000
517	16900.000	550.000
518	16900.000	610.000
519	16900.000	660.000
520	16900.000	710.000
521	17000.000	0.0
522	17000.000	90.000
523	17000.000	180.000
524	17000.000	260.000
525	17000.000	340.000
526	17000.000	390.000
527	17000.000	450.000
528	17000.000	500.000
529	17000.000	550.000
530	17000.000	600.000
531	17000.000	650.000
532	17000.000	700.000
533	17100.000	0.0
534	17100.000	90.000
535	17100.000	180.000
536	17100.000	260.000
537	17100.000	340.000
538	17100.000	390.000
539	17100.000	450.000
540	17100.000	500.000
541	17100.000	550.000
542	17100.000	600.000
543	17100.000	650.000
544	17100.000	700.000
545	17250.000	0.0
546	17250.000	90.000
547	17250.000	180.000
548	17250.000	260.000
549	17250.000	340.000
550	17250.000	390.000
551	17250.000	450.000
552	17250.000	500.000
553	17200.000	550.000
554	17200.000	600.000
555	17200.000	650.000
556	17200.000	700.000
557	17400.000	0.0
558	17400.000	90.000
559	17400.000	180.000
560	17400.000	260.000
561	17400.000	340.000
562	17400.000	390.000
563	17400.000	450.000
564	17400.000	500.000
565	17350.000	550.000

Table B.2. (continued)

```
 566 17300.000    600.000
 567 17300.000    650.000
 568 17300.000    700.000
 569 17600.000      0.0
 570 17600.000     90.000
 571 17600.000    180.000
 572 17600.000    260.000
 573 17600.000    340.000
 574 17600.000    390.000
 575 17600.000    450.000
 576 17550.000    500.000
 577 17500.000    550.000
 578 17450.000    600.000
 579 17400.000    650.000
 580 17400.000    700.000
 581 17800.000      0.0
 582 17800.000     90.000
 583 17800.000    180.000
 584 17800.000    260.000
 585 17800.000    340.000
 586 17800.000    390.000
 587 17800.000    450.000
 588 17650.000    490.000
 589 18000.000      0.0
 590 18000.000     90.000
 591 18000.000    180.000
 592 18000.000    260.000
 593 18000.000    340.000
 594 18000.000    390.000
 595 18000.000    450.000
C
C ------- DATA SET 9: ELEMENT DEFINITIONS
   1    1   13   14    2     1   11   12
 133  145  157  158  146     1
 139  151  163  164  152     1
 140  157  165  166  158     1    7    5
 175  197  209  210  198     1   11   31
 516  569  581  582  570     1
 522  575  587  588  576     1
 523  581  589  590  582     1
 528  586  594  595  587     1
C
C ------- DATA SET 10 MATERIAL CORRECTION IS NOT REQUIRED SINCE NCM=0
C
C ------- DATA SET 11: CARD INPUT FOR INITIAL OR PRE-INITIAL CONDITIONS
   1       0.
 595       0.
C
C ------- DATA SET 12: INTEGER PARAMETERS FOR STEADY-STATE OR TRANSIENT
   7    6    0    0   29   29
C
C ------- DATA SET 13 RAINFALL PROFILES ARE NOT NEEDED SINCE NRFPR=0
C
C ------- DATA SET 14: RAINFALL TYPE AND PONDING DEPTH
 244                 0.
 580         12      0.
C
C ------- DATA SET 15: RAINFALL-SEEPGAE SURFACE ELEMENT SIDES
 218  244  256    0
 515  568  580   11
 515  579  580    0
C
C ------- DATA SET 16: DIRICHLET BOUNDARY CONDITIONS
 579            0.0
 578           50.0
 577          100.0
 576          150.0
 588          160.0
 587          200.0
 595          200.0
C
C ------- DATA SET 17: NEUMANN BOUNDARY CONDITIONS
 152  164    0           -4.E-4     -4.E-4
 196  204    1           -4.E-4     -4.E-4
C
C ------- DATA SET 18 THROUGH DATA 23 ARE NOT NEEDED SINCE KSS=0 AND NTI=0
C
C ------- FINALLY A BLANK CARD TO END THE JOB
```

B-III. A SOLID WASTE DISPOSAL AREA PROBLEM

B-III.1. Problem Description

A typical solid waste disposal area consists of waste trenches, trench soil cover, a clay admixture seal, and seal soil cover. The cross-section of such a typical solid waste disposal area (SWDA) is shown in Fig. B-7. For this particular example, it is assumed that the seal soil cover is about 60 cm thick, the clay admixture seal is approximately 30 cm thick, and the trench soil cover is around 63 cm thick. Under the seal, there are three waste trenches, each about 63 cm deep and 10 m wide. A stream is about 40 m down slope from the disposal area. The region used for this example and its surface topography are also sketched in Fig. B-7. The properties of both soil and clay admixture are given in Fig. B-8. A constant net rainfall of 25.344 mm/h ($7.0 \cdot 10^{-4}$ cm/s) is assumed to fall on the surface for a duration of approximately 1.97 h. The problem is to use the FEMWATER program to simulate the transient hydrodynamic variables within the region in Fig. B-1 for, say, 6.13 h. The initial condition is to be obtained by steady-state solution with a constant net rainfall of 63 cm/yr ($2.0 \cdot 10^{-6}$ cm/s) falling on the surface. The boundary conditions are: (1) a variable condition is imposed on the surface, (2) the right vertical boundary under the stream is considered a Dirichlet boundary with hydrostatic pressure, (3) all other boundaries are treated as impervious.

For the FEMWATER execution, the region is discretized by 532 nodes and 486 elements as illustrated in Fig. B-9. Both the nodes and elements are numbered vertically from the bottom to top column by

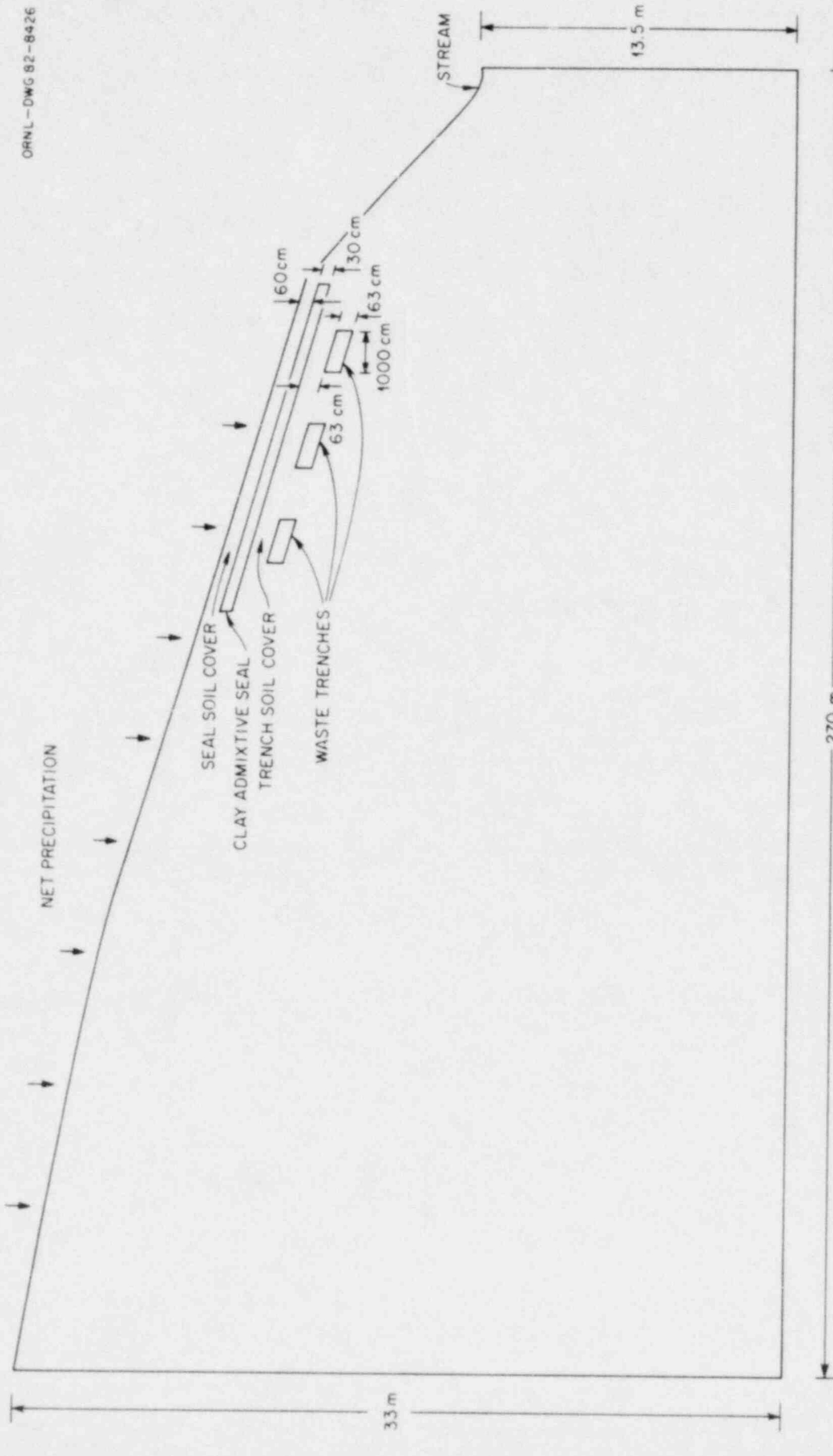


Fig. B-7. Sketch of the region of interest for the solid waste disposal area problem

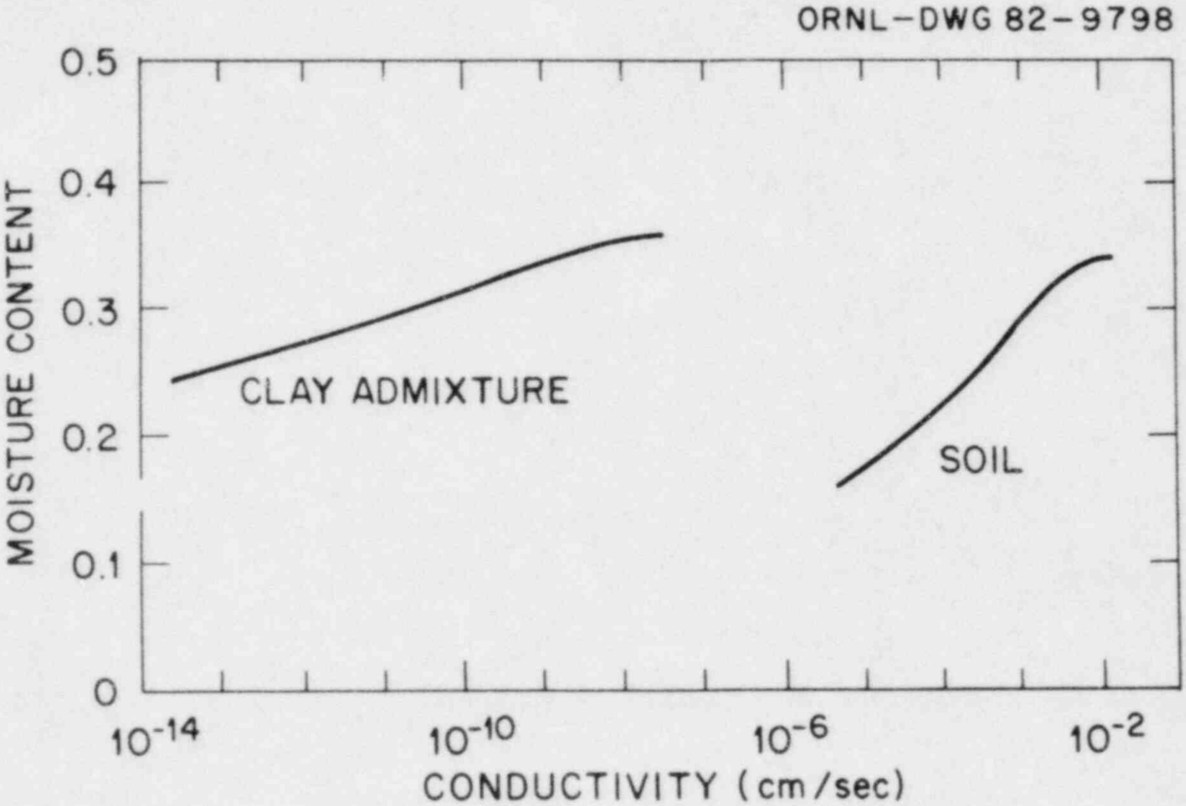


Fig. B-8. Hydraulic property functions used for the solid waste disposal area problem

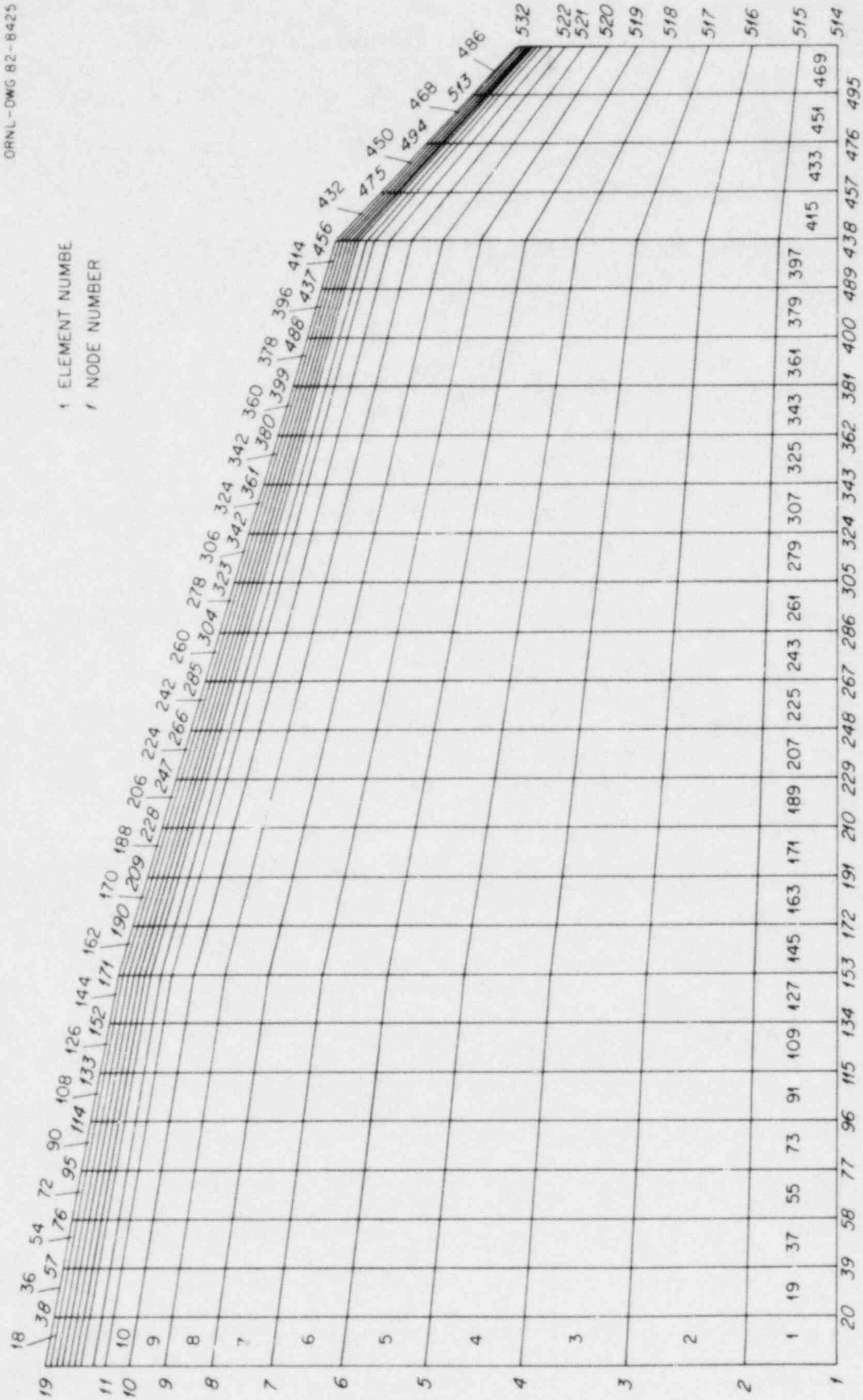


Fig. B-9. Finite element discretization for the solid waste disposal area problem column starting with the first column on the left. This would yield the smallest bandwidth for the coefficient matrix. The initial time step is assumed to be 0.05 s. Each subsequent time step is increased by 20%. The maximum time-step size will not be greater than 5 min. With this specification, 159 time steps are required for 6.13 h real time computation.

B-III.2. Input Deck

Input data for this solid waste disposal area is given in Table B.3. Cards starting on column 1 with a "C" should not be part of the input. They are provided to explain the data. The steady state solution is used as initial condition of the subsequent transient-state computation for 159 time steps; thus KSS = 0, and NTI = 159. The media are composed of two different materials; hence NMAT = 2 and and fourteen elements (elements 301, 319, 337, 355, 373, 391, 409, 302, 338, 356, 374, 392, and 410) are to be corrected with material properties; hence NCM = 1.

Table B.3. Input data for a solid waste disposal area problem

```
C
C ------- DATA SET 1: TITLE
 1000  RESTROPECTIVE EVALUATION OF BENTONITE SEAL AT SWDA #6 WITH SEAL          11
C
C  ------ DATA SET 2: BASIC INTEGER PARAMETERS
  532  486    2   14  159    0    1   32    1    0    1    0   30   30    5
    0    0
C
C ------- DATA SET 3: BASIC REAL PARAMETERS
 0.05      0.2       300.0     1000000.  0.        0.01      0.001     1.
980.6      .013      1.
C
C ------- DATA SET 4: PRINTER OUTPUT AND DISK STORE CONTROL
55111111111111111111111111111111111111111111111151111151111111111155111111111111
11111111111111111111111111111111111115111115111111111111111111111111111111111115
11                                               1     1           11
                                    1     1                                    1
C
C ------- DATA SET 5: MATERIAL PROPERTIES
0.        0.        .341      .01389    .01389
0.        0.        .364      .000001   .000001
C
C ------- DATA SET 6 ANALYTIC SOIL PARAMETERS ARE NOT NEEDED SINCE KSP.NE.0
C
C ------- DATA SET 7: SOIL PROPERTIES IN TABULAR FORM
C ------- PRESSURE HEAD
-0.2570 04-0.1840 04-0.1310 04 -937.     -669.     -478.     -342.     -244.
 -174.     -124.     -88.9     -63.5     -45.4     -32.4     -23.1     -16.5
 -11.8     -8.43     -6.02     -4.30     -3.07     -2.20     -1.57     -1.12
0.        50.       100.      500.      1000.     5000.     10000.    50000.
-0.2570 04-0.1840 04-0.1310 04 -937.     -669.     -478.     -342.     -244.
 -174.     -124.     -88.9     -63.5     -45.4     -32.4     -23.1     -16.5
 -11.8     -8.43     -6.02     -4.30     -3.07     -2.20     -1.57     -1.12
0.        50.       100.      500.      1000.     5000.     10000.    50000.
C ------- MOISTURE CONTENT
 0.160     0.180     0.203     0.228     0.252     0.276     0.296     0.311
 0.322     0.329     0.334     0.337     0.338     0.340     0.340     0.340
 0.341     0.341     0.341     0.341     0.341     0.341     0.341     0.341
.34101    .34102    .34103    .34104    .34105    .34106    .34107    .34108
 0.243     0.249     0.254     0.260     0.266     0.273     0.279     0.286
 0.292     0.299     0.306     0.313     0.319     0.326     0.332     0.338
 0.343     0.348     0.352     0.355     0.357     0.359     0.360     0.361
.36401    .36402    .36403    .36404    .36405    .36406    .36406    .36407
C ------- RELATIVE HYDRAULIC CONDUCTIVITY
 0.332D-03 0.100D-02 0.288D-02 0.777D-02 0.194D-01 0.429D-01 0.842D-01 0.145D-00
 0.222D-00 0.307D-00 0.397D-00 0.481D-00 0.599D-00 0.628D-00 0.688D-00 0.744D-00
 0.784D-00 0.820D-00 0.849D-00 0.878D-00 0.899D-00 0.914D-00 0.928D-00 0.942D-00
 0.99286   0.99353   0.99424   0.99496   0.99568   0.99640   0.99712   0.99784
 0.198D-06 0.417D-06 0.877D-06 0.185D-05 0.38[illegible]D-05 0.812D-05 0.170D-04 0.355D-04
 0.738D-04 0.152D-03 0.313D-03 0.636D-03 0.128D-02 0.250D-02 0.478D-02 0.887D-02
 0.158D-01 0.271D-01 0.443D-01 0.689D-01 0.103D-00 0.145D-00 0.199D-00 0.262D-00
 0.9335    0.9427    0.9519    0.9612    0.9704    0.9797    0.9889    0.9982
C ------- MOISTURE CONTENT CAPACITY
 0.768D-04 0.124D-03 0.192D-03 0.282D-03 0.386D-03 0.482D-03 0.547D-03 0.567D-03
 0.544D-03 0.494D-03 0.432D-03 0.368D-03 0.309D-03 0.257D-03 0.212D-03 0.175D-03
 0.144D-03 0.118D-03 0.969D-04 0.795D-04 0.652D-04 0.535D-04 0.439D-04 0.360D-04
  .370E-04  .365E-04  .365E-04  .355E-04  .350E-04  .345E-04  .340E-04  .335E-04
 0.204D-04 0.294D-04 0.423D-04 0.609D-04 0.875D-04 0.126D-03 0.180D-03 0.257D-03
 0.365D-03 0.517D-03 0.727D-03 0.101D-02 0.139D-02 0.187D-02 0.247D-02 0.317D-02
 0.393D-02 0.472D-02 0.546D-02 0.611D-02 0.662D-02 0.699D-02 0.722D-02 0.734D-02
 0.734D-02 0.735D-02 0.736D-02 0.737D-02 0.738D-02 0.739D-02 0.740D-02 0.741D-02
C
C ------- DATA SET 8: NODAL-POINT POSITIONS
    1       0.0       0.0
    2       0.0     379.5000
    3       0.0     874.5000
    4       0.0    1320.0000
    5       0.0    1716.0000
    6       0.0    2062.5000
    7       0.0    2359.5000
    8       0.0    2607.0000
    9       0.0    2805.0000
   10       0.0    2953.5000
   11       0.0    3052.5000
   12       0.0    3102.0000
   13       0.0    3151.5000
   14       0.0    3176.2500
   15       0.0    3201.0000
   16       0.0    3225.7500
   17       0.0    3250.5000
   18       0.0    3275.2500
   19       0.0    3300.0000
   20    1000.00      0.0
   21    1000.00    375.1875
   22    1000.00    864.5625
```

Table B.3. (continued)

23	1000.00	1305.0000
24	1000.00	1656.5000
25	1000.00	2039.0625
26	1000.00	2332.6875
27	1000.00	2577.3750
28	1000.00	2773.1250
29	1000.00	2919.9375
30	1000.00	3017.8125
31	1000.00	3066.7500
32	1000.00	3115.6875
33	1000.00	3140.1563
34	1000.00	3164.6250
35	1000.00	3189.0938
36	1000.00	3213.5625
37	1000.00	3238.0313
38	1000.00	3262.5000
39	2000.00	0.0
40	2000.00	370.8750
41	2000.00	854.6250
42	2000.00	1290.0000
43	2000.00	1677.0000
44	2000.00	2015.6250
45	2000.00	2305.8750
46	2000.00	2547.7500
47	2000.00	2741.2500
48	2000.00	2886.3750
49	2000.00	2983.1250
50	2000.00	3031.5000
51	2000.00	3079.8750
52	2000.00	3104.0625
53	2000.00	3128.2500
54	2000.00	3152.4375
55	2000.00	3176.6250
56	2000.00	3200.8125
57	2000.00	3225.0000
58	3000.00	0.0
59	3000.00	366.5625
60	3000.00	844.6875
61	3000.00	1275.0000
62	3000.00	1657.5000
63	3000.00	1992.1875
64	3000.00	2279.0625
65	3000.00	2518.1250
66	3000.00	2709.3750
67	3000.00	2852.8125
68	3000.00	2948.4375
69	3000.00	2996.2500
70	3000.00	3044.0625
71	3000.00	3067.9688
72	3000.00	3091.8750
73	3000.00	3115.7813
74	3000.00	3139.6875
75	3000.00	3163.5938
76	3000.00	3187.5000
77	4000.00	0.0
78	4000.00	362.2500
79	4000.00	834.7500
80	4000.00	1260.0000
81	4000.00	1638.0000
82	4000.00	1968.7500
83	4000.00	2252.2500
84	4000.00	2488.5000
85	4000.00	2677.5000
86	4000.00	2819.2500
87	4000.00	2913.7500
88	4000.00	2961.0000
89	4000.00	3008.2500
90	4000.00	3031.8750
91	4000.00	3055.5000
92	4000.00	3079.1250
93	4000.00	3102.7500
94	4000.00	3126.3750
95	4000.00	3150.0000
96	5000.00	0.0
97	5000.00	357.9375
98	5000.00	824.8125
99	5000.00	1245.0000
100	5000.00	1618.5000
101	5000.00	1945.3125
102	5000.00	2225.4375
103	5000.00	2458.8750
104	5000.00	2645.6250
105	5000.00	2785.6875
106	5000.00	2879.0625
107	5000.00	2925.7500
108	5000.00	2972.4375

Table B.3. (continued)

109	5000.00	2995.7813
110	5000.00	3019.1250
111	5000.00	3042.4688
112	5000.00	3065.8125
113	5000.00	3089.1563
114	5000.00	3112.5000
115	6000.00	0.0
116	6000.00	353.6250
117	6000.00	814.8750
118	6000.00	1230.0000
119	6000.00	1599.0000
120	6000.00	1921.8750
121	6000.00	2198.6250
122	6000.00	2429.2500
123	6000.00	2613.7500
124	6000.00	2752.1250
125	6000.00	2844.3750
126	6000.00	2890.5000
127	6000.00	2936.6250
128	6000.00	2959.6875
129	6000.00	2982.7500
130	6000.00	3005.8125
131	6000.00	3028.8750
132	6000.00	3051.9375
133	6000.00	3075.0000
134	7000.00	0.0
135	7000.00	349.3125
136	7000.00	804.9375
137	7000.00	1215.0000
138	7000.00	1579.5000
139	7000.00	1898.4375
140	7000.00	2171.8125
141	7000.00	2399.6250
142	7000.00	2581.8750
143	7000.00	2718.5625
144	7000.00	2809.6875
145	7000.00	2855.2500
146	7000.00	2900.8125
147	7000.00	2923.5938
148	7000.00	2946.3750
149	7000.00	2969.1563
150	7000.00	2991.9375
151	7000.00	3014.7188
152	7000.00	3037.5000
153	8000.00	0.0
154	8000.00	345.0000
155	8000.00	795.0000
156	8000.00	1200.0000
157	8000.00	1560.0000
158	8000.00	1875.0000
159	8000.00	2145.0000
160	8000.00	2370.0000
161	8000.00	2550.0000
162	8000.00	2685.0000
163	8000.00	2775.0000
164	8000.00	2820.0000
165	8000.00	2865.0000
166	8000.00	2887.5000
167	8000.00	2910.0000
168	8000.00	2932.5000
169	8000.00	2955.0000
170	8000.00	2977.5000
171	8000.00	3000.0000
172	9000.00	0.0
173	9000.00	338.1000
174	9000.00	779.1000
175	9000.00	1176.0000
176	9000.00	1528.8000
177	9000.00	1837.5000
178	9000.00	2102.1000
179	9000.00	2322.6000
180	9000.00	2499.0000
181	9000.00	2631.3000
182	9000.00	2719.5000
183	9000.00	2763.6000
184	9000.00	2807.7000
185	9000.00	2829.7500
186	9000.00	2851.8000
187	9000.00	2873.8500
188	9000.00	2895.9000
189	9000.00	2917.9500
190	9000.00	2940.0000
191	10000.00	0.0
192	10000.00	331.2000
193	10000.00	763.2000
194	10000.00	1152.0000

Table B.3. (continued)

195	10000.00	1497.6000
196	10000.00	1800.0000
197	10000.00	2059.2000
198	10000.00	2275.2000
199	10000.00	2448.0000
200	10000.00	2577.6000
201	10000.00	2664.0000
202	10000.00	2707.2000
203	10000.00	2750.4000
204	10000.00	2772.0000
205	10000.00	2793.6000
206	10000.00	2815.2000
207	10000.00	2836.8000
208	10000.00	2858.4000
209	10000.00	2880.0000
210	11000.00	0.0
211	11000.00	324.3000
212	11000.00	747.3000
213	11000.00	1128.0000
214	11000.00	1466.4000
215	11000.00	1762.5000
216	11000.00	2016.3000
217	11000.00	2227.8000
218	11000.00	2397.0000
219	11000.00	2523.9000
220	11000.00	2608.5000
221	11000.00	2650.8000
222	11000.00	2693.1000
223	11000.00	2714.2500
224	11000.00	2735.4000
225	11000.00	2756.5500
226	11000.00	2777.7000
227	11000.00	2798.8500
228	11000.00	2820.0000
229	12000.00	0.0
230	12000.00	317.4000
231	12000.00	731.4000
232	12000.00	1104.0000
233	12000.00	1435.2000
234	12000.00	1725.0000
235	12000.00	1973.4000
236	12000.00	2180.4000
237	12000.00	2346.0000
238	12000.00	2470.2000
239	12000.00	2553.0000
240	12000.00	2594.4000
241	12000.00	2635.8000
242	12000.00	2656.5000
243	12000.00	2677.2000
244	12000.00	2697.9000
245	12000.00	2718.6000
246	12000.00	2739.3000
247	12000.00	2760.0000
248	13000.00	0.0
249	13000.00	310.5000
250	13000.00	715.5000
251	13000.00	1080.0000
252	13000.00	1404.0000
253	13000.00	1687.5000
254	13000.00	1930.5000
255	13000.00	2133.0000
256	13000.00	2295.0000
257	13000.00	2416.5000
258	13000.00	2497.5000
259	13000.00	2538.0000
260	13000.00	2578.5000
261	13000.00	2598.7500
262	13000.00	2619.0000
263	13000.00	2639.2500
264	13000.00	2659.5000
265	13000.00	2679.7500
266	13000.00	2700.0000
267	14000.00	0.0
268	14000.00	303.6000
269	14000.00	699.6000
270	14000.00	1056.0000
271	14000.00	1372.8000
272	14000.00	1650.0000
273	14000.00	1887.6000
274	14000.00	2085.6000
275	14000.00	2244.0000
276	14000.00	2362.8000
277	14000.00	2442.0000
278	14000.00	2481.6000
279	14000.00	2521.2000
280	14000.00	2541.0000

Table B.3. (continued)

281	14000.00	2560.8000
282	14000.00	2580.6000
283	14000.00	2600.4000
284	14000.00	2620.2000
285	14000.00	2640.0000
286	15000.00	0.0
287	15000.00	296.7000
288	15000.00	683.7000
289	15000.00	1032.0000
290	15000.00	1341.6000
291	15000.00	1612.5000
292	15000.00	1844.7000
293	15000.00	2038.2000
294	15000.00	2193.0000
295	15000.00	2309.1000
296	15000.00	2386.5000
297	15000.00	2425.2000
298	15000.00	2463.9000
299	15000.00	2483.2500
300	15000.00	2502.6000
301	15000.00	2521.9500
302	15000.00	2541.3000
303	15600.00	2560.6500
304	15000.00	2580.0000
305	16000.00	0.0
306	16000.00	289.8000
307	16000.00	667.8000
308	16000.00	1008.0000
309	16000.00	1310.4000
310	16000.00	1575.0000
311	16000.00	1801.8000
312	16000.00	1990.8000
313	16000.00	2142.0000
314	16000.00	2255.4000
315	16000.00	2331.0000
316	16000.00	2368.8000
317	16000.00	2406.6000
318	16000.00	2425.5000
319	16000.00	2444.4000
320	16000.00	2463.3000
321	16000.00	2482.2000
322	16000.00	2501.1000
323	16000.00	2520.0000
324	17000.00	0.0
325	17000.00	282.9000
326	17000.00	651.9000
327	17000.00	984.0000
328	17000.00	1279.2000
329	17000.00	1537.5000
330	17000.00	1758.9000
331	17000.00	1943.4000
332	17000.00	2091.0000
333	17000.00	2201.7000
334	17000.00	2275.5000
335	17000.00	2312.4000
336	17000.00	2349.3000
337	17000.00	2367.7500
338	17000.00	2386.2000
339	17000.00	2404.6500
340	17000.00	2423.1000
341	17000.00	2441.5500
342	17000.00	2460.0000
343	18000.00	0.0
344	18000.00	276.0000
345	18000.00	636.0000
346	18000.00	960.0000
347	18000.00	1248.0000
348	18000.00	1500.0000
349	18000.00	1716.0000
350	18000.00	1896.0000
351	18000.00	2040.0000
352	18000.00	2148.0000
353	18000.00	2220.0000
354	18000.00	2256.0000
355	18000.00	2292.0000
356	18000.00	2310.0000
357	18000.00	2328.0000
358	18000.00	2346.0000
359	18000.00	2364.0000
360	18000.00	2382.0000
361	18000.00	2400.0000
362	19000.00	0.0
363	19000.00	269.1000
364	19000.00	620.1000
365	19000.00	936.0000
366	19000.00	1216.8000

Table B.3. (continued)

367	19000.00	1462.5000
368	19000.00	1673.1000
369	19000.00	1848.6000
370	19000.00	1989.0000
371	19000.00	2094.3000
372	19000.00	2164.5000
373	19000.00	2199.6000
374	19000.00	2234.7000
375	19000.00	2252.2500
376	19000.00	2269.8000
377	19000.00	2287.3500
378	19000.00	2304.9000
379	19000.00	2322.4500
380	19000.00	2340.0000
381	20000.00	0.0
382	20000.00	262.2000
383	20000.00	604.2000
384	20000.00	912.0000
385	20000.00	1185.6000
386	20000.00	1425.0000
387	20000.00	1630.2000
388	20000.00	1801.2000
389	20000.00	1938.0000
390	20000.00	2040.6000
391	20000.00	2109.0000
392	20000.00	2143.2000
393	20000.00	2177.4000
394	20000.00	2194.5000
395	20000.00	2211.6000
396	20000.00	2228.7000
397	20000.00	2245.8000
398	20000.00	2262.9000
399	20000.00	2280.0000
400	21000.00	0.0
401	21000.00	255.3000
402	21000.00	588.3000
403	21000.00	888.0000
404	21000.00	1154.4000
405	21000.00	1387.5000
406	21000.00	1587.3000
407	21000.00	1753.8000
408	21000.00	1887.0000
409	21000.00	1986.9000
410	21000.00	2053.5000
411	21000.00	2086.8000
412	21000.00	2120.1000
413	21000.00	2136.7500
414	21000.00	2153.4000
415	21000.00	2170.0500
416	21000.00	2186.7000
417	21000.00	2203.3500
418	21000.00	2220.0000
419	22000.00	0.0
420	22000.00	249.4000
421	22000.00	572.4000
422	22000.00	864.0000
423	22000.00	1123.2000
424	22000.00	1350.0000
425	22000.00	1544.4000
426	22000.00	1706.4000
427	22000.00	1836.0000
428	22000.00	1933.2000
429	22000.00	1998.0000
430	22000.00	2030.4000
431	22000.00	2062.8000
432	22000.00	2079.0000
433	22000.00	2095.2000
434	22000.00	2111.4000
435	22000.00	2127.6000
436	22000.00	2143.8000
437	22000.00	2160.0000
438	23000.00	0.0
439	23000.00	241.5000
440	23000.00	556.5000
441	23000.00	840.0000
442	23000.00	1092.0000
443	23000.00	1312.5000
444	23000.00	1501.5000
445	23000.00	1659.0000
446	23000.00	1785.0000
447	23000.00	1879.5000
448	23000.00	1942.5000
449	23000.00	1974.0000
450	23000.00	2005.5000
451	23000.00	2021.2500
452	23000.00	2037.0000

Table B.3. (continued)

```
453  23000.00 2052.7500
454  23000.00 2068.5000
455  23000.00 2084.2500
456  23000.00 2100.0000
457  24000.00    0.0
458  24000.00  219.9375
459  24000.00  506.8125
460  24000.00  765.0000
461  24000.00  994.5000
462  24000.00 1195.3125
463  24000.00 1367.4375
464  24000.00 1510.8750
465  24000.00 1625.6250
466  24000.00 1711.6875
467  24000.00 1769.0625
468  24000.00 1797.7500
469  24000.00 1826.4375
470  24000.00 1840.7813
471  24000.00 1855.1250
472  24000.00 1869.4688
473  24000.00 1893.8125
474  24000.00 1898.1563
475  24000.00 1912.5000
476  25000.00    0.0
477  25000.00  198.3750
478  25000.00  457.1250
479  25000.00  690.0000
480  25000.00  897.0000
481  25000.00 1079.1250
482  25000.00 1233.3750
483  25000.00 1362.7500
484  25000.00 1466.2500
485  25000.00 1543.8750
486  25000.00 1595.6250
487  25000.00 1621.5000
488  25000.00 1647.3750
489  25000.00 1660.3125
490  25000.00 1673.2500
491  25000.00 1686.1875
492  25000.00 1699.1250
493  25000.00 1712.0625
494  25000.00 1725.0000
495  26000.00    0.0
496  26000.00  176.8125
497  26000.00  407.4375
498  26000.00  615.0000
499  26000.00  799.5000
500  26000.00  960.9375
501  26000.00 1099.3125
502  26000.00 1214.6250
503  26000.00 1306.8750
504  26000.00 1375.0625
505  26000.00 1422.1875
506  26000.00 1445.2500
507  26000.00 1468.3125
508  26000.00 1479.8438
509  26000.00 1491.3750
510  26000.00 1502.9063
511  26000.00 1514.4375
512  26000.00 1525.9688
513  26000.00 1537.5000
514  27000.00    0.0
515  27000.00  155.2500
516  27000.00  357.7500
517  27000.00  540.0000
518  27000.00  702.0000
519  27000.00  843.7500
520  27000.00  965.2500
521  27000.00 1066.5000
522  27000.00 1147.5000
523  27000.00 1208.2500
524  27000.00 1248.7500
525  27000.00 1269.0000
526  27000.00 1289.2500
527  27000.00 1299.3750
528  27000.00 1309.5000
529  27000.00 1319.6250
530  27000.00 1329.7500
531  27000.00 1339.8750
532  27000.00 1350.0000
C
C -------- DATA SET 9: ELEMENT DEFINITIONS
    1    1   20   21    2    1   18   27
C
C -------- DATA SET 10: MATERIAL CORRECTIONS
  301    2  409   18
```

Table B.3. (continued)

```
  302    2  410   19
C
C ------- DATA SET 11: CARD INPUT FOR INITIAL OR PRE-INITIAL CONDITIONS
    1           0.
  532           0.
C
C ------- DATA SET 12: INTEGER PARAMETERS FOR STEADY-STATE OR TRANSIENT
   19    0    1    3   26   27
C
C ------- DATA SET 13:  RAINFALL PROFILES
 0.0          999999.0  1000000.0
   2.0E-06    2.0E-06       0.0
C
C ------- DATA SET 14: RAINFALL TYPE AND PONDING DEPTH
   19    1    0        0.0
  513    1   19        0.0
C
C ------- DATA SET 15: RAINFALL-SEEPGAE SURFACE ELEMENT SIDES
   18   19   38    0
  468  494  513   18
C
C ------- DATA SET 16: DIRICHLET BOUNDARY CONDITIONS
  514        1350.0
  515        1194.75
  516         992.25
  517         810.0
  518         648.0
  519         506.25
  520         384.75
  521         283.5
  522         202.5
  523         141.75
  524         101.25
  525          81.0
  526          60.75
  527          50.625
  528          40.5
  529          30.375
  530          20.25
  531          10.125
  532           0.0
C
C ------- DATA SET 17  NEUMANN BOUNDARY CONDITIONS ARE NOT NEEDED SINCE NST=0
C
C ------- DATA SET 18:  TRANSIENT STATE INTEGER PARAMETERS
   19    0    1    5   26   27
C
C ------- DATA SET 19: RAINFALL PROFILES
 0.0          7097.700  7097.705  999999.0  1000000.0
   7.0E-04    7.0E-04 0.0         0.0         0.0
C
C ------- DATA SET 20:  RAINFALL TYPE AND PONDING DEPTH
   19    1    0        0.0
  513    1   19        0.0
C
C ------- DATA SET 21: RAINFALL-SEEPAGE SURFACE ELEMENT SIDES
   18   19   38    0
  468  494  513   18
C
C ------- DATA SET 22:  DIRICHLET BOUNDARY CONDITIONS
  514        1350.0
  515        1194.75
  516         992.25
  517         810.0
  518         648.0
  519         506.25
  520         384.75
  521         283.5
  522         202.5
  523         141.75
  524         101.25
  525          81.0
  526          60.75
  527          50.625
  528          40.5
  529          30.375
  530          20.25
  531          10.125
  532           0.0
C
C ------- DATA SET 23 NEUMANN BOUNDARY CONDITIONS ARE NOT NEEDED SINCE NST=0
C
C ------- FINALLY A BLANK CARD TO END THE JOB
```

B-IV. A SHALLOW TRENCH BURIAL PROBLEM

B-IV.1. Problem Description

Low-level wastes are normally buried in trenches and are covered with the natural soil after filling. On the ground surface, artificial materials, such as asphalt or bentonite, may or may not be used for sealing purposes. A typical cross-section through the trench and its associated surface seep are shown in Fig. B-10. The trench is 3.2 m wide (only half of the width is shown because of symmetry) and 5.75 m deep, with only the lower 2.35 m filled with radioactive wastes. The transporting fluid enters the soil material (weathered shale) in the form of infiltrating precipitation, travels horizontally as well as vertically toward the water table, and eventually emanates at the downslope seep and at the stream as depicted in Fig. B-10. Disposal of solid coal wastes, chemicals, and sanitary wastes in landfills resembles this type of practice. For this sample problem, it is assumed that only the steady-state hydrodynamic variables will be desired as functions of space under the condition of averaged net rainfall being applied on the surface. To properly address this problem soil properties must be given, which are plotted in Fig. B-11. To apply FEMWATER, the region of interest is discretized into 533 nodes and 480 elements as in Fig. B-12. An averaged net rainfall rate of 77.6 cm/yr is assumed. The boundary conditions for the FEMWATER computations are specified as follows: (a) variable boundary conditions are imposed on the ground surface, (b) Dirichlet boundary conditions with zero head are implied on that portion of the

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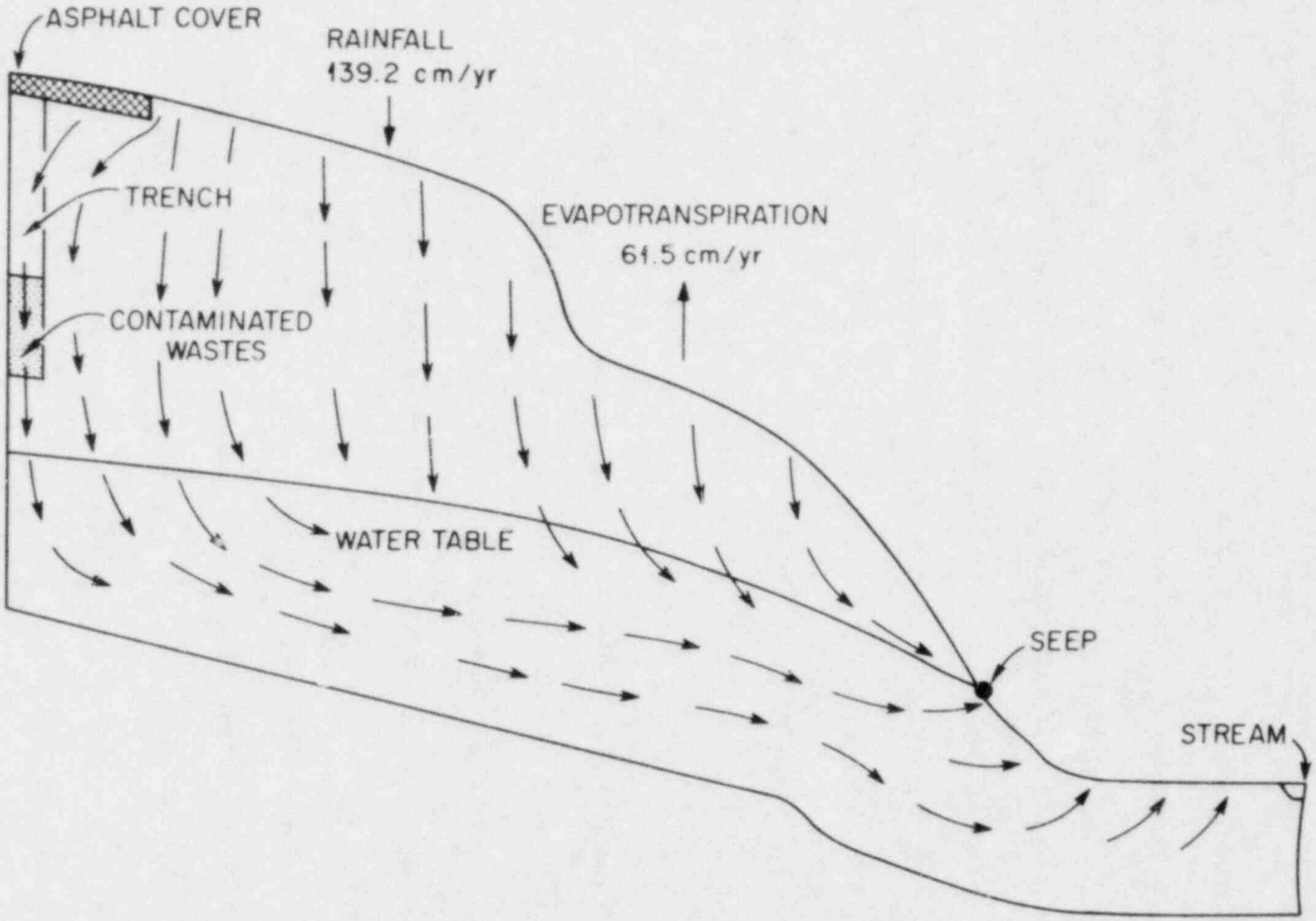

Fig. B-10. Sketch of the region of interest for the shallow trench burial problem

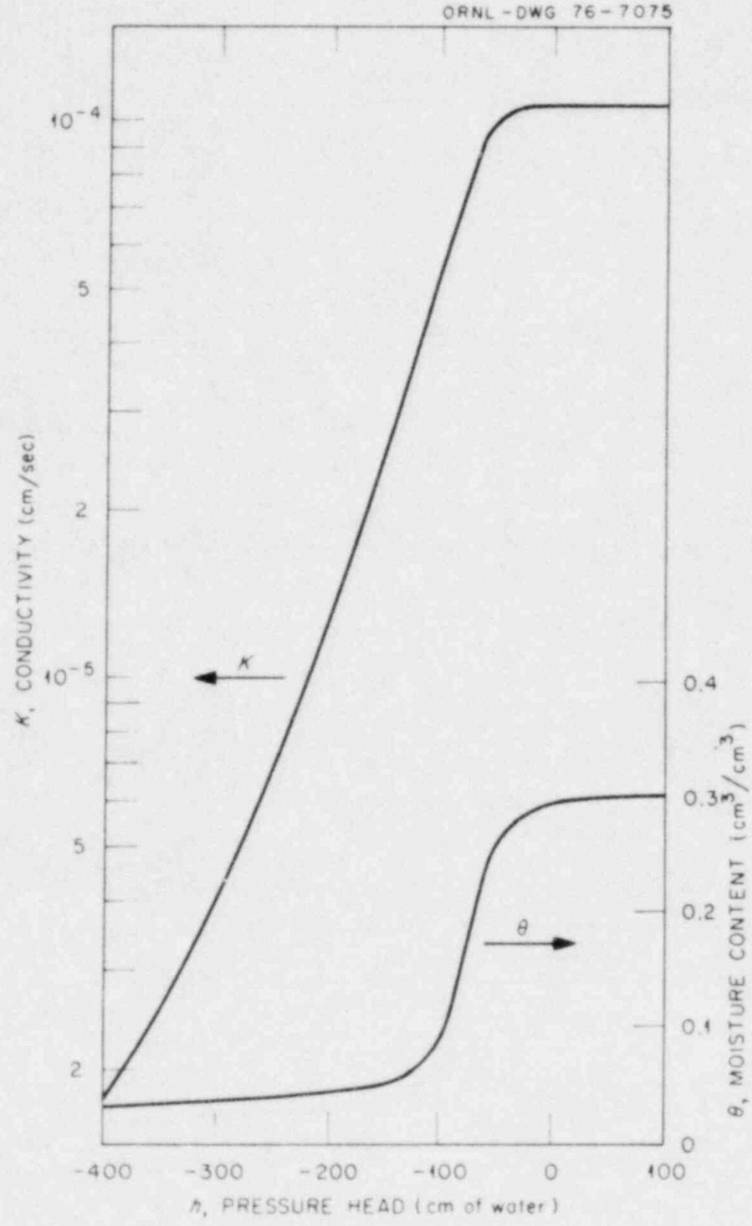

Fig. B-11. Hydraulic property functions used for the shallow trench burial problem

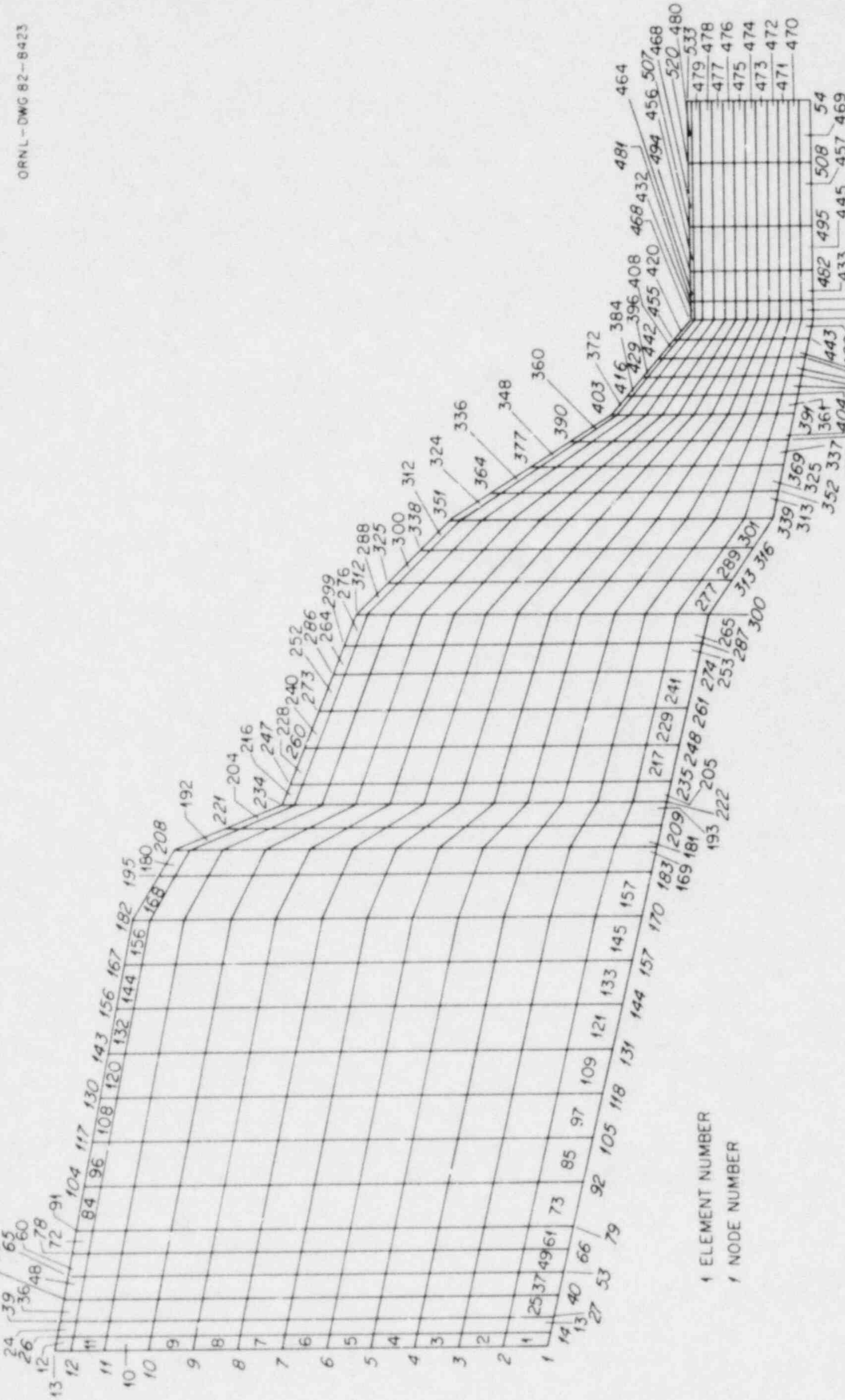

Fig. B-12. Finite element discretization for the shallow trench problem ground surface down slope from the seep, and (c) Neumann zero-flux boundary conditions are used for all other boundaries of the region of interest.

B-IV.2. Input Deck

Following the intructions given in Section A-V.3 of APPENDIX A, one should be able to prepare an input deck similar to the one given in Table B.4. It should be noted that the first four numbers on Card Data Set 3 can be anything because only the steady-state solution is desired. Because only the steady-state solution is sought, NTI = 0 and KSS = 0. A single homogeneous material is considered; thus NMAT = 1 and NCM = 0. Again, the comment cards are for explanation and must be removed for execution.

Table B.4. Input data for a shallow trench burial problem

```
C
C ------- DATA SET 1: TITLE
   5 SHALLOW TRENCH BURIAL WATER FLOW STEADY STATE SIMULATION - FEMWATER
C
C  ------ DATA SET 2: BASIC INTEGER PARAMETERS
  533  480    1    0    0    0    1   16    1    0    1    0  100    7    5
    0    0
C
C ------- DATA SET 3: BASIC REAL PARAMETERS
300.       .5         21600.0    2678400.0 0.         .01        .1         1.
980.6      .013       1.
C
C ------- DATA SET 4: PRINTER OUTPUT AND DISK STORE CONTROL
55
11
C
C ------- DATA SET 5: MATERIAL PROPERTIES
0.         0.         .3                   1.01E-4    1.01E-4
C
C ------- DATA SET 6 ANALYTIC SOIL PARAMETERS ARE NOT NEEDED SINCE KSP.NE.0
C
C ------- DATA SET 7: SOIL PROPERTIES IN TABULAR FORM
C ------- PRESSURE HEAD
 -800.0    -400.      -200.      -175.      -150.      -125.      -100.      -62.5
 -50.0     -37.5      -25.       -12.5      0.         50.        100.       2000.
C ------- MOISTURE CONTENT
.024       .032       .0425      .045       .050       .0625      .09        .21
.25        .275       .285       .250       .2925      .2975      .2995      .3
C ------- RELATIVE HYDRAULIC CONDUCTIVITY
 0.015      0.018      0.103      0.190      0.280      0.420      0.500      0.98
 1.0        1.01       1.01       1.01       1.01       1.01       1.01       1.01
C ------- MOISTURE CONTENT CAPACITY
    0.         .52E-4     .10E-3     .20E-3     .50E-3     .11E-2     .32E-2     .32E-2
    .20E-2     .80E-3     .40E-3     .20E-3     .10E-3     .40E-4     .26E-6     0.
C
C ------- DATA SET 8: NODAL-POINT POSITIONS
     1      0.0        600.000
     2      0.0        697.200
     3      0.0        794.400
     4      0.0        891.600
     5      0.0        988.800
     6      0.0       1086.000
     7      0.0       1183.200
     8      0.0       1280.400
     9      0.0       1377.600
    10      0.0       1474.800
    11      0.0       1572.000
    12      0.0       1644.000
    13      0.0       1680.000
    14     80.000      592.700
    15     80.000      690.003
    16     80.000      787.306
    17     80.000      884.609
    18     80.000      981.913
    19     80.000     1079.216
    20     80.000     1176.519
    21     80.000     1273.822
    22     80.000     1371.125
    23     80.000     1468.428
    24     80.000     1565.732
    25     80.000     1637.808
    26     80.0       1673.846
    27    160.000      585.400
    28    160.000      682.806
    29    160.000      780.213
    30    160.000      877.619
    31    160.000      975.025
    32    160.000     1072.432
    33    160.000     1169.838
    34    160.000     1267.244
    35    160.000     1364.650
    36    160.000     1462.057
    37    160.000     1559.463
    38    160.000     1631.616
    39    160.0       1667.692
    40    285.000      573.994
    41    285.000      671.561
    42    285.000      769.129
    43    285.000      866.696
    44    285.000      964.264
    45    285.000     1061.831
    46    285.000     1159.399
    47    285.000     1256.966
    48    285.000     1354.534
    49    285.000     1452.101
    50    285.000     1549.669
```

Table B.4. (continued)

51	285.000	1621.941
52	285.0	1658.077
53	410.000	562.588
54	410.000	660.316
55	410.000	758.045
56	410.000	855.773
57	410.000	953.502
58	410.000	1051.231
59	410.000	1148.959
60	410.000	1246.688
61	410.000	1344.417
62	410.000	1442.145
63	410.000	1539.874
64	410.000	1612.266
65	410.0	1648.462
66	535.000	551.181
67	535.000	649.071
68	535.000	746.961
69	535.000	844.851
70	535.000	942.741
71	535.000	1040.630
72	535.000	1138.520
73	535.000	1236.410
74	535.000	1334.300
75	535.000	1432.190
76	535.000	1530.080
77	535.000	1602.591
78	535.0	1638.846
79	660.000	539.775
80	660.000	637.826
81	660.000	735.877
82	660.000	833.928
83	660.000	931.979
84	660.000	1030.030
85	660.000	1128.081
86	660.000	1226.132
87	660.000	1324.183
88	660.000	1422.234
89	660.000	1520.285
90	660.000	1592.916
91	660.0	1629.231
92	900.000	517.875
93	900.000	616.235
94	900.000	714.596
95	900.000	812.956
96	900.000	911.317
97	900.000	1009.677
98	900.000	1108.039
99	900.000	1206.398
100	900.000	1304.759
101	900.000	1403.119
102	900.000	1501.480
103	900.000	1574.339
104	900.0	1610.769
105	1140.000	495.975
106	1140.000	594.645
107	1140.000	693.315
108	1140.000	791.985
109	1140.000	890.655
110	1140.000	989.325
111	1140.000	1087.995
112	1140.000	1186.665
113	1140.000	1285.335
114	1140.000	1384.004
115	1140.000	1482.674
116	1140.000	1555.767
117	1140.0	1592.308
118	1380.000	474.075
119	1380.000	573.054
120	1380.000	672.034
121	1380.000	771.013
122	1380.000	869.993
123	1380.000	968.972
124	1380.000	1067.951
125	1380.000	1166.931
126	1380.000	1265.910
127	1380.000	1364.890
128	1380.000	1463.869
129	1380.000	1537.187
130	1380.0	1573.846
131	1620.000	452.175
132	1620.000	551.464
133	1620.000	650.753
134	1620.000	750.042
135	1620.000	849.330
136	1620.000	948.619

Table B.4. (continued)

137	1620.000	1047.909
138	1620.000	1147.197
139	1620.000	1246.486
140	1620.000	1345.775
141	1620.000	1445.064
142	1620.000	1518.611
143	1620.0	1555.385
144	1860.000	430.275
145	1860.000	529.873
146	1860.000	629.472
147	1860.000	729.070
148	1860.000	828.668
149	1860.000	928.267
150	1860.000	1027.865
151	1860.000	1127.463
152	1860.000	1227.062
153	1860.000	1326.660
154	1860.000	1426.258
155	1860.000	1500.025
156	1860.0	1536.923
157	2100.000	408.375
158	2100.000	508.283
159	2100.000	608.191
160	2100.000	708.098
161	2100.000	808.006
162	2100.000	907.914
163	2100.000	1007.822
164	2100.000	1107.730
165	2100.000	1207.637
166	2100.000	1307.545
167	2100.000	1407.453
168	2100.000	1481.459
169	2100.0	1518.462
170	2340.000	386.475
171	2340.000	486.692
172	2340.000	586.909
173	2340.000	687.127
174	2340.000	787.344
175	2340.000	887.561
176	2340.000	987.778
177	2340.000	1087.996
178	2340.000	1188.213
179	2340.000	1288.430
180	2340.000	1388.648
181	2340.000	1462.883
182	2340.000	1500.000
183	2580.000	364.575
184	2580.000	461.509
185	2580.000	558.443
186	2580.000	655.378
187	2580.000	752.312
188	2580.000	849.246
189	2580.000	946.180
190	2580.000	1043.114
191	2580.000	1140.049
192	2580.000	1236.983
193	2580.000	1333.917
194	2580.000	1405.720
195	2580.000	1441.622
196	2710.000	352.717
197	2710.000	447.868
198	2710.000	543.024
199	2710.000	638.180
200	2710.000	733.336
201	2710.000	828.492
202	2710.000	923.648
203	2710.000	1018.804
204	2710.000	1113.960
205	2710.000	1209.115
206	2710.000	1304.271
207	2710.000	1374.757
208	2710.000	1410.000
209	2835.000	341.306
210	2835.000	426.914
211	2835.000	512.521
212	2835.000	598.129
213	2835.000	683.736
214	2835.000	769.343
215	2835.000	854.951
216	2835.000	940.558
217	2835.000	1026.166
218	2835.000	1111.773
219	2835.000	1197.381
220	2835.000	1260.794
221	2835.000	1292.500
222	2960.000	329.900

Table B.4. (continued)

223	2960.000	405.959
224	2960.000	482.018
225	2960.000	558.077
226	2960.000	634.136
227	2960.000	710.195
228	2960.000	786.254
229	2960.000	862.313
230	2960.000	938.372
231	2960.000	1014.431
232	2960.000	1090.490
233	2960.000	1146.830
234	2960.000	1175.000
235	3080.000	318.950
236	3080.000	394.281
237	3080.000	469.612
238	3080.000	544.943
239	3080.000	620.274
240	3080.000	695.605
241	3080.000	770.936
242	3080.000	846.267
243	3080.000	921.598
244	3080.000	996.929
245	3080.000	1072.260
246	3080.000	1128.061
247	3080.000	1155.962
248	3280.000	300.700
249	3280.000	374.818
250	3280.000	448.936
251	3280.000	523.053
252	3280.000	597.171
253	3280.000	671.289
254	3280.000	745.407
255	3280.000	819.524
256	3280.000	893.642
257	3280.000	967.760
258	3280.000	1041.878
259	3280.000	1096.780
260	3280.000	1124.231
261	3480.000	282.450
262	3480.000	355.355
263	3480.000	428.259
264	3480.000	501.164
265	3480.000	574.069
266	3480.000	646.973
267	3480.000	719.877
268	3480.000	792.782
269	3480.000	865.686
270	3480.000	938.591
271	3480.000	1011.495
272	3480.000	1065.458
273	3480.000	1092.500
274	3680.000	264.200
275	3680.000	335.891
276	3680.000	407.582
277	3680.000	479.274
278	3680.000	550.965
279	3680.000	622.656
280	3680.000	694.347
281	3680.000	766.039
282	3690.000	837.730
283	3680.000	909.421
284	3680.000	981.112
285	3680.000	1034.217
286	3680.000	1060.769
287	3840.000	249.600
288	3840.000	320.321
289	3840.000	391.041
290	3840.000	461.762
291	3840.000	532.482
292	3840.000	603.203
293	3840.000	673.924
294	3840.000	744.644
295	3840.000	815.365
296	3840.000	886.086
297	3840.000	956.806
298	3840.000	1009.192
299	3840.000	1035.385
300	4000.000	235.000
301	4000.000	304.750
302	4000.000	374.500
303	4000.000	444.250
304	4000.000	514.000
305	4000.000	583.750
306	4000.000	653.500
307	4000.000	723.250
308	4000.000	793.000

Table B.4. (continued)

309	4000.000	862.750
310	4000.000	937.500
311	4000.000	984.167
312	4000.000	1010.000
313	4175.000	186.667
314	4175.000	254.317
315	4175.000	321.967
316	4175.000	389.617
317	4175.000	457.267
318	4175.000	524.917
319	4175.000	592.567
320	4175.000	660.217
321	4175.000	727.867
322	4175.000	795.517
323	4175.000	863.167
324	4175.000	913.278
325	4175.000	938.333
326	4350.000	138.333
327	4350.000	203.883
328	4350.000	269.433
329	4350.000	334.983
330	4350.000	400.533
331	4350.000	466.083
332	4350.000	531.633
333	4350.000	597.183
334	4350.000	662.733
335	4350.000	728.283
336	4350.000	793.833
337	4350.000	842.389
338	4350.0	866.667
339	4525.000	90.000
340	4525.000	153.450
341	4525.000	216.900
342	4525.000	280.350
343	4525.000	343.800
344	4525.000	407.250
345	4525.000	470.700
346	4525.000	534.150
347	4525.000	597.600
348	4525.000	661.050
349	4525.000	724.500
350	4525.000	771.500
351	4525.000	795.000
352	4665.000	78.387
353	4665.000	135.120
354	4665.000	191.852
355	4665.000	248.585
356	4665.000	305.318
357	4665.000	362.050
358	4665.000	418.783
359	4665.000	475.516
360	4665.000	532.248
361	4665.000	588.981
362	4665.000	645.714
363	4665.000	687.738
364	4665.000	708.750
365	4805.000	66.774
366	4805.000	116.790
367	4805.000	166.805
368	4805.000	216.820
369	4805.000	266.835
370	4805.000	316.851
371	4805.000	366.866
372	4805.000	416.881
373	4805.000	466.897
374	4805.000	516.912
375	4805.000	566.927
376	4805.000	603.976
377	4805.000	622.500
378	4945.000	55.161
379	4945.000	98.459
380	4945.000	141.757
381	4945.000	185.055
382	4945.000	228.353
383	4945.000	271.651
384	4945.000	314.949
385	4945.000	358.247
386	4945.000	401.545
387	4945.000	444.843
388	4945.000	488.141
389	4945.000	520.214
390	4945.000	536.250
391	5085.000	43.549
392	5085.000	80.129
393	5085.000	116.710
394	5085.000	153.290

Table B.4. (continued)

395	5085.000	189.871
396	5085.000	226.452
397	5085.000	263.032
398	5085.000	299.613
399	5085.000	336.194
400	5085.000	372.774
401	5085.000	409.355
402	5085.000	436.452
403	5085.000	450.000
404	5190.000	34.839
405	5190.000	68.963
406	5190.000	103.088
407	5190.000	137.212
408	5190.000	171.337
409	5190.000	205.461
410	5190.000	239.586
411	5190.000	273.710
412	5190.000	307.835
413	5190.000	341.959
414	5190.000	376.084
415	5190.000	401.361
416	5190.000	414.000
417	5295.000	26.129
418	5295.000	57.797
419	5295.000	89.466
420	5295.000	121.134
421	5295.000	152.803
422	5295.000	184.471
423	5295.000	216.139
424	5295.000	247.808
425	5295.000	279.476
426	5295.000	311.145
427	5295.000	342.813
428	5295.000	366.271
429	5295.000	378.000
430	5400.000	17.419
431	5400.000	46.632
432	5400.000	75.844
433	5400.000	105.056
434	5400.000	134.268
435	5400.000	163.481
436	5400.000	192.693
437	5400.000	221.905
438	5400.000	251.117
439	5400.000	280.330
440	5400.000	309.542
441	5400.000	331.161
442	5400.000	342.000
443	5505.000	8.710
444	5505.000	35.466
445	5505.000	62.222
446	5505.000	88.978
447	5505.000	115.734
448	5505.000	142.490
449	5505.000	169.246
450	5505.000	196.003
451	5505.000	222.759
452	5505.000	249.515
453	5505.000	276.271
454	5505.000	296.090
455	5505.000	306.000
456	5610.000	0.0
457	5610.000	24.300
458	5610.000	48.600
459	5610.000	72.900
460	5610.000	97.200
461	5610.000	121.500
462	5610.000	145.800
463	5610.000	170.100
464	5610.000	194.400
465	5610.000	218.700
466	5610.000	243.000
467	5610.000	261.000
468	5610.000	270.000
469	5715.000	0.0
470	5715.000	24.300
471	5715.000	48.600
472	5715.000	72.900
473	5715.000	97.200
474	5715.000	121.500
475	5715.000	145.800
476	5715.000	170.100
477	5715.000	194.400
478	5715.000	218.700
479	5715.000	243.000
480	5715.000	261.000

Table B.4. (continued)

```
 481   5715.000     270.000
 482   5880.000       0.0
 483   5880.000      24.300
 484   5880.000      48.600
 485   5880.000      72.900
 486   5880.000      97.200
 487   5880.000     121.500
 488   5880.000     145.800
 489   5880.000     170.100
 490   5880.000     194.400
 491   5880.000     218.700
 492   5880.000     243.000
 493   5880.000     261.000
 494   5880.000     270.000
 495   6130.000       0.0
 496   6130.000      24.300
 497   6130.000      48.600
 498   6130.000      72.900
 499   6130.000      97.200
 500   6130.000     121.500
 501   6130.000     145.800
 502   6130.000     170.100
 503   6130.000     194.400
 504   6130.000     218.700
 505   6130.000     243.000
 506   6130.000     261.000
 507   6130.0       270.000
 508   6480.000       0.0
 509   6480.000      24.300
 510   6480.000      48.600
 511   6480.000      72.900
 512   6480.000      97.200
 513   6480.000     121.500
 514   6480.000     145.800
 515   6480.000     170.100
 516   6480.000     194.400
 517   6480.000     218.700
 518   6480.000     243.000
 519   6480.000     261.000
 520   6480.000     270.000
 521   6830.000       0.0
 522   6830.000      24.300
 523   6830.000      48.600
 524   6830.000      72.900
 525   6830.000      97.200
 526   6830.000     121.500
 527   6830.000     145.800
 528   6830.000     170.100
 529   6830.000     194.400
 530   6830.000     218.700
 531   6830.000     243.000
 532   6830.000     261.000
 533   6830.000     270.000
C
C ------- DATA SET 9: ELEMENT DEFINITIONS
   1     1    14    15     2     1    12    40
C
C ------- DATA SET 10 MATERIAL CORRECTION IS NOT REQUIRED SINCE NCM=0
C
C ------- DATA SET 11: CARD INPUT FOR INITIAL OR PRE-INITIAL CONDITIONS
   1       0.
 533        0.0
C
C ------- DATA SET 12: INTEGER PARAMETERS FOR STEADY-STATE OR TRANSIENT
  23     0     1     2    24    25     0
C
C ------- DATA SET 13: RAINFALL PROFILES
0.0           2678400.0
  2.46E-6    2.46E-6
C
C ------- DATA SET 14: RAINFALL TYPE AND PONDING DEPTH
  91     1     0       0.
 403     1    13        0.0
C
C ------- DATA SET 15: RAINFALL-SEEPAGE SURFACE ELEMENT SIDE
  84    91   104     0
 260   390   403     1
C
C ------- DATA SET 16: DIRICHLET BOUNDARY CONDITIONS
 403      0 0.0
 533     13 0.0
 521      0 270.0
 522      0 245.7
 523      0 221.4
 524      0 197.1
```

Table B.4. (continued)

```
 525     0 172.8
 526     0 148.5
 527     0 124.2
 528     0 99.9
 529     0 75.6
 530     0 51.3
 531     0 27.0
 532     0 9.0
C
C ------- DATA SET 17 NEUMANN BOUNDARY CONDITIONS ARE NOT NEEDED SINCE NST=0
C
C ------- DATA SET 18 THROUGH DATA SET 23 ARE NOT NEEDED SINCE KSS=0 AND NTI=0
C
C ------- FINALLY A BLANK CARD TO END THE JOB
```

APPENDIX C: LIST OF FORTRAN SOURCE PROGRAM

```
C
C      ************************************************************
C      *                                                          *
C      *                        FEMWATER                          *
C      *                                                          *
C      ************************************************************
C
C
C  THIS COMPUTER CODE IS CONTAINED IN THE FOLLOWING REPORT:
C  YEH, G. T. AND D. S. WARD, 1980, "FEMWATER: A FINITE-ELEMENT MODEL
C  OF WATER FLOW THROUGH SATURATED-UNSATURATED POROUS MEDIA", ORNL-5567,
C  OAK RIDGE NATIONAL LABORATORY, OAK RIDGE, TN 37830
C                                                                          CDC
C  THIS VERSION OF THE FEMWATER CODE IS MODIFIED TO OPERATE ON CDC         CDC
C  EQUIPMENT. NEW OR CHANGED STATEMENTS FOR THIS PURPOSE ARE MARKED        CDC
C  BY CDC BEGINNING IN COLUMN 75.                                          CDC
C
C  A SLIGHTLY UPDATED VERSION IS CONTAINED IN:
C  YEH, G. T. AND R. H. STRAND, 1981, "FECWATER: USER'S MANUAL OF A
C  FINITE ELEMENT COMPUTER CODE FOR SIMULATING WATER FLOW THROUGH
C  SATURATED-UNSATURATED POROUS MEDIA," ORNL/TM-7316, OAK RIDGE
C  NATIONAL LABORATORY, OAK RIDGE, TN. 37830
C
C  FOR ANY QUESTION, PLEASE CONTACT DR. G. T. YEH AT (615) 574-7285
C
C  ADDITIONAL REFERENCES IS:
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
      PROGRAM FEMWAT(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE1,TAPE2)    CDC
C                                                                          CDC
      IMPLICIT REAL   (A-H,O-Z)                                            CDC
C
      DIMENSION X(595),Z(595),IE(528,5)
C
      DIMENSION C(595,21),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 DLR(199),DCOSXR(199),DCOSZR(199),RFLX(200),RFLXP(200),
     > NRE(199),ISR(199,4),NPR(200)
C
      DIMENSION DL(99),DCOSX(99),DCOSZ(99),DCYFLX(100),FLX(100),
     > RSFLX(100),HCON(100),NRSE(99),IS(99,4),NPRS(100),NPCON(100),
     > NPFLX(100),IRFTYP(100)                                              CDC
C
C
      DIMENSION RP(30),NPST(30), HH(40),NN(40)
C
      DIMENSION PROP(3,5),THPROP(3,52),AKPROP(3,52),HPROP(3,52),
     > CAPROP(3,52)
C
      DIMENSION KPR(500),KDSK(500)
C
      COMMON /GEOM/ SNFE,CSFE,NNP,NEL,IBAND
```

```
      COMMON /CNTRL/ NTT,MAXCY,MAXIT,NSTRT,KSTR,KPRO,KDSKO,KSS,KSP
      COMMON /TOTLNS/ TOLA,TOLB
      COMMON /PARAM/ DELT,CHNG,DELMAX,TMAX,DELTO
      COMMON /BRSND/ NBEL,NBN,NRSEL,NRSN,NRFPR,NRFPAR
      COMMON /BCST/ NBC,NST,NSTN
      COMMON /MTL/ NMAT,NMPPM,NSPPM
      COMMON /OPT/ ILUMP,IMID
C
      DATA MAXEL,MAXNP,MAXHBP /528,595,21/
      DATA MAXBEL,MAXBNP /199,200/
      DATA MXRSEL,MXRSNP /99,100/
      DATA MXSTEL,MXSTNP,MAXBCN /29,30,40/
      DATA MAXMAT,MXSPPM,MXMPPM /3,52,5/
      DATA MAXNTI /500/
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 IH=1,MAXHBP
  100       C(NP,IH)=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,MAXBNP
```

```
          HFLX(NP)=0.0
          HFLXP(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,MXRSNP
          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 SURFACE  TERM POINT FLUX
C
      DO 500 NP=1,MXSTNP
          NPST(NP)=0
  500     RP(NP)=0.0
C
C
C ------- INITIATE ARRAYS FOR DIRICHLENT BOUNDARY CONDITIONS
C
      DO 510 NP=1,MAXBCN
          HB(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,MXMPPM
  610        PROP(I,J)=0.0
C
          DO 630 J=1,MXSPPM
             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 ------- 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,NRSF,IS,NPRS,NPCON,NPFLX,IRFTYP,               CDC
     > RP,NPST, BB,NN, PROP,THPROP,AKPROP,HPROP,CAPROP, KPR,KDSK,           CDC
     > MAXEL,MAXNP,MAXHBP, MAXBEL,MAXBNP, MXRSEL,MXRSNP, MXSTEL,MXSTNP,     CDC
     > MAXBCN, MAXMAT,MXSPPM, MAXNTI)                                        CDC
C                                                                       MAIN1080
      STOP                                                              MAIN1085
      END                                                               MAIN1090
      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,NBF,ISB,NPB,  DL,DCOSX,     GW2D 010
     > DCOSZ,DCYFLX,FLX,RSFLX,HCON,NRSF,IS,NPRS,NPCON,NPFLX,IRFTYP,         CDC
     > RP,NPST, BB,NN, PROP,THPROP,AKPROP,HPROP,CAPROP, KPR,KDSK,           CDC
     > MAXEL,MAXNP,MAXHBP, MAXBEL,MAXBNP, MXRSEL,MXRSNP, MXSTEL,MXSTNP,     CDC
     > MAXBCN, MAXMAT,MXSPPM, MAXNTI)                                        CDC
C                                                                       GW2D 045
      IMPLICITT REAL  (A-H,O-Z)                                             CDC
      REAL    PMAT,THPAR,AKPAR,SUBBD                                        CDC
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),NBF(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),NRSF(MXRSEL),IS(MXRSEL,4),GW2D 120
     > NPRS(MXRSNP),NPCON(MXRSNP),NPFLX(MXRSNP),IRFTYP(MXRSNP)              CDC
C                                                                       GW2D 135
      DIMENSION RP(MXSTNP),NPST(MXSTNP),BB(MAXBCN),NN(MAXBCN)           GW2D 140
C                                                                       GW2D 145
      DIMENSION PROP(MAXMAT,5),THPROP(MAXMAT,MXSPPM),                       CDC
     > AKPROP(MAXMAT,MXSPPM),HPROP(MAXMAT,MXSPPM),CAPROP(MAXMAT,MXSPPM) GW2D 155
C                                                                       GW2D 160
      DIMENSION KPR(MAXNTI),KDSK(MAXNTI)                                GW2D 180
C                                                                           CDC
      DIMENSION TRF(3,20),RF(3,20),RFALL(3)                                 CDC
      DIMENSION FRATE(10),FLOW(10),TFLOW(10)                                CDC
      DIMENSION PMAT(3,5),AKPAR(3,8),THPAR(3,8),SUBBD(8,3)                  CDC
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,DELTO                        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                                                                           CDC
      DATA PMAT/4H    ,4H ALP,4H    ,4H   B,4HETAP,4H    ,4H    ,           CDC
     > 4H POR,4H    ,4H    ,4H KX ,4H    ,4H    ,4H KZ ,4H    /             CDC
      DATA THPAR/4H    ,4H TH1,4H    ,4H    ,4H TH2,4H    ,4H    ,          CDC
     > 4H  H0 ,4H    ,4H    ,4H  A1,4H    ,4H    ,4H  A2,4H    ,4H    ,     CDC
     > 4H  B1,4H    ,4H    ,4H  B2,4H    ,4H    ,4H   C,4H    /             CDC
C                                                                           CDC
      DATA AKPAR/4H    ,4H  B1,4H    ,4H    ,4H  B2,4H    ,18*4H    /       CDC
C                                                                           CDC
```

```
      DATA SUBHD/4HINPU,4HT IN,4HITIA,4HL CO,4HNDIT,4HIONS,2*4H          CDC
     > 4HSTEA,4HDY-S,4HTATE,4H INI,4HTIAL,4H CON,4HDITI,4HONS , 8*      CDC
     > 4H                                                               CDC
C                                                                       CDC
C                                                                       CDC
C ------- INITIATE ARRAYS FOR RAINFALL INFORMATION                      CDC
C                                                                       CDC
      DO 5 I=1,5                                                        CDC
         RFALL(I)=0.0                                                   CDC
         DO 5 J=1,20                                                    CDC
            TRF(I,J)=0.0                                                CDC
    5       RF(I,J)=0.0                                                 CDC
C                                                                       CDC
C                                                                       CDC
C ------- INITIATE ARRAYS FOR FLOW THROUGH VARIOUS TYPES OF BOUNDARIES   CDC
C                                                                       CDC
      DO 8 I=1,10                                                       CDC
         FRATE(I)=0.0                                                   CDC
         FLOW(I)=0.0                                                    CDC
    8    TFLOW(I)=0.0                                                   CDC
C                                                                       CDC
C                                                                       GW2D
C  PROBLEM  IDENTIFICATION  AND  DESCRIPTION                            GW2D
C                                                                       GW2D
   10 READ 10000,NPROB, (TITLE(I),I=1,9),IBUG,ICHNG                     GW2D
      IF (NPROB.LE.0) GO TO 270                                         GW2D
      PRINT 10100,NPROB,(TITLE(I),I=1,9)                                GW2D
C                                                                       GW2D
C  READ AND PRINT INPUT DATA                                            GW2D
C                                                                       GW2D
      KOUT=0                                                            GW2D
      KSS=1                                                             GW2D
C                                                                       GW2D
C                                                                       GW2D
      CALL DATAIN(X,Z,IE, H,HT,TH,VX,VZ,  DLH,DCOSXH,DCOSZH,NHE,        GW2D
     > ISH,NPH,  DL,DCOSX,DCOSZ,HCON,NRSE,IS,NPRS,NPCON,NPFLX,IRFTYP,   GW2D
     > IRF,RF, RP,NPST, BB,NN, PROP,THPROP,AKPROP,HPROP,CAPROP,          CDC
     > MAXEL,MAXNP,MAXBEL,MAXBNP,MXRSEL,MXRSNP,MXSTNP,                   CDC
     > MAXBCN, MAXMAT,MXSPPM, MAXNTI, PMAT,AKPAR,THPAR, KPR,KDSK,        CDC
     > ISTOP, MAXDIF,W,TIME,TITLE,NPROB, 1)                             CDC
C                                                                       GW2D
      KDIG=NSTRT                                                        GW2D
      IF (ISTOP.GT.0) GO TO 270                                         GW2D
C                                                                       GW2D
C  COMPUTE BAND-WIDTH VARIABLES                                         GW2D
C                                                                       GW2D
      IHALFB=MAXDIF                                                     GW2D
      IBAND=2*IHALFB+1                                                  GW2D
      IHBP=IHALFB+1                                                     GW2D
      IF (IHBP.GT.MAXHBP) GO TO 260                                     GW2D
C                                                                       GW2D
C  PREPARE INITIAL VARIABLES                                            GW2D
C                                                                       GW2D
      CALL SPROP(IE, H,TH,DTH,AKX,AKZ,PROP,THPROP,AKPROP,HPROP,         GW2D
     >             CAPROP, MAXEL,MAXNP, MAXMAT,        MXSPPM, NEL,KSP) GW2D
C                                                                       GW2D
      CALL VELT(X,Z,IE, C,H,HT,VX,VZ,AKX,AKZ, MAXEL,MAXNP,MAXHBP)       GW2D
C                                                                       GW2D
      KFLOW=-1                                                          GW2D
C                                                                       GW2D
```

```
      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)
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,SUBBD(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,NIT,
     > 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,                   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
C        DO 50 NP=1,NNP
C  50       H(NP)=HP(NP)
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,       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,         KSS,W,DELT)
C
C   APPLY STEADY-STATE BOUNDARY CONDITIONS
C
          CALL BC(C,R, FLX,HCON,NPCON,NPFLX, RP,NPST,BB,NN,
     >            MAXNP,MAXHBP, MXBSNP,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= ABS(R(NP)-H(NP))
             RES=AMAX1(RES,RESNP)
             IF (H(NP).NE.0.D0) RD=AMAX1(RD, ABS(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(IDBUG.NE.0) PRINT 10200,NIT,RES,RD,NNCVN
          IF (IT.EQ.1) GO TO 80
          IF (RES.LT.TOLA) GO TO 90
   80     CONTINUE
      PRINT 10210, ICY,IT,MAXIT
C
C   END OF ITERATION LOOP ON THE NONO-LINEAR EQUATION
C
C
C   PRINT NONCONVERGING NODES
C
        IF(IDBUG.EQ.0) GO TO 90
        PRINT 10500
        PRINT 10600,(NPCNV(NPP),NPP=1,NNCVN)
C
C
C   PRINT RAINFALL-SEEPAGE B. C. CHANGE 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,         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,REALL, MAXEL,
    >     MAXNP, MXRSEL,MXRSNP,                    TIME,NCHG)
         IF (NCHG.EQ.0) GO TO 110
  100    CONTINUE
      PRINT 10610, ICY,IT,MAXCY,MAXIT
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,ISB,
     > NBE,NPB, NPRS,      NPST,NN, FRATE,FLOW,TFLOW, MAXNP,MAXEL,
     > MAXBEL,MAXBNP, MXRSNP,          MXSTNP,MAXHCN,KFLOW,DELT,DTH,H,HP,
     > PROP,MAXMAT)
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,SURHD(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, HR,NN, PROP,THPROP,AKPROP,HPROP,CAPROP,
     > MAXEL,MAXNP,MAXBEL,MAXBNP,MXRSEL,MXRSNP,MXSTNP,
     > MAXHCN, MAXMAT,MXSPPM, MAXNTI, PMAT,AKPAR,THPAR, KPR,KDSK,
     > ISTOP, MAXDIF,W,TIME,TITLE,NPROB, 2)
```

```
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,                    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,        MXSPPM,NEL,KSP)
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,        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,MAXHCN, 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= ABS(R(NP)-H(NP))
                RES=AMAX1(RES,RESNP)                                  CDC
                IF (H(NP).NE.0.D0) RD=AMAX1(RD, ABS(RESNP/H(NP)))     CDC
                IF (RESNP.LE.TOLB) GO TO 190                          CDC
                NPP=NPP+1
                NPCNV(NPP)=NP
 190            CONTINUE
C
             NNCVN=NPP
C
C  UPDATE PRESSURE 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 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.AND.ITM.EQ.1) GO TO 210
             IF (RES.LT.TOLB) GO TO 220
 210         CONTINUE
      PRINT 10710, ITM,ICY,IT,MAXIT
C
C  END THE ITERATION LOOP 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) GO TO 225
           PRINT 10402
           DO 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,        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 240
C
            CALL RCPREP(IE, H,VX,VZ, DL,DCOSX,DCOSZ,DCYFLX,FLX,RSFLX,
     >       HCON,NRSE,IS,NPRS,NPCON,NPFLX,IRFTYP,TRF,RF,RFALL, MAXEL,
     >       MAXNP, MXRSEL,MXRSNP,                 TIME,NCHG)
            IF (NCHG.EQ.0) GO TO 240
  230       CONTINUE
      PRINT 10810, ITM,ICY,IT,MAXCY,MAXIT
C
C  END THE ITERATION LOOP ON THE SEEPAGE-RAINFALL BOUNDARY CONDITITONS
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)=HB(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)
C
C  PRINT VARIABLES AT EACH TIME STEP
C
      CALL PRINIT(VX,VZ,H,HT,TH, NPB,BFLX, NPRS,RSFLX,NPCON,NPFLX,
     > FRATE,FLOW,TFLOW, MAXNP,MAXEL, MAXBNP,MXRSNP, NNP,NEL, NBN,NRSN,
     > TIME,DELT,SURHD(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,NBEL,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=AMIN1(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/)
10200 FORMAT(5X,I10,3X,E12.4,3X,E12.4,15X,I10)
10300 FORMAT(///26H HALF-BANDWIDTH-PLUS-ONE =,I4,
     > 25H EXCEEDS MAX. ALLOWABLE =,I4)
10400 FORMAT(1H1,52H****************************************************
     > 62H**************************************************************
     > 5H*****//:17H DIAGNOSTIC TABLE,I4,12H.. AT TIME =,1PE12.4,
     > 9H ,(DELT = 1PE12.4,1H))
10401 FORMAT(///30H TABLE OF ITERATIVE PARAMETERS// 6X,
     > 9HITERATION,7X,8HRESIDUAL,6X,9HDEVIATION,6X,
     > 19HNO. NON-CONV. NODES)
10402 FORMAT(//44H TABLE OF RAINFALL-SEEPAGE B. C. INFORMATION,/ 6X,
     > 87HIRSN   NPRS(IRSN)    NPCON(IRSN)   HCON(NPRS)    NPFLX(IRSN)
     > FLX(NPRS)   DCYFLX(NPRS))
10403 FORMAT(1H ,I10,I13,I15,E13.4,I15,E13.3,E15.3)
10500 FORMAT(//30H TABLE OF NON-CONVERGING NODES)
10600 FORMAT(/(5X,20I5))
10210 FORMAT(1H0,'WARNING: NON-CONVERGENCE OCCUR DURING STEADY STATE SOL
     1UTION AT',I5,' -TH CYCLE'/1H ,'IT = ',I3,'  .GT.  MAXIT = ',I3)
10610 FORMAT(1H0,'ABSOLUTELY WARNING: STEADY STATE SOLUTION IS NG'/1H ,
     > 'ICY = ',I5,'  IT = ',I3,'  MAXCY = ',I3,'  MAXIT = ',I3)
10710 FORMAT(1H0,'WARNING: NON-CONVERGENCE OCCUR AT',I5,' -TH TIME STEP'
     >,I3,' -TH CYCLE'/1H ,'IT = ',I3,'  .GT.  MAXIT = ',I3)
10810 FORMAT(1H0,'ABSOLUTELY WARNING: TRANSIENT SOLUTION IS NG AT ',I5,
     > ' -TH TIME STEP'/1H ,'ICY = ',I3,'  IT = ',I3,'  MAXCY = ',I3,
     > '  MAXIT = ',I3)
      END
      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,
     > IRF,RF, RP,NPST, BB,NN, PROP,THPROP,AKPROP,HPROP,CAPROP,
     > MAXEL,MAXNP,MAXBEL,MAXBNP,MXRSEL,MXRSNP,MXSTNP,
     > MAXBCN, MAXMAT,MXSPPM, MAXNTI, PMAT,AKPAR,THPAR, KPR,KDSK,
     > ISTOP, MAXDIF,W,TIME,TITLE,NPROB, IPASS)
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  (A-H,O-Z)
      REAL    PMAT,THPAR,AKPAR
C
      DIMENSION TITLE(9)
      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)
```

```
C
      DIMENSION RP(MXSTNP),NPST(MXSTNP),BB(MAXBCN),NN(MAXBCN)
      DIMENSION PROP(MAXMAT,3),THPROP(MAXMAT,MXSPPM),
     > AKPROP(MAXMAT,MXSPPM),HPROP(MAXMAT,MXSPPM),CAPROP(MAXMAT,MXSPPM)
C
      DIMENSION KPR(MAXNTT),KDSK(MAXNTT)
C
      DIMENSION THF(3,20),HF(3,20)
      DIMENSION PMAT(3,5),AKPAR(3,8),THPAR(3,8)
C
      COMMON /GEOM/ SNFE,CSFE,NNP,NEL,THAND
      COMMON /CNTRL/ NTT,MAXCY,MAXIT,NSTRT,KSTR,KPRO,KDSKO,KSS,KSP
      COMMON /TOTLNS/ TOLA,TOLB
      COMMON /PARAM/ DELT,CHNG,DELMAX,TMAX,DELTO
      COMMON /BRSND/ NBEL,NBN,NRSEL,NRSN,NREPR,NREPAR
      COMMON /BCST/ NBC,NST,NSTN
      COMMON /MTL/ NMAT,NMPPM,NSPPM
      COMMON /OPT/ ILUMP,TMID
C
      IF (KSS.EQ.0) GO TO 505
      ISTOP=0
C
      READ 12000,NNP,NEL,NMAT,NCM,NTT,KSS,KSP,NSPPM,KSTR,KCP,KGRAV,
     >           NSTRT,MAXIT,MAXCY,NMPPM
      READ 12000, ILUMP,TMID
      READ 12300, DELT,CHNG,DELMAX,TMAX,FE,TOLA,TOLB,RHO,GRAV,VISC,W
      DELTO=DELT
      READ 12100,KPRO,(KPR(ITM),ITM=1,NTT)
      READ 12100, KDSKO,(KDSK(ITM),ITM=1,NTT)
C
      IF(TMAX.LE.0.0) TMAX=1.0E50
C
      PRINT 10000,NNP,NEL,NMAT,NCM,NTT,KSS,KSP,NSPPM,KSTR,KCP,KGRAV,
     > NSTRT,MAXIT,MAXCY
      PRINT 10001, ILUMP,TMID
      PRINT 10100,DELT,CHNG,DELMAX,TMAX,FE,TOLA,TOLB,RHO,GRAV,VISC,W
      PRINT 10200
      PRINT 12200,KPRO,(KPR(ITM),ITM=1,NTT)
      PRINT 10201
      PRINT 12200, KDSKO,(KDSK(ITM),ITM=1,NTT)
C
      PI=3.14159265
      FE=FE*PI/180.
      SNFE= SIN(FE)
      CSFE= COS(FE)
      IF (KGRAV.EQ.0) SNFE=0.
      IF (KGRAV.EQ.0) 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   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
          DO 180 J=1,NBPPM
  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
      INPTAB=6
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)
  290 MJ = MJ + 1
      IF (MI-MJ) 300,330,310
  300 PRINT 15200, MI
      PRINT 13000, MI,(IE(MI,I),I=1,5),MND
      ISTOP = ISTOP + 1
  310 DO 320 IQ=1,4
  320    IE(MJ,IQ) = IE(MJ-1,IQ) + 1
      IE(MJ,5) = IE(MJ-1,5)
```

```
  330 PRINT 13000, MJ,(IE(MJ,I),I=1,5),MND
      IF (MJ.LT.MI) GO TO 290
      IF (MJ.EQ.NEL) GO TO 370
      IF (MODL.LE.0) GO TO 270
      DO 360 I=1,NLAY
         LL=2
         DO 360 J=1,MODL
            IF (MJ.EQ.MI) GO TO 350
            DO 340 KQ=1,4
  340          IE(MJ,KQ) = IE(MJ-1,KQ) + LL
            IE(MJ,5)=IE(MJ-1,5)
            PRINT 13000, MJ,(IE(MJ,K),K=1,5),MND
            KLINE=KLINE+1
            IF(MOD(KLINE,50).EQ.0) PRINT 10800
  350       LL = 1
  360       MJ = MJ + 1
      MJ = MJ - 1
      IF (MJ.LT.NEL) GO TO 270
  370 CONTINUE
C
C  MODIFY MATERIAL TYPES FOR SELECTED ELEMENTS IF NECESSARY
C
      IF (NCM.LE.0) GO TO 410
      PRINT 10900
      L=0
  380 READ 12000, MI,MTYP,MK,MINC
      IE(MI,5) = MTYP
      PRINT 13100, MI,IE(MI,5)
      L = L + 1
      IF (MK.LE.MI) GO TO 400
      IF (MINC.LE.0) MINC = 1
      MI = MI + MINC
      DO 390 MJ=MI,MK,MINC
         IE(MJ,5) = MTYP
         PRINT 13100, MJ,IE(MJ,5)
  390    L = L + 1
  400 IF (L.LT.NCM) GO TO 380
  410 CONTINUE
      DO 420 M=1,NEL
         MTYP=IE(M,5)
         IF (MTYP.GT.0.AND.MTYP.LE.NMAT) GO TO 420
         PRINT 15900,M
         ISTOP=ISTOP+1
  420    CONTINUE
      IF(ISTOP.EQ.0) GO TO 430
      PRINT 15000, ISTOP
      STOP
C
C  READ INITIAL CONDITIONS
C
  430 TIME=0.000
      IF (NSTRT.EQ.0) GO TO 450
      REWIND 1
      REWIND 2
      READ(2) (DUM,I=1,9),IDUM,NPT,NET,NBN,NBEL,IDUM,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),(NBF(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,
     >      NEL),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,NBF,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
      INPTAB=INPTAB+1
      IF(KSS.EQ.0 .AND. IPASS.EQ.1) PRINT 11000, INPTAB,NBC,NST,
     > NRFPR,NRFPAR,NRSEL,NRSN
      IF(KSS.EQ.0 .AND. IPASS.EQ.2) PRINT 11300, INPTAB,NBC,NST,
     > NRFPR,NRFPAR,NRSEL,NRSN
      IF(KSS.EQ.1) PRINT 11300, INPTAB,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
```

```
      INPTAB=INPTAB+1
      IF(KSS.EQ.0 .AND. IPASS.EQ.1) PRINT 11400, INPTAB
      IF(KSS.EQ.0 .AND. IPASS.EQ.2) PRINT 11410, INPTAB
      IF(KSS.EQ.1) PRINT 11410,INPTAB
      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
      HCUN(NPP)=HCONI
      GO TO 610
  640 IF (NPP.GT.0) GO TO 650
      ISTOP=ISTOP+1
      PRINT 15500
  650 NJ=NPRS(NPP)
      JTYP=IRFTYP(NPP)
      HCONJ=HCON(NPP)
      NJ=NJ+NPINC
      NK=NI-1
      DO 660 NP=NJ,NK,NPINC
         NPP=NPP+1
         NPRS(NPP)=NP
         IRFTYP(NPP)=JTYP
  660    HCON(NPP)=HCONJ
      GO TO 630
  670 CONTINUE
      INPTAB=INPTAB+1
      IF(KSS.EQ.0 .AND. IPASS.EQ.1) PRINT 11600, INPTAB
      IF(KSS.EQ.0 .AND. IPASS.EQ.2) PRINT 11610, INPTAB
      IF(KSS.EQ.1) PRINT 11610, INPTAB
      DO 680 NPP=1,NRSN
         NP=NPRS(NPP)
  680    PRINT 13800,NP,IRFTYP(NPP),HCON(NPP)
C
C  STEADY STATE OR TRANSIENT RAINFALL-SEEPAGE ELEMENT SURFACE INFORMAT.
C
      MPI=0
  690 IF (MPI.EQ.NRSEL) GO TO 740
      READ 12000,MI,IS1,IS2,KINC
      IF (KINC.GT.0) GO TO 710
  700 MPI=MPI+1
      NRSE(MPI)=MI
      IS(MPI,1)=IS1
      IS(MPI,2)=IS2
```

```
      GO TO 690
  710 IF (MPI.GT.0) GO TO 720
      ISTOP=ISTOP+1
      PRINT 15600
  720 NPINC=IS(MPI,2)-IS(MPI,1)
      MINC=IABS(NPINC)-1
      MINC=MAX0(MINC,1)
      MJ=NRSE(MPI)+MINC
      MK=MI-1
      DO 730 M=MJ,MK,MINC
         MPJ=MPI
         MPI=MPI+1
         NRSE(MPI)=M
         IS(MPI,1)=IS(MPJ,1)+NPINC
  730    IS(MPI,2)=IS(MPJ,2)+NPINC
      GO TO 700
  740 CONTINUE
      INPTAB=INPTAB+1
      IF(KSS.EQ.0 .AND. IPASS.EQ.1) PRINT 11700, INPTAB
      IF(KSS.EQ.0 .AND. IPASS.EQ.2) PRINT 11710, INPTAB
      IF(KSS.EQ.1) PRINT 11710, INPTAB
      DO 750 MP=1,NRSEL
         M=NRSE(MP)
  750    PRINT 13000,M,IS(MP,1),IS(MP,2)
C
C  DETERMINE DIRECTION COSINES FOR STEADY STATE OR TRANSIENT
C  RAINFALL-SEEPAGE SURFACES
C
       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,MXSTNP
  810    RP(NP)=0.
      IF (NBC.EQ.0) GO TO 900
C
C  READ STEADY STATE OR TRANSIENT BOUNDARY CONDITIONS OF THE FORM H=HB
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 CONTINUE
      INPTAB=INPTAB+1
      IF(KSS.EQ.0 .AND. IPASS.EQ.1) PRINT 11100, INPTAB
      IF(KSS.EQ.0 .AND. IPASS.EQ.2) PRINT 11110, INPTAB
      IF(KSS.EQ.1) PRINT 11110, INPTAB
      DO 890 NPP=1,NBC
  890    PRINT 13200,NN(NPP),BB(NPP)
  900 IF (NST.LE.0) GO TO 1000
C
C  READ STEADY STATE OR TRANSIENT SURFACE-TERM POINT FLUXES
C
      NPP=0
      MP=0
      INPTAB=INPTAB+1
      IF(KSS.EQ.0 .AND. IPASS.EQ.1) PRINT 11200, INPTAB
      IF(KSS.EQ.0 .AND. IPASS.EQ.2) PRINT 11210, INPTAB
      IF(KSS.EQ.1) PRINT 11210, INPTAB
  910 IF (MP.EQ.NST) GO TO 960
      READ 13400,NI,NJ,KINC,EI,FJ
      IF (KINC.GT.0) GO TO 930
  920 MP=MP+1
      DX=X(NI)-X(NJ)
      DZ=Z(NI)-Z(NJ)
      EL= SQRT(DX*DX+DZ*DZ)                                  CDC
      PRINT 13500,NI,NJ,FI,FJ
      IF(MP.GT.1) GO TO 921
      NPP=NPP+1
      NPST(NPP)=NI
      NII=NPP
      NPP=NPP+1
      NPST(NPP)=NJ
      NJJ=NPP
      GO TO 928
  921 DO 922 I=1,NPP
         IJ=NPST(I)
         IF(IJ.EQ.NI) GO TO 923
  922    CONTINUE
      NPP=NPP+1
      NPST(NPP)=NI
      NII=NPP
      GO TO 924
  923 NII=I
  924 DO 925 J=1,NPP
```

```
      IJ=NPST(J)
      IF(IJ.EQ.NJ) GO TO 926
925   CONTINUE
     NPP=NPP+1
     NPST(NPP)=NJ
     NJJ=NPP
     GO TO 928
926  NJJ=J
928  RP(NII)=RP(NII)+EI*FL/3.0+EJ*FL/6.0
     RP(NJJ)=RP(NJJ)+EI*FL/6.0+EJ*FL/3.0
     EK=EJ
     GO TO 910
930  IF (MP.GT.0) GO TO 940
     ISTOP=ISTOP+1
     PRINT 15700
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)
        FL= SQRT(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  NSIN=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)=HB(NPP)
 1020 IF (ISTOP.EQ.0) GO TO 1030
      PRINT 15800, ISTOP
C
 1030 CONTINUE
C
      PRINT 20000, NBN,(NPB(I),I=1,NBN)
      PRINT 21000, NBEL,(NBE(I),I=1,NBEL)
      IF(NRSN.NE.0) PRINT 22000, NRSN,(NPRS(I),I=1,NRSN)
      IF(NRSEL.NE.0) PRINT 23000, NRSEL,(NRSE(I),I=1,NRSEL)
      IF(NST.NE.0) PRINT 26000, NST,NSTN,(NPST(I),I=1,NSTN)
      IF(NBC.NE.0) PRINT 27000, NBC,(NN(I),I=1,NBC)
C
      RETURN
C
C
10000 FORMAT(35H0INPUT TABLE 1.. BASIC PARAMETERS    // 5X,
     > 40H NUMBER OF NODAL POINTS. . . . . . . . . ,I5/ 5X,
     > 40H NUMBER OF ELEMENTS. . . . . . . . . . . ,I5/ 5X,
     > 40H NUMBER OF DIFFERENT MATERIALS . . . . . ,I5/ 5X,
     > 40H NUMBER OF CORRECTION MATERIALS. . . . . ,I5/ 5X,
     > 40H NUMBER OF TIME INCREMENTS . . . . . . . ,I5/ 5X,
     > 40H STEADY-STATE I.C. CONTROL . . . . . . . ,I5/ 5X,
     > 40H SOIL-PROPERTY CONTROL . . . . . . . . . ,I5/ 5X,
     > 40H NUMBER OF SOIL PARAMETERS . . . . . . . ,I5/ 5X,
     > 40H AUXILIARY STORAGE CONTROL . . . . . . . ,I5/ 5X,
     > 40H CONDUCTIVITY-PERMEABILITY CONTROL . . . ,I5/ 5X,
     > 40H GRAVITY CONTROL . . . . . . . . . . . . ,I5/ 5X,
     > 40H RESTART PARAMETER . . . . . . . . . . . ,I5/ 5X,
     > 40H MAXIMUM ITERATIONS PER CYCLE. . . . . . ,I5/ 5X,
     > 40H MAXIMUM CYCLES PER TIME STEP. . . . . . ,I5)
10001 FORMAT(1H ,4X,
     > 40H LUMPING INDICATOR, ILUMP. . . . . . . . ,I5/ 5X,
     > 40H TIME-DIFFERENCE INDICATOR, IMID . . . . ,I5)
10100 FORMAT(5X,40H TIME INCREMENT. . . . . . . . . . . . . ,F10.6/ 5X,
     > 40H MULTIPLIER FOR INCREASING DELT. . . . . ,F10.6/ 5X,
     > 40H MAXIMUM VALUE OF DELT . . . . . . . . . ,1PE10.4/ 5X,
     > 40H MAXIMUM VALUE OF TIME . . . . . . . . . ,1PE10.4/ 5X,
     > 40H DEGREES OF PRIN-AXIS INCLINATION. . . . ,0P,F10.6/ 5X,
     > 40H STEADY-STATE TOLERANCE. . . . . . . . . ,F10.6/ 5X,
     > 40H TRANSIENT STATE TOLERANCE ............. ,F10.6/ 5X,
     > 40H DENSITY OF WATER. . . . . . . . . . . . ,F10.6/ 5X,
     > 40H ACCELERATION OF GRAVITY . . . . . . . . ,F10.3/ 5X,
     > 40H VISCOSITY OF WATER. . . . . . . . . . . ,F10.6/ 5X,
     > 40H TIME-INTEGRATION PARAMETER. . . . . . . ,F10.6)
10200 FORMAT(//6X,14HOUTPUT CONTROL)
10201 FORMAT(//6X,19HDISK OUTPUT CONTROL)
10300 FORMAT(36H1INPUT TABLE 2.. MATERIAL PROPERTIES// 9H MAT. NO., 9(
     > 3A4))
10400 FORMAT(53H1INPUT TABLE 3.. SOIL-PROPERTIES INTERPOLATION VALUES//
     > 9H MAT. NO.,9X,8HPRESSURE,13X,16HMOISTURE CONTENT,4X,
     > 25HCONDUCTIVITY/PERMEABILITY,6X,14HWATER CAPACITY)
10500 FORMAT(44H1INPUT TABLE 3.. MOISTURE-CONTENT PARAMETERS//
     > 9H MAT. NO.,8(3A4))
10600 FORMAT(40H1INPUT TABLE 4.. CONDUCTIVITY PARAMETERS// 9H MAT. NO.,
     > 2(3A4))
10700 FORMAT(32H1INPUT TABLE 5. NODAL POINT DATA//2X,
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     > 4HNODE,10X,1HX,10X,1HZ,4X,4HNODE,10X,1HX,10X,1HZ,4X,4HNODE,       DATA3155
     > 10X,1HX,10X,1HZ,4X,4HNODE,10X,1HX,10X,1HZ/                        DATA3160
     > 27H***************************,3X,27H***************************,DATA3165
     >3X,27H***************************,3X,27H***************************DATA3170
     >*/)                                                                DATA3175
10800 FORMAT(29H1INPUT TABLE 6.. ELEMENT DATA// 11X,                     DATA3180
     > 31HGLOBAL INDICES OF ELEMENT NODES/7X,7HELEMENT,3X,1H1,7X,1H2,    DATA3185
     > 7X,1H3,7X,1H4,6X,8HMATERIAL,4X,10HNODE DIFF.)                     DATA3190
10900 FORMAT (64H CORRECTIONS TO MATERIAL TYPES AND CLASSES FOR SELECTEDDATA3195
     > ELEMENTS)                                                         DATA3200
11000 FORMAT(1H1,'INPUT TABLE',I3,' STEADY-STATE B. C. PARAMETERS'//5X,  DATA3205
     > 40H NUMBER OF BOUNDARY CONDITIONS . . . . . .,I5/ 5X,             DATA3210
     > 40H NUMBER OF SURFACE TERMS . . . . . . . . .,I5/ 5X,             DATA3215
     > 40H NUMBER OF RAINFALL PROFILES . . . . . . .,I5/ 5X,             DATA3220
     > 40H NUMBER OF RAINFALL PARAMETERS . . . . . .,I5/ 5X,             DATA3225
     > 40H NUMBER OF RAINFALL-SEEPAGE ELEMENTS . . .,I5/ 5X,             DATA3230
     > 40H NUMBER OF RAINFALL-SEEPAGE NODES. . . . .,I5)                 DATA3235
11100 FORMAT(1H1,'INPUT TABLE',I3,'  STEADY-STATE B. C. OF ',            DATA3240
     > 9HFORM H=HB//6H  NODE,7X,2HHB)                                    DATA3245
11110 FORMAT(1H1,'INPUT TABLE',I3,'  TRANSIENT B. C. OF FORM H=HB'//     DATA3250
     > 6H  NODE,7X,2HHB)                                                 DATA3255
11200 FORMAT(1H1,'INPUT TABLE',I3,'  STEADY-STATE SURFACE TERMS',        DATA3260
     > 33H F=EI AT NODE NI, E=EJ AT NODE NJ//8X,2HNI,8X,2HNJ,10X,2HEI,   DATA3265
     > 13X,2HEJ/)                                                        DATA3270
11210 FORMAT(1H1,'INPUT TABLE',I3,'  TRANSIENT SURFACE TERMS',           DATA3275
     > 33H F=EI AT NODE NI, E=EJ AT NODE NJ// 5H   NI,5H   NJ,6X,2HEI,   DATA3280
     > 12X,2HEJ/)                                                        DATA3285
11300 FORMAT(1H1,'INPUT TABLE',I3,' TRANSIENT B.C. PARAMETERS'//5X,      DATA3290
     > 40H NUMBER OF BOUNDARY CONDITIONS . . . . . .,I5/ 5X,             DATA3295
     > 40H NUMBER OF SURFACE TERMS . . . . . . . . .,I5/ 5X,             DATA3300
     > 40H NUMBER OF RAINFALL PROFILES . . . . . . .,I5/ 5X,             DATA3305
     > 40H NUMBER OF RAINFALL PARAMETERS . . . . . .,I5/ 5X,             DATA3310
     > 40H NUMBER OF RAINFALL-SEEPAGE ELEMENTS . . .,I5/ 5X,             DATA3315
     > 40H NUMBER OF RAINFALL-SEEPAGE NODES. . . . .,I5)                 DATA3320
11400 FORMAT(1H1,'INPUT TABLE',I3,'  STEADY-STATE RAINFALL DATA')        DATA3325
11410 FORMAT(1H1,'INPUT TABLE',I3,'  TRANSIENT RAINFALL DATA')           DATA3330
11500 FORMAT(/8H PROFILE,I5/8X,4HTIME,11X,4HRATE)                        DATA3335
11600 FORMAT(1H1,'INPUT TABLE',I3,'  STEADY STATE RAINFALL DISTRIBUTION DATA3340
     >AND PONDING'//6X,4HNODE,6X,4HTYPE,5X,5HDEPTH)                      DATA3345
11610 FORMAT(1H1,'INPUT TABLE',I3,'  TRANSIENT RAINFALL DISTRIBUTION ANDDATA3350
     > PONDING'//6X,4HNODE,6X,4HTYPE,5X,5HDEPTH)                         DATA3355
11700 FORMAT(1H1,'INPUT TABLE',I3,'  STEADY-STATE RAINFALL-SEEPAGE SURFADATA3360
     >CE INFORMATION'//5X,7HELEMENT,2X,6HNODE 1,2X,6HNODE 2)             DATA3365
11710 FORMAT(1H1,'INPUT TABLE',I3,'  TRANSIENT RAINFALL-SEEPAGE SURFACE DATA3370
     >INFORMATION'//5X,7HELEMENT,2X,6HNODE 1,2X,6HNODE 2)                DATA3375
12000 FORMAT(16I5)                                                       DATA3380
12100 FORMAT(80I1)                                                       DATA3385
12200 FORMAT(10X,101I1)                                                  DATA3390
12300 FORMAT(8F10.0)                                                     DATA3395
12400 FORMAT(2(1PE15.4))                                                 DATA3400
12500 FORMAT(I8,1P9E12.4)                                                DATA3405
12600 FORMAT(1P,I8,F19.4,3E25.4/(2X,4E25.4))                             DATA3410
12700 FORMAT(I8,9E12.4/(8X,9E12.4))                                      DATA3415
12800 FORMAT(I5,2F10.3)                                                  DATA3420
12900 FORMAT(1H,1P,I5,2E11.3,3X,I5,2E11.3,3X,I5,2E11.3,3X,I5,2E11.3)     DATA3425
13000 FORMAT(I10,4I8,I10,I13)                                            DATA3430
13100 FORMAT(I10,32X,I10,32X,I10)                                        DATA3435
13200 FORMAT(I5,1PE15.4)                                                 DATA3440
13300 FORMAT(2I5,2F10.0)                                                 DATA3445
13400 FORMAT(3I5,5X,2F10.0)                                              DATA3450
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13500 FORMAT(2I10,2(1PE15.4))
13600 FORMAT(I5,5X,F10.0)
14300 FORMAT(////37H CHECK BOUNDARY CONDITIONS, MAXIMUM =,I5///)
14800 FORMAT(////43H TOO MANY RAINFALL-SEEPAGE NODES, MAXIMUM =,I5///)
14900 FORMAT(////34H ERROR IN SURFACE CARD FOR ELEMENT,I5///)
15000 FORMAT(////28H EXECUTION HALTED BECAUSE OF,I5,13H FATAL ERRORS///)
15100 FORMAT(////30H ERROR IN NODAL-POINT CARD NO.,I5///)
15200 FORMAT(////26H ERROR IN ELEMENT CARD NO.,I5///)
15300 FORMAT(////36H ERROR IN INITIAL-CONDITION CARD NO.,I5///)
15400 FORMAT(////49H ERROR IN FIRST H=BB TYPE BOUNDARY-CONDITION CARD //
     >  /)
15500 FORMAT(////48H ERROR IN FIRST RAINFALL-TYPE-PONDING-DEPTH CARD///)
15600 FORMAT(////45H ERROR IN FIRST RAINFALL-SEEPAGE ELEMENT CARD///)
15700 FORMAT(////33H ERROR IN FIRST SURFACE-TERM CARD///)
15800 FORMAT(////45H ASSEMBLY AND SOLUTION WILL NOT BE PERFORMED,,I5,
     > 19H  FATAL CARD ERRORS///)
15900 FORMAT(////40H ERROR IN MATERIAL TYPE CODE FOR ELEMENT,I5///)
20000 FORMAT(1H1,5X,'CHECK ALL BOUNDARY NODAL AND ELEMENT INFORMATION'//
     > /5X,'TOTAL NUMBER OF BOUNDARY NODES =',I5/5X,
     > 'THEY ARE LISTED BELOW:'/(5X,10I5))
21000 FORMAT(1H0,4X,'TOTAL NUMBER OF BOUNDARY ELEMENTS =',I5/5X,
     > 'THEY ARE LISTED BELOW:'/(5X,10I5))
22000 FORMAT(1H0,4X,'TOTAL NUMBER OF RAINFALL-SEEPAGE BOUNDARY NODES =',
     > I5/5X,'THEY ARE LISTED BELOW:'/(5X,10I5))
23000 FORMAT(1H0,4X,'TOTAL NUMBER OF RAINFALL-SEEPAGE BOUNDARY ELEMENT =
     > ',I5/5X,'THEY ARE LISTED BELOW:'/(5X,10I5))
26000 FORMAT(1H0,4X,'TOTAL NUMBER OF SURFACE TERM BOUNDARY ELEMENTS =',
     > I5/5X,'TOTAL NUMBER OF SURFACE TERM BOUNDARY NODES =',I5/5X,
     > 'THEY ARE LISTED BELOW:'/(5X,10I5))
27000 FORMAT(1H0,4X,'TOTAL NUMBER OF DIRICHLET NODES =',I5/5X,
     > 'THEY ARE LISTED BELOW:'/(5X,10I5))
      END
      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  (A-H,O-Z)                                          CDC
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,NREPR,NREPAR
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
         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)= SQRT(DX*DX+DZ*DZ)                                      CDC
C
      BETA= ATAN2(DZ,DX)                                              CDC
      DCOSXB(MP)= SIN(BETA)                                           CDC
      DCOSZB(MP)=- COS(BETA)                                          CDC
   70 CONTINUE
      RETURN
      END
      SUBROUTINE VELT(X,Z,IE, C,H,HT,VX,VZ,AKX,AKZ, MAXEL,MAXNP,MAXBBP)
C
```

```
C  FUNCTION OF SUBROUTINE TO COMPUTE DARCY VELOCITY VX AND VZ
C
      IMPLICIT REAL  (A-H,O-Z)                                       CDC
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 180 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,C[illegible])
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,HIQ,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    (A-H,O-Z)                                        CDC
      REAL    N(4)                                                      CDC
C
      DIMENSION QQ(4,4),RQ(4),XQ(4),ZQ(4),HIQ(4),AKXQ(4),AKZQ(4)
      DIMENSION S(4),T(4),DNX(4),DNZ(4)
      DIMENSION PJAC(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 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)
```

```
      IT=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)
   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 SPROP(IE, H,TH,DTH,AKX,AKZ,PROP,THPROP,AKPROP,HPROP,
     > CAPROP,  MAXEL,MAXNP, MAXMAT,          MXSPPM, NEL,KSP)
C
C
C  FUNCTION OF SUBROUTINE--TO CALCULATE SOIL PROPERTIES, I.E. THE
C  WATER CONTENTS TH(M,IQ), WATER CAPACITIES DTH(M,IQ), AND
C  PRINCIPAL VALUES OF THE CONDUCTIVITY TENSOR AKX(M,IQ) AND AKZ(M,IQ).
C
C
      IMPLICIT REAL  (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,5),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 TO 80
      DO 70 M=1,NEL
         MTYP=IE(M,5)
         SATKX=PROP(MTYP,4)
         SATKZ=PROP(MTYP,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=0.
            GO TO 50
   20       DO 30 J=2,NSPPM
               JU=J
               IF (HPROP(MTYP,J).GT.HNP) GO TO 40
   30          CONTINUE
   40       JL=JU-1
            A=(HNP-HPROP(MTYP,JL))/(HPROP(MTYP,JU)-HPROP(MTYP,JL))
   50       TH(M,IQ)=THPROP(MTYP,JL)+A*(THPROP(MTYP,JU)-THPROP(MTYP,JL))
            DTH(M,IQ)=CAPROP(MTYP,JL)+A*(CAPROP(MTYP,JU)-CAPROP(MTYP,JL)
     >        )
            USKFCT=AKPROP(MTYP,JL)+A*(AKPROP(MTYP,JU)-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 MATERUALS
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=THPRUP(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= SQRT(RWC)*(1.0-TERM)*(1.-TERM)
           AKX(M,IQ)=SATKX*RK
           AKZ(M,IQ)=SATKZ*RK
           DTH(M,IQ)=ALPH*(RN-1.0)*TERM*RWC**(1.0/RM)
C
  90    CONTINUE
  95 CONTINUE
     RETURN
     END
     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,                  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    (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)
     DIMENSION TRF(3,20),RF(3,20),RFALL(3)
C
```

```
      COMMON /GEOM/ SNFE,CSFE,NNP,NEL,THAND
      COMMON /RRSND/ NREL,NRN,NRSEL,NRSN,NREPR,NREPAR
C
C   CALCULATE THE RAINFALL REALL(I) FROM EACH PROFILE
C
      IF (NREPR.EQ.0) GO TO 40
      DO 30 I=1,NREPR
         DO 20 J=2,NREPAR
            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
         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 SO
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
      SUBROUTINE ASEMBL(X,Z,IE, C,R,H,HP,TH,DTH,AKX,AKZ, PROP,
     > MAXNP,MAXEL,MAXBBP, MAXMAT,          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  (A-H,O-Z)
C
      DIMENSION X(MAXNP),Z(MAXNP),IE(MAXEL,5)
      DIMENSION C(MAXNP,MAXBBP),R(MAXNP),H(MAXNP),HP(MAXNP),
     > TH(MAXEL,4),DTH(MAXEL,4),AKX(MAXEL,4),AKZ(MAXEL,4)
```

```
      DIMENSION PROP(MAXMAT,5)                                          CDC
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 /Q4PAR/ ALP,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(MTYP,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(IQ,JQ)*DELTT
             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 JQ=1,4
             NJ=IEM(JQ)
             QA(IQ,JQ)=2.0D0*QA(IQ,JQ)*DELTT
             R(NI)=R(NI) + QA(IQ,JQ)*HP(NJ)
             IF(NJ.LT.NI) GO TO 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   (A-H,O-Z)
      REAL   N(4)
C
      COMMON /Q4PAR/ ALP,BETAP,POR,SNFE,CSFE
      COMMON /OPT/ ILUMP,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)=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
      AKXQP=0.
      AKZQP=0.
      THQP=0.
      DTHQP=0.
C
C  ACCUMULATE THE SUMS TO EVALUATE THE MATRIX INTEGRALS QA(IQ,JQ),
C  QB(IQ,JQ), AND RQ(IQ)
C
      DO 20 IQ=1,4
         AKXQP=AKXQP+AKXQ(IQ)*N(IQ)
         AKZQP=AKZQP+AKZQ(IQ)*N(IQ)
         THQP=THQP+THQ(IQ)*N(IQ)
 20      DTHQP=DTHQP+DTHQ(IQ)*N(IQ)
      FHP=ALP*THQP/POR+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(IQ,JQ)+FHP*N(IQ)*N(JQ)
            QB(IQ,JQ)=QB(IQ,JQ)+DNX(IQ)*AKXQP*DNX(JQ) +
     >                DNZ(IQ)*AKZQP*DNZ(JQ)
 30         CONTINUE
 40   CONTINUE
    IF(ILUMP.NE.0) GO TO 50
C
    RETURN
 50 CONTINUE
    DO 52 I=1,4
       SUM=0.0
       DO 52 J=1,4
          SUM=SUM+QA(I,J)
```

```
 51        QA(I,J)=0.0
       QA(I,I)=SUM
 52    CONTINUE
    RETURN
    END
    SUBROUTINE BASE(N,DNSS,DNTT,SS,TT)
C
C  FUNCTION OF THE SUBROUTINE-TO COMPUTE THE VALUES OF BASIS FUNCTIONS
C
C
    IMPLICIT REAL   (A-H,O-Z)                                            CDC
    REAL   N(4)                                                          CDC
C
    DIMENSION DNSS(4),DNTT(4)
C
    SM=1.0-SS
    SP=1.0+SS
    TM=1.0-TT
    TP=1.0+TT
    N(1)=0.25*SM*TM
    N(2)=0.25*SP*TM
    N(3)=0.25*SP*TP
    N(4)=0.25*SM*TP
    DNSS(1)=-0.25*TM
    DNSS(2)=0.25*TM
    DNSS(3)=0.25*TP
    DNSS(4)=-0.25*TP
    DNTT(1)=-0.25*SM
    DNTT(2)=-0.25*SP
    DNTT(3)=0.25*SP
    DNTT(4)=0.25*SM
    RETURN
    END
    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  (A-H,O-Z)                                             CDC
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,NREPR,NREPAR
    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
C
C   MODIFY ROW NN
C
   60     DO 70 KB=1,IBBP
   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/DN=C
C
   90 IF (NST.EQ.0) GO TO 110
      DO 100 NPP=1,NSTN
         NP=NPST(NPP)
  100    R(NP)=R(NP)-RP(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
  190     CONTINUE
C
C   APPLY NEUMANN TIME-VARIABLE (RAINFALL-SEEPAGE) CONDITIONS
C
      DO 200 NPP=1,NBSN
          NP=NPFLX(NPP)
          IF (NP.EQ.0) GO TO 200
          R(NP)=R(NP)-FLX(NPP)
  200     CONTINUE
  210 RETURN
      END
      SUBROUTINE BANSOL(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  (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
                  C(NK,JB)=C(NK,JB)-A*C(NI,KB)
   10         CONTINUE
              C(NI,LB)=A
   20     CONTINUE
      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
            C(NK,JB)=C(NK,JB)-A*C(NI,KB)
 30      CONTINUE
         C(NI,LB)=A
 40   CONTINUE
      RETURN
C
C   MODIFY LOAD VECTOR R
C
 50 NU=NNP-IHALFB
    DO 60 NI=1,NU
       NJ=NI-1
       A=R(NI)
       R(NI)=A/C(NI,1)
       DO 60 LB=2,IHBP
          NK=NJ+LB
 60       R(NK)=R(NK)-C(NI,LB)*A
    NL=NU+1
    DO 70 NI=NL,NNP1
       NJ=NI-1
       MB=NNP-NJ
       A=R(NI)
       R(NI)=A/C(NI,1)
       DO 70 LB=2,MB
          NK=NJ+LB
 70       R(NK)=R(NK)-C(NI,LB)*A
C
C   BACK-SOLVE
C
    R(NNP)=R(NNP)/C(NNP,1)
    DO 80 IB=1,IHALFB
       NI=NNP-IB
       NJ=NI-1
       MB=IB+1
       DO 80 KB=2,MB
          NK=NJ+KB
 80       R(NI)=R(NI)-C(NI,KB)*R(NK)
    DO 90 IB=IHBP,NNP1
       NI=NNP-IB
       NJ=NI-1
       DO 90 KB=2,IHBP
          NK=NJ+KB
 90       R(NI)=R(NI)-C(NI,KB)*R(NK)
    RETURN
    END
    SUBROUTINE SFLOW(X,Z,IE, IB,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)
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  (A-H,O-Z)                                         CDC
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,5)                                         CDC
      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     HFLXP(NP)=HFLX(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+HFLX(NP)
   70    SUMP=SUMP+HFLXP(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+HFLX(NII)
   80    SUMP=SUMP+HFLXP(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
  116    CONTINUE
         BFLXA=.5*(BFLX(NII)+BFLXP(NII))
         IF (BFLXA.LT.0.D0) GO TO 120
         SUMS=SUMS+BFLX(NII)
         SUMSP=SUMSP+BFLXA
         GO TO 130
  120    SUMR=SUMR+BFLX(NII)
         SUMRP=SUMRP+BFLXA
  130    CONTINUE
      FRATE(3)=SUMS
      FLOW(3)=SUMSP*DELT
      FRATE(4)=SUMR
      FLOW(4)=SUMRP*DELT
C
C  NUMERICAL FLOW THROUGH UNSPECIFIED BOUNDARY NODES
C
  140 SUM=0.
      SUMP=0.
      DO 150 I=1,4
         SUM=SUM+FRATE(I)
  150    SUMP=SUMP+FLOW(I)
      FRATE(5)=FRATE(6)-SUM
      FLOW(5)=FLOW(6)-SUMP
C
C  FINALLY, CALCULATE THE INCREASE IN THE INTEGRATED WATER CONTENT
C
      WTHP=WTH
      WTH=0.
      DO 170 M=1,NEL
         MTYP=IE(M,5)
         ALP=PROP(MTYP,1)
         BETAP=PROP(MTYP,2)
         POR=PROP(MTYP,3)
C
         DO 160 IQ=1,4
            NP=IE(M,IQ)
```

```
            XW(IW)=X(NP)
            ZW(IW)=Z(NP)
            THW(IW)=TH(M,IW)
            IF(KKFLOW.GE.0) THW(IW)=(DTH(M,IW)+THW(IW)*ALP/POR+BETAP)*
     >       (H(NP)-HP(NP))
  160     CONTINUE
C
          CALL W4TH(WTHM,THW,XW,ZW)
C
          WTH=WTH+WTHM
  170     CONTINUE
      FLOW(7)=WTH
      IF(KKFLOW.LT.0)  FLOW(7)=0.0
      FRATE(7)=FLOW(7)/DELT
      DO 180 I=1,7
  180     TFLOW(I)=TFLOW(I)+FLOW(I)
      RETURN
      END
      SUBROUTINE W4TH(WTHM,THW,XW,ZW)
C
C  FUNCTION OF SUBROUTINE--TO EVALUATE THE WATER-CONTENT INTEGRAL
C  OVER THE AREA OF ONE ELEMENT.
C
      IMPLICIT REAL    (A-H,O-Z)
      REAL    N(4)
C
      DIMENSION THW(4),S(4),T(4),XW(4),ZW(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
      WTHM=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(IW)
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)+ZW(I)*DNTT(I)
            PJAB(1,2)=PJAB(1,2)-ZW(I)*DNSS(I)
            PJAB(2,1)=PJAB(2,1)-XW(I)*DNTT(I)
   12       PJAB(2,2)=PJAB(2,2)+XW(I)*DNSS(I)
         DJAC=PJAB(2,2)*PJAB(1,1)-PJAB(1,2)*PJAB(2,1)
C
C  INTERPOLATE TO OBTAIN THE WATER CONTENT THWP AT THE GAUSS POINT KG
C
         THWP=0.
         DO 10 IW=1,4
   10       THWP=THWP+THW(IW)*N(IW)
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  (A-H,O-Z)                                           CDC
      REAL    SUBHD                                                      CDC
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,ITIM,(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
        NJMN=M
        NJMX=MINO(M+1,NEL)
        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)
   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)
   70   PRINT 11000, (NJ,VX(NJ),VZ(NJ),NJ=NJMN,NJMX)
      RETURN
C
10000 FORMAT(I7,8(1PE15.4))
10100 FORMAT(1P,8E15.4)
10101 FORMAT(1H0,'VALUES OF NPCON'/(8I15))
10102 FORMAT(1H0,'VALUES OF NPFLX'/(8I15))
10103 FORMAT(1H ,2(1X,I7,2X,1PE12.4,1PE12.4,1PE12.4,1PE12.4,2X,))
10200 FORMAT(13H1OUTPUT TABLE,I4,27H.. PRESSURE HEADS AT TIME =,
    > 1PE12.4,9H ,(DELT =,1PE12.4,15H),(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 =, 1PE12.4,
    > 9H ,(DELT =,1PE12.4,15H),(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 =,
     > 1PE12.4,9H ,(DELT =,1PE12.4,15H),(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 =,
     > 1PE12.4,9H ,(DELT =,1PE12.4,15H),(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 =,1PE12.4,9H ,(DELT = 1PE12.4,1H),6H ITIM=,I4//5X,
     > 13H TYPE OF FLOW,35X,4HRATE,8X,9HINC. FLOW,7X,10HTOTAL FLOW/5X
     > 40H CONSTANT-PRESSURE-NODE FLOW . . . . . .,3(F12.4,5X)/5X
     > 40H CONSTANT-FLUX-NODE FLOW . . . . . . . .,3(F12.4,5X)/5X
     > 40H SEEPAGE . . . . . . . . . . . . . . . .,3(F12.4,5X)/5X
     > 40H RAINFALL. . . . . . . . . . . . . . . .,3(F12.4,5X)/5X
     > 40H NUMERICAL LOSSES. . . . . . . . . . . .,3(F12.4,5X)/5X
     > 40H NET FLOW. . . . . . . . . . . . . . . .,3(F12.4,5X)/5X
     > 40H INCREASE IN VOLUMETRIC WATER CONTENT. .,3(F12.4,5X))
10700 FORMAT(/29H RAINFALL-SEEPAGE NODAL FLOWS)
11000 FORMAT(1H,1P,I5,2E11.3,3X,I5,2E11.3,3X,I5,2E11.3,3X,I5,2E11.3)
      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  (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
   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)
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      RETURN                                                          STOR 175
      END                                                             STOR 180
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16. ABSTRACT *(200 words or less)*

This report documents a training course conducted for the U.S. Nuclear Regulatory Commission (NRC) on the implementation of a Finite Element Model of WATER flow through saturated-unsaturated porous media (FEMWATER) - ORNL-5567. In addition to presenting basic program operation (APPENDIX A-V), the course also covered the following topics: (1) Mathematical equations and physical principles that lead to the code development (APPENDIX A-I), (2) The finite element method (APPENDIX A-II), (3) Finite-element derivation of FEMWATER (APPENDIX A-III), (4) FEMWATER program structure (APPENDIX A-IV), (5) Uniqueness and limitations of FEMWATER (APPENDIX A-VI), and (6) Running of four sample problems (APPENDIX B) to demonstrate various options that FEMWATER can handle. The purpose of the training seminar is to enable the NRC staff to use the model (and to be able to modify the code if necessary) for checking information provided by a licensee, for evaluating alternative sites and designs for burial, and for comparing their results from other methods of solution.

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